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Bringing Hay to the City: Comparing Plant Richness, Composition and Surrounding Vegetation in Urban Meadows

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Acknowledgements

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Abstract

Urban flower meadows may benefit urban biodiversity and function, but it is not yet clear which means for establishing these meadows provide the best results. In this study, we used dry hay as a seed source, establishing three urban flower meadows (receptor sites) in the city of Porsgrunn. The seed-containing hay derived from two local hay meadows (donor sites). By comparing species richness and species composition of vascular plants between the two donor sites and the three receptor sites, I evaluated the restoration success of the critical first year after establishment. Lastly, I investigated whether hay cover and surrounding vegetation had an impact on the species richness and composition at site.

Vegetation analyses of 10 plots were performed on each of the five sites. The cover of vascular plant species, hay litter and four vegetation layers were visually estimated. Surrounding the receptor meadows, the closest distance of each vascular plant species was recorded in a spiral of 100 m radius. T-tests, ANOVA and ordination methods were used to detect differences in vegetation layers, species richness, hay litter cover and species composition. GLMs were used to detect potential effects of hay litter cover and surrounding species of the receptor meadows. Lastly, I used four parameters to evaluate restoration success of the three receptor meadows.

Species composition was significantly different between donor sites and receptor sites, and donor sites contained a significantly higher number of meadow species than the receptor sites. Yet, many meadow species were observed in the new meadows, and 19 meadow species were most likely successfully transferred from donated hay. The three new meadows, Sundjordet, Helleberget and Lysthusåsen, received a success score of medium, low, and very low, respectively. More hay litter at the receptor sites led to an overall higher number of meadow species, indicating that more hay could have been used. A species distance to a receptor meadow was negatively correlated with its abundance in the receptor meadow, suggesting that a considerable amount of dispersal from pioneer species occurred from the surroundings.

My findings show that it is not possible to acquire an urban hay meadow within one year. Nevertheless, many meadow species can be transferred using dry hay, demonstrating that this establishment technique works well for creating diverse flower meadows in an urban setting. Such meadows may contribute to increasing plant and insect diversity in the city as well as being an incentive for maintaining current hay meadows on the countryside.

Keywords: *urban flower meadows, hay transfer, restoration ecology, urban biodiversity*

Samandrag

Urbane blomsterenger kan bidra til å fremme biologisk mangfald og funksjon, men det er ennå uklart kva for etableringsmetodar som gjev best resultat. I denne studien blei tørka høy brukt som frøkjelde for å etablere tre urbane blomsterenger (nyenger) i Porsgrunn. Høyet kom frå to lokale slåttemarker (donorenger). Ved å samanlikne artsrikdom og artssamansetning av karplanter mellom slåttemarkene og dei nye engene evaluerte eg restaureringssuksessen i det kritiske fyrste året. I tillegg undersøkte eg om høydekke og omkringliggjande vegetasjon hadde innverknad for artssamansetninga og -rikdomen i nyengene.

På kvar av dei fem lokalitetane utførte eg 10 ruteanalyser der eg gjorde ein visuell estimering av dekninga til høyet, alle karplanteartar og fire vegetasjonssjikt. Rundt nyengene registrerte eg avstanden til omkringliggjande artar i ein spiral med 100 m radius. For å oppdage potensielle ulikskapar i vegetasjonssjikt, artsrikdom, høydekke og artssamansetning, brukte eg t-testar, ANOVA og ordinasjonsmetodar. I tillegg brukte eg lineær regresjon for å avdekkje potensielle effektar av høydekke og omkringliggjande artar ved nyengene. Til slutt tok eg i bruk fire parametrar for å evaluere restaureringssuksessen til dei tre nyengene.

Artssamansetninga var signifikant forskjellig mellom slåttemarkene og nyengene, og slåttemarkene inneheldt klart fleire engartar enn nyengene. Likevel blei mange engartar observert i nyengene, og heile 19 engartar blei overført via det donerte høyet. Dei tre nye engene, Sundjordet, Helleberget og Lysthusåsen, endte med ein suksesskår på medium, låg og veldig låg. Meir høy førte til fleire engartar, noko som tyder på at det med fordel kunne blitt brukt meir høy under etableringa. Avstanden artane hadde i vegetasjonen rundt negativt korrelert med mengda i nyengene, noko som kan tyde på at mange pionerartar har spreidd seg frå omgjevnadane.

Funna mine viser at det ikkje er mogleg å etablere ei urban slåtteeng innan eitt år, men det går likevel an å overføre mange engartar ved å bruke tørt høy frå slåtteenger. Studien viser at denne etableringsmetoden fungerer godt til å lage mangfaldige blomsterenger i ein urban kontekst. Studien viser at denne etableringsmetoden fungerer godt til å lage mangfaldige blomsterenger. Slike urbane enger kan bidra til å auke plante- og insektmangfaldet i byen samt at det kan vere eit insentiv til å halde i hevd dagens slåttemarker på landet.

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1 Introduction

Urban and agricultural areas already constitute about a third of all terrestrial land (IPBES, 2019). Still, human populations are growing, cities expand, and agricultural practices are intensified, leading to further loss of habitat (IPBES, 2019; United Nations, 2019). This had led to the proposal of the world entering the Anthropocene, a new human-induced epoch (IPBES, 2019). In the past however, extensive human intervention spawned unique niches for a range of organisms. While natural grasslands are the result of environmental conditions and wild herbivores, semi-natural grasslands, also called cultural landscapes, are additionally formed by, and dependent on, human influence, such as grazing or mowing (Hejcman et al., 2013). Semi-natural grasslands, that once were commonplace, are now quickly being lost to urban or agricultural land, or are simply abandoned, leading to shrubification and forest succession (Fischer et al., 2013; Schulp et al., 2019).

One type of semi-natural grassland that is declining rapidly are hay meadows. Humans and hay meadows share a long history of mutual benefits. Vegetation is mowed frequently, promoting growth of forbs and graminoids, which in turn serves as food for husbandry. Hay meadows can be dated back to the invention of scythes around 700-600 BC (Hejcman et al., 2013). In Norway, hay meadows can be dated to the late bronze age, 500 BC (Direktoratet for naturforvaltning, 2009). Before modern fertilisers, growing sufficient food in the croplands benefitted from fertilisers from animal manure (Direktoratet for naturforvaltning, 2009). Therefore, having enough food for animal husbandry was crucial for growing enough vegetables. Many places, hay meadows replaced leaf fodder as they were over ten times more efficient than collecting leaves from trees (Hejcman et al., 2013). The surface was cleared from trees, shrubs, and rocks, which eased mowing of the field. The hay was harvested and dried and was an important source for husbandry during the winter. The meadows could also be sparingly grazed during summer.

The frequent hay cutting opened a niche for many local wild species (IPBES, 2019), leaving room for stress-tolerant plant species (Svalheim, 2022). Hay meadows differ from other types of grasslands by relying on human intervention through annual or biannual cutting. They are often dry, well drained, high in sand and silt content and low in nutrients. As a result, they contain a unique and diverse flora of forbs and graminoids, including rare and endangered species. Additionally, they are home and food to numerous organisms of fungi and insects. In fact, hay meadows can be considered biological hotspots, as they contain among the highest number of species richness on small spatial scales (Wilson et al., 2012).

Despite being dependent on extensive human disturbance, hay meadows cease to exist with excessive human influence, such as being overly fertilised or ploughed (Svalheim, 2022). Modern agriculture, through rapid development of fertilisers and machines, has made harvesting from hay meadows relatively ineffective. Therefore, hay meadows have been either converted for other land uses, such as intensive farmland or residential areas, or left unmanaged, resulting in shrubification and forest succession (Fischer et al., 2013). As a result, hay meadows are in rapid decline, being categorised as an endangered nature type in 2011 (Norderhaug & Johansen, 2011), and later, advanced to critically endangered in 2018 (Hovstad et al., 2018).

Although conserving existing habitat is the most effective way of protecting biodiversity and functionality (Dinerstein et al., 2019), there is a growing consensus that conservation alone is not sufficient, but that restoring and establishing new habitat is also needed (Dickson et al., 2021). With the ongoing expansion of urban land, there is increasing attention towards what can be improved within the city to sustain biodiversity (Elmqvist et al., 2019). Urban land is dominated by hardscape such as concrete, cement, and buildings, leaving little space for greenery (Forman, 2014). Urban landscapes are highly fragmented (Angel et al., 2012), and urban ecosystems are often degraded in functions and services (Bolund & Hunhammar, 1999). On the bright side, urban land harbours potential to sustain biodiversity (Fischer, L. et al., 2013; Klaus, 2013; Oke et al., 2021) and may even host several threatened species (Ives et al., 2016).

In recent years, establishing urban flower meadows has become a popular trend. Not only do flower meadows look nice – they can house large numbers of local flora in a tight space (Aamlid & Svalheim, 2020), facilitate food and nesting sites for pollinating insects (Daniels et al., 2020; Griffiths-Lee et al., 2022), and potentially assist a highly valuable, but critically endangered ecosystem (Hovstad et al., 2018). Despite the recent popularity around sowing your own flower meadows, it is yet not understood which establishment methods yield the best results in terms of obtaining desired plant diversity.

Establishing new hay meadows is difficult and requires several years of careful management. Yet, it is not impossible, and has been done before with good results (Austad & Rydgren, 2014; Norton et al., 2019; Starr-Keddle, 2022). However, a reoccurring problem is an overflow of weeds, which takes time and effort to reduce, in addition to a low degree of rare species. A more tangible goal than to completely mimic traditional hay meadows, however, is to rather create biodiverse flower meadows with similar functions as traditional hay meadows. This attracts pollinators, sustains local flora and fauna and increases connectivity.

When establishing a flower meadow, the choice for introducing plant species is fundamental. The most common method is to sow seeds. Commercial seed mixtures can be purchased (Bretzel et al., 2016), or seeds can be picked locally (Fernandes et al., 2023) or collected through threshed hay from donor meadows (Böhmer, 2006). Alternatively, hay can be harvested from donor meadows and distributed, fresh or dry (Fischer et al., 2013). Moreover, plug plants or turf rolls can be planted on the desired area (Martensson, 2017), or areas can be allowed to naturally revegetate by reducing mowing frequency (Chollet et al., 2018). Secondly, the substrate may be processed to modify drainage or nutritional content. However, this is more costly and requires more effort. Finally, the cost and the availability of materials impacts the choice of method for creating a flower meadow.

The Porsgrunn Pollinator Project is attempting to establish plant diverse flower meadows using dry donor hay from local traditional hay meadows. The Porsgrunn Pollinator Project is a collaboration between the municipality of Porsgrunn and the Norwegian Institute for Nature Research (NINA), which aims to attract and sustain pollinating insects in the city of Porsgrunn. As urbanisation threatens insect diversity (Wagner et al., 2021), providing insect habitat could counteract or decrease this effect. One way to sustain pollinators is to increase what they are most dependent on: Flowering plants are essential in pollinator conservation, rooted in their co-evolvement over millions of years. With this in mind, three urban meadows were constructed in Porsgrunn using hay from nearby hay meadows. The aim for the new meadows is to accommodate a locally sourced meadow flora with local adaptations and improve life conditions for pollinating insects. It is also expected that this project will improve connectivity in the urban landscape as the meadows can function as steppingstones for plants and insects.

My goal was to evaluate whether the establishment of the new urban meadows (receptor sites) worked and how closely they resembled the original hay meadows from where the hay was taken (donor sites). Additionally, I investigated potential causes for the acquired plant composition at the receptor sites, by assessing hay cover and surrounding vegetation. Hay does not only directly influence plant composition by containing seeds but may also play a role in inhibiting or permitting growth by functioning as a physical barrier. Potential pathways for plant colonisation could be revealed by comparing the surrounding vegetation of receptor sites with the vegetation within the receptor sites.

By comparing plant species richness, vegetation cover and plant species composition between receptor sites and donor sites, I wanted to test the following hypotheses:

1. Donor sites have higher total species richness, meadow species richness and field layer cover than receptor sites.
2. Species composition at receptor sites and donor sites are different.
3. There is a relationship between hay cover and meadow species richness.
4. The proximity of a species in the surroundings is negatively correlated with its abundance at the receptor sites.

2 Methods

2.1 Study site and meadow establishment

Located at the edge of the Oslo Rift, on the south-eastern coast of Norway, the municipality of Porsgrunn is rich in geological variation. The bedrock consists of sedimentary rocks such as limestone, sandstone and shale (Norges geologiske undersøkelse, 2021). Climate-wise, Porsgrunn is within the boreonemoral zone and experiences weak oceanic influence (Moen, 1998). Winters (Dec., Jan., Feb.) are relatively mild, with a mean temperature around 0 °C, and the summers (Jun., Jul., Aug.) have a mean temperature around 17 °C, calculated from the past 5 years (Norwegian Centre for Climate Services, 2023). The vegetation is a mosaic of different nature types, such as forest, natural and semi-natural grasslands, croplands and cityscape (Miljødirektoratet, 2023a). There are few (<15) mapped hay meadows in the municipality (Miljødirektoratet, 2023b).

The Porsgrunn Pollinator Project created a GIS-model to determine which parks were more suitable for enhancing living conditions for wild insect pollinators. With additional recommendations from the municipality, it was decided to establish three urban meadows at Sundjordet (SU), Helleberget (HE) and Lysthusåsen (LY) (Figure 1). The new meadows (i.e. receptor sites) were to be fairly distributed around the city centre, functioning as steppingstones for insects. The three sites were located in parks, originally covered with lawn, and shared similar conditions with the traditional hay meadows (donor sites) at Bånnåsen (BÅ) and Tangen (TA), such as suitable sun exposure and drainage capability.

Seed-containing hay was taken from two traditional hay meadows located within or close to the city centre (Figure 1). These donor meadows were chosen for their large number of typical hay meadow species and a minimum of invasive or other problematic species. The hay was cut in the late summer of 2020 and stored and dried under roof during winter.

When establishing the three new meadows, the lawn was removed, and sand was mixed into the soil to reduce nutrient content and increase soil drainage (Figure 2-A). The dry hay was spread across the field as illustrated in Figure 2-B and kept in place using threads and sticks. To ensure aesthetic value for park visitors, additional locally picked daisy seeds (*Chrysanthemum leucanthemum*) were spread evenly across the three new meadows.

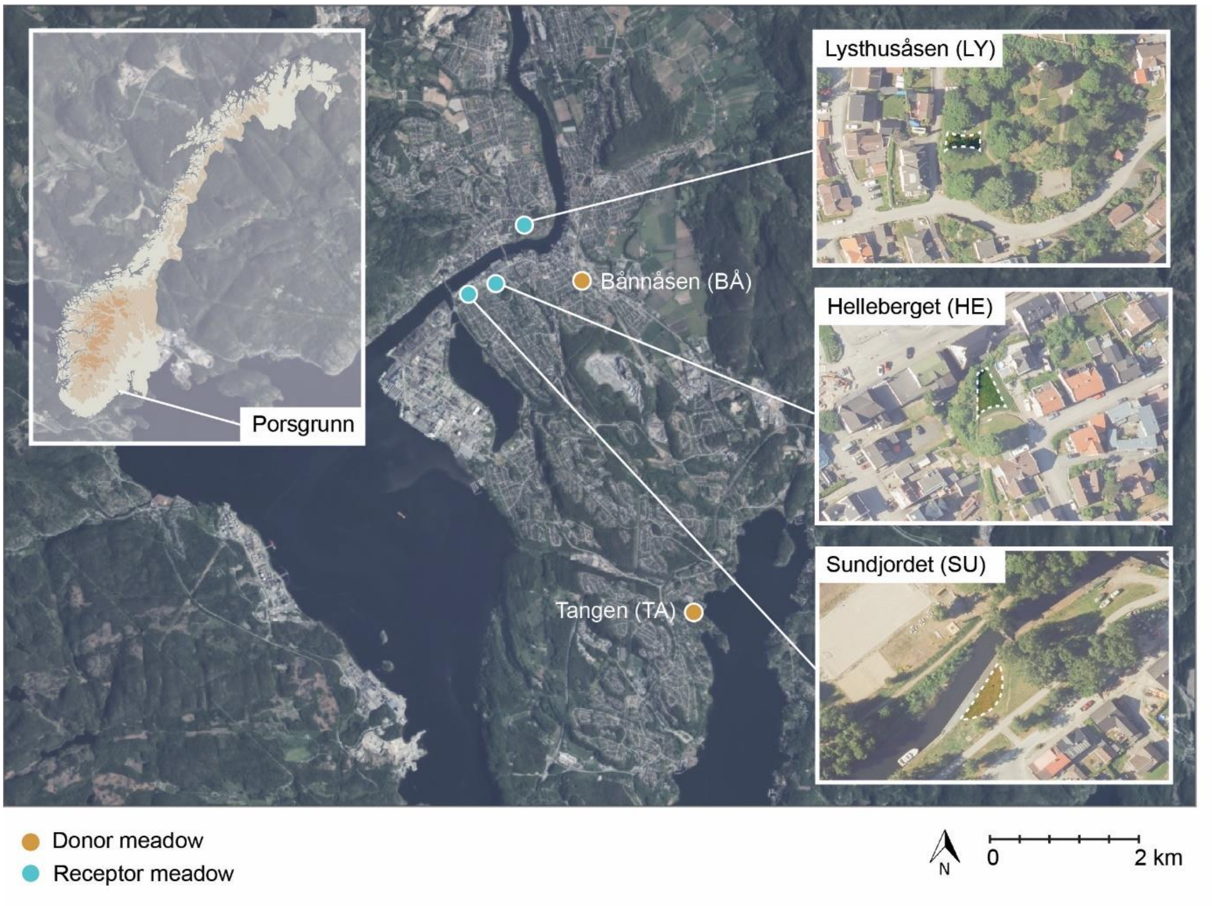

Figure 1 *Map showing the location of the study in the municipality of Porsgrunn, Norway. There were five sites in total, including two donor sites, Bånnåsen and Tangen (orange), and three receptor sites, Lysthusåsen, Helleberget and Sundjordet (blue). Background maps were retrieved from Norge i Bilder (Terratec AS, 2018; 2022).*

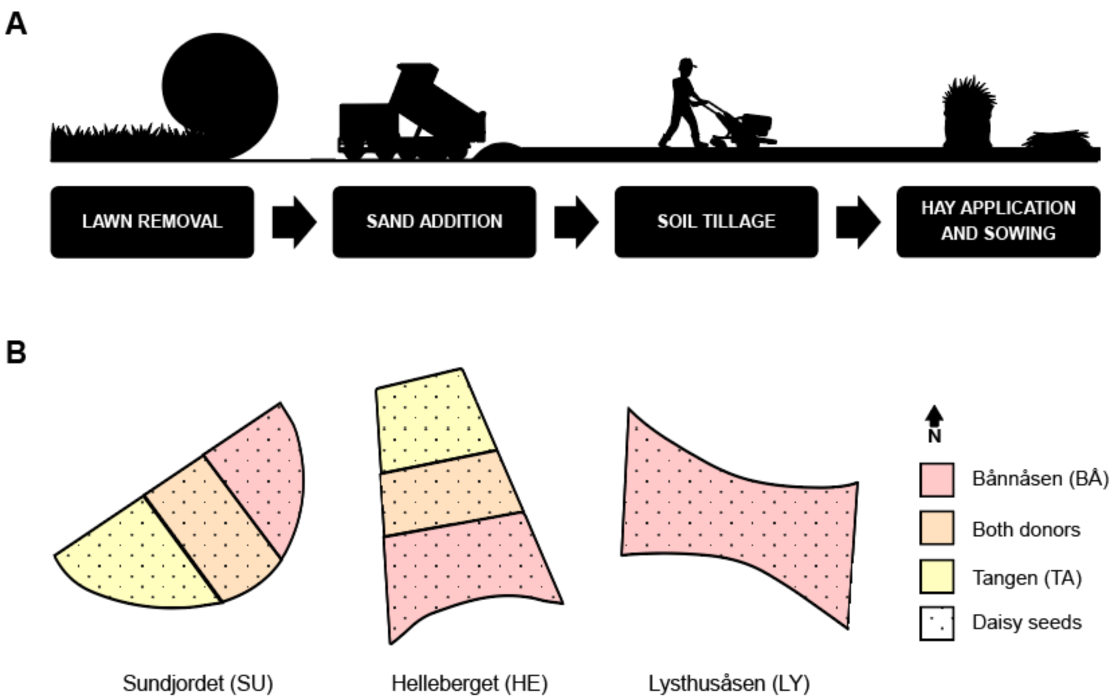

Figure 2 *(A) Meadow establishment and (B) hay placement of three receptor sites. (A) shows the four steps used to form the new meadows, including lawn removal, sand addition, soil tillage and hay spreading and sowing. A last step (not illustrated) included fastening the hay with sticks and threads. (B) shows the placement of donor hay and sowing of daisy seeds for the three receptor meadows established. Hay from Bånnåsen is shown in red, hay from Tangen in yellow and hay from both donor meadows in orange. Daisy seeds were spread across all three receptor sites.*

2.2 Vegetation analysis

Vegetation analyses were performed in the donor meadows in 2021, and both donor and receptor meadows in 2022. Ten 50×50 cm plot analyses were performed for each site. To ensure a random selection of plots, two transects were parallelly laid out across the meadow, roughly facing north (Figure 3). The width between the transects ranged from 3 to 10 meters depending on the width of the meadow. The length of the transects varied according to the length of the meadow. Each 50 cm of the transect was assigned a number, and ten of these were chosen at random with the help of the mobile app Random Number Generator (Chiou, 2015). The plots were placed on the right (east) side of the transect.

In each plot, vascular plant species were recorded, and their coverage of the plot (in percentage) was visually estimated. Both rootbound and plants leaning into the plot counted. The coverage of other physical factors was also recorded, such as four vegetation layers (ground, field, shrub and tree), open rock, hay litter, total litter, invasive species, forbs and graminoids. Field layer included all vascular plants regardless of height. Ground layer was everything excluding vascular plants, such as lichen, bryophytes, litter, open ground, and rock. Shrub layer was woody plants above 80 cm tall. Tree layer was above 2 meters tall. Each plot was photographed from above.

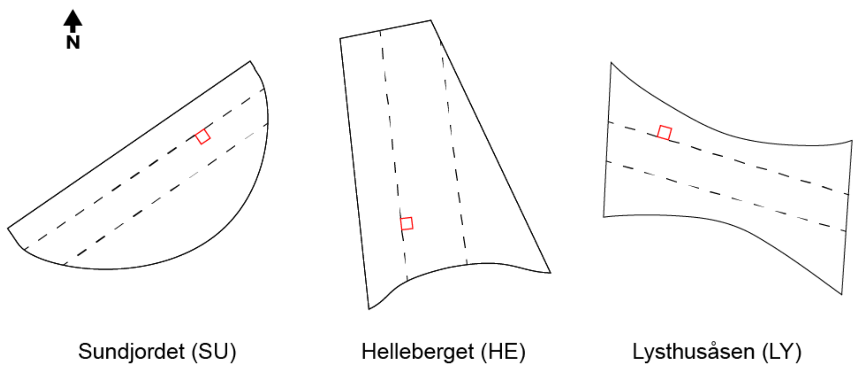

Figure 3 *Selection of plots for vegetation analysis. The illustration shows how the transects were laid for each receptor meadow. 10 plots (red square) per site were chosen randomly per 50 cm of the transects.*

2.3 Species distance spiral

Within a 100 meter radius from the receptor sites, the closest distance of each vascular plant species was measured using the ITEX species pool protocol (Rixen et al., n. d.). The method involved walking in a spiral starting from the borders of the meadow with a 10 m distance between each circle (fig. 3). The name of each species and their coordinates were registered. Considering the many obstacles found in a city: buildings, fences and slopes, the method was difficult to follow but was completed as much as practicable. Observed species and their coordinates were loaded into QGIS (QGIS.org, 2022), and their distance to the centre point of each receptor meadow was measured using the analysis tool Distance Matrix.

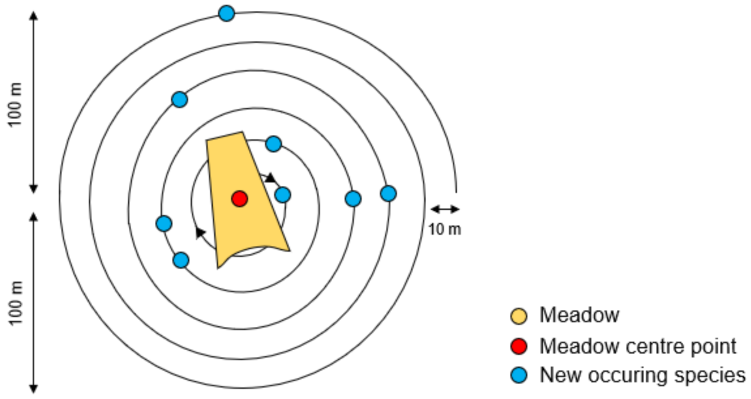

Figure 4 The ITEX species pool protocol. *The illustration shows how data on surrounding vascular plant species of each receptor site was collected. Starting from the border of the meadow, each new occurring species and their distance to the centre point of the meadow was registered.*

2.4 Restoration success criterium

Four parameters for comparing donor sites with the receptor sites were identified, and these will be used to evaluate restoration success of the new urban meadows. Vegetation layers say something about the density of plants and the stage of succession. The percentage of field cover, which includes grasses and herbs, is the most relevant in grasslands, and was therefore chosen as a criterium.

Each species recorded through vegetation analysis was determined to be either a meadow species or not (Table S1). Species were selected based on expert knowledge of what belongs in hay meadows. The selected meadow species were considered to be desirable to find at the new receptor meadows and was used as a second criterium for evaluating restoration success.

Different groups of species were defined based on their presence at donor sites, receptor sites or receptor surroundings (Figure 5). Meadow species which were found at donor sites but not at receptor sites were considered an *unsuccessful transfer*. Meadow species which were found at both donor and receptor sites were potentially successfully transferred from the donor to the receptor sites but may also have derived from the surrounding area. Meadow species which were found at *both* donor *and* receptor sites and were not found in the surrounding vegetation within a 100 m radius of the receptor meadows, were considered a *successful transfer.* In other words, these species were not spread from the surroundings but rather derived from the seeds from the donated hay. The number of species belonging to this group of successfully transferred species was chosen as a third criterium for evaluating the restoration success of the new meadows. Species found at receptor sites and their surroundings, but not at the donor sites were considered to have arrived there by *colonisation*. They likely spread from the surroundings and are typical weeds with r-selection strategy (MacArthur & Wilson, 2001), but may also have emerged from the soil's seed bank.

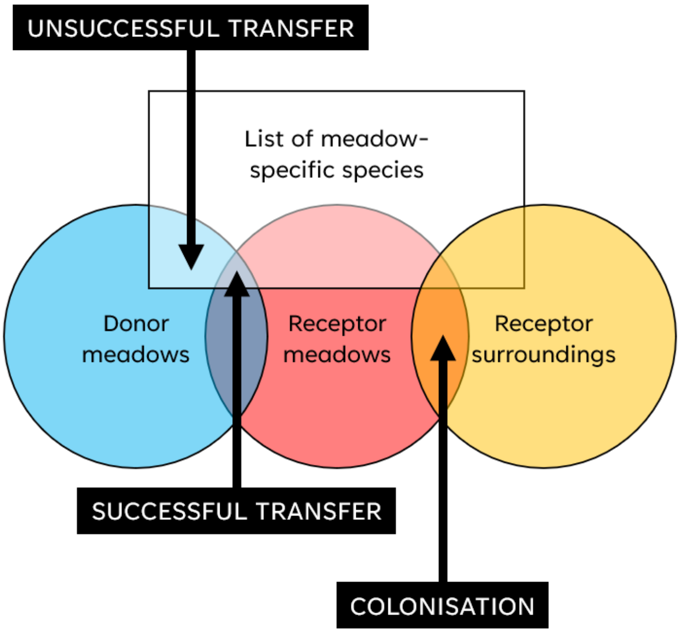

Figure 5 *Illustration showing how different groups of species were divided. The groups are determined to be a successful transfer, an unsuccessful transfer and colonisation based on where a species is found.*

Lastly, comparing the composition of vascular plant species between receptor sites and the donor sites tell us to what degree the receptor sites are approaching their reference ecosystem (donor sites).

In total, four parameters for evaluating restoration success were chosen:

1. The difference in vegetation cover between donor and receptor meadows
2. The number of meadow species at receptor meadows
3. The number of successful transfers
4. The difference in species composition between donor and receptor meadows

2.5 Data analysis

Data visualisation and analysis were carried out in R version 4.2.2 (R Core Team, 2022) using RStudio 2022.12.0 (RStudio Team, 2020). Figures for visualising the data were made with packages 'readxl' (Wickham & Bryan, 2023), 'ggpubr' (Kassambara, 2023) and 'tidyverse' (Wickham et al., 2019).

The Welch Two Sample t-test was used to detect differences in field layer and ground layer cover (response variables) between sites and treatments, i. e. donor or receptor (explanatory variables). Tree and shrub cover was not tested due to their insignificant presence. Both a t-test and an ANOVA was run to investigate whether the five sites (explanatory variable) were different in total species richness and meadow species richness (response variables). Tukey's post-hoc test was used to examine differences between the sites. Model validations were done for the ANOVA models by plotting residuals vs. fitted values and Normal QQ plots.

To investigate whether there were differences between a donor meadow and its associated receptor half (Figure 2-B), t-tests were applied. Species richness and meadow species richness were used as response variables whereas the donor site and its hay location on a receptor site was the explanatory variable. Similarly, t-tests were also used to investigate whether the hay origin (explanatory variable) used *within* a receptor site played a role for the same response variables as above. Differences in species richness and meadow species richness were compared to the type of hay used (i.e., from which donor meadow) at each receptor site. This was only done for the receptor meadows that contained two different hay origins, namely Sundjordet and Helleberget.

To investigate whether the hypothesis of receptor and donor sites were different in species composition, ordination was performed using the vegan package (Jari Oksanen et. al, 2022). Global nonmetric multidimensional scaling (GNMDS) plots were used to visualise the proximity between different sites and treatments in ordination space. Detrended Correspondence Analysis (DCA) was used to test whether Constrained Correspondence Analysis (CCA) or Redundancy Analysis (RDA) was more suitable for further investigation. All DCA tests had DCA1 axis lengths above 4, meaning CCA should be used (Leps & Smilauer, 2003). CCA was then used to test for significant differences between site and treatment (explanatory variables) and species composition (response variable). CCA tests were performed on all sites and treatments simultaneously and by comparing each single pair of receptor site and its associated donor site.

A generalised linear model (GLM) was used to assess whether there was a correlation between the amount of hay litter at a receptor site and species richness. The cover of hay litter was treated as an explanatory variable, whereas two response variables was tested: species richness and meadow species richness. Lastly, I wanted to find out whether the surroundings played a role in the abundance of species observed at the receptor sites, using GLM models. For this, the abundance of each species at the receptor sites was calculated as being the average plot cover per site. This species abundance was used as a response variable, whereas the species' closest distance in a 100 m radius from the receptor site (Figure 4) was used as an explanatory variable. A GLM was run for each receptor site.

3 Results

3.1 Evaluation of restoration success

In total, 37 meadow species were found across the receptor sites (Table S2). The meadow species *Achillea millefolium, Alchemilla sp., Galium boreale, Geum sp., Festuca rubra, Hypericum sp., Leucanthemum vulgare* and *Poa compressa* occurred in all three receptor sites. There were also 18 other meadow species recorded (Table S3), but these species were only found at donor sites and not at the receptor sites. These species include e.g., *Anthoxanthum odoratum*, *Botrychium lunaria*, *Geranium sylvaticum*, *Knautia arvensis* and *Pimpinella saxifrage*, and belong to the unsuccessful transferred group illustrated in Figure 5.

Out of the 37 meadow species found at the receptor sites, only 24 of them were recorded at the donor sites. These 24 species are potential successfully transferred to the new meadows but could also have derived from dispersal or pre-existing seedbanks. Some of these species were also found in the surrounding 100 meters of each receptor meadow, excluding them from the successful transfer in Figure 5. At Sundjordet, there were 11 meadow species found that were also present at a donor site, but not in the surroundings, and these numbers for Helleberget and Lysthusåsen were 8 and 7, respectively (Table S4). In total, for the three receptor meadows, there were 19 meadow-species which belong to the successfully transferred group illustrated in Figure 5 (Table S4).

3.1.1 Species richness and meadow species richness

Receptor sites had higher or similar total species richness compared to the donor sites, but the donor sites were, as expected, richer in meadow species (Figure 6-A). The T-test confirmed this impression: there was no significant difference between the total number of species between receptor sites (mean=16.17) and donor sites (mean=14.70) ($t=1.57$, $df=47.91$, $p=.123$). There was, however, significantly more meadow species at the donor sites than at the receptor sites ($t=3.53$, $df=46.57$, $p<.001$), with a mean of 10.85 at the donor sites and 8.13 at receptor sites.

According to the ANOVA tests, there were significant differences between the sites both regarding total species richness ($df=4$, mean square=32, $f=3.014$, $p=.028$) and meadow species richness ($df=4$, mean square=25, $f=3.089$, $p=.025$). The mean vascular plant species richness ranged from 13.8 (LY) to 18.3 (HE) per plot (Figure 6-B). The two donor meadows were quite similar in total species richness, whereas Lysthusåsen contained the lowest species richness. Helleberget differed the most from the donor sites, containing the highest total species number. These trends correlated with the differences from the post hoc test (Table 1). For meadow species, the mean ranged from 7.6 (SU) to 11.3 (TA) (Figure 6-C). The two donor meadows, Tangen and Bånnåsen, although not having the highest mean of species in total, had the highest mean for meadow species. The post hoc test showed that the number of meadow species was highest at the donor meadows Tangen and Bånnåsen (Table 1). Sundjordet and Lysthusåsen were the lowest with a large difference to the donor meadows. Helleberget was the most similar to the donor meadows regarding the number of meadow species.

There were generally few significant differences in species richness and meadow species richness between donor meadows and where their donated hay was assigned (Figure 2-B). However, some significant differences were identified. For example, total species richness at Tangen was lower compared to its associated half at Helleberget, and Bånnåsen contained more meadow species than its respective halves at Sundjordet (SU-BÅ vs. BÅ) and Lysthusåsen (LY-BÅ vs. BÅ) (Table 2).

The T-test showed no significant differences in total species richness nor meadow species richness for the two halves within a single receptor meadow. For Helleberget and Lysthusåsen, one half had hay donated from Bånnåsen and the other side had hay donated from Tangen (Figure 2-B).

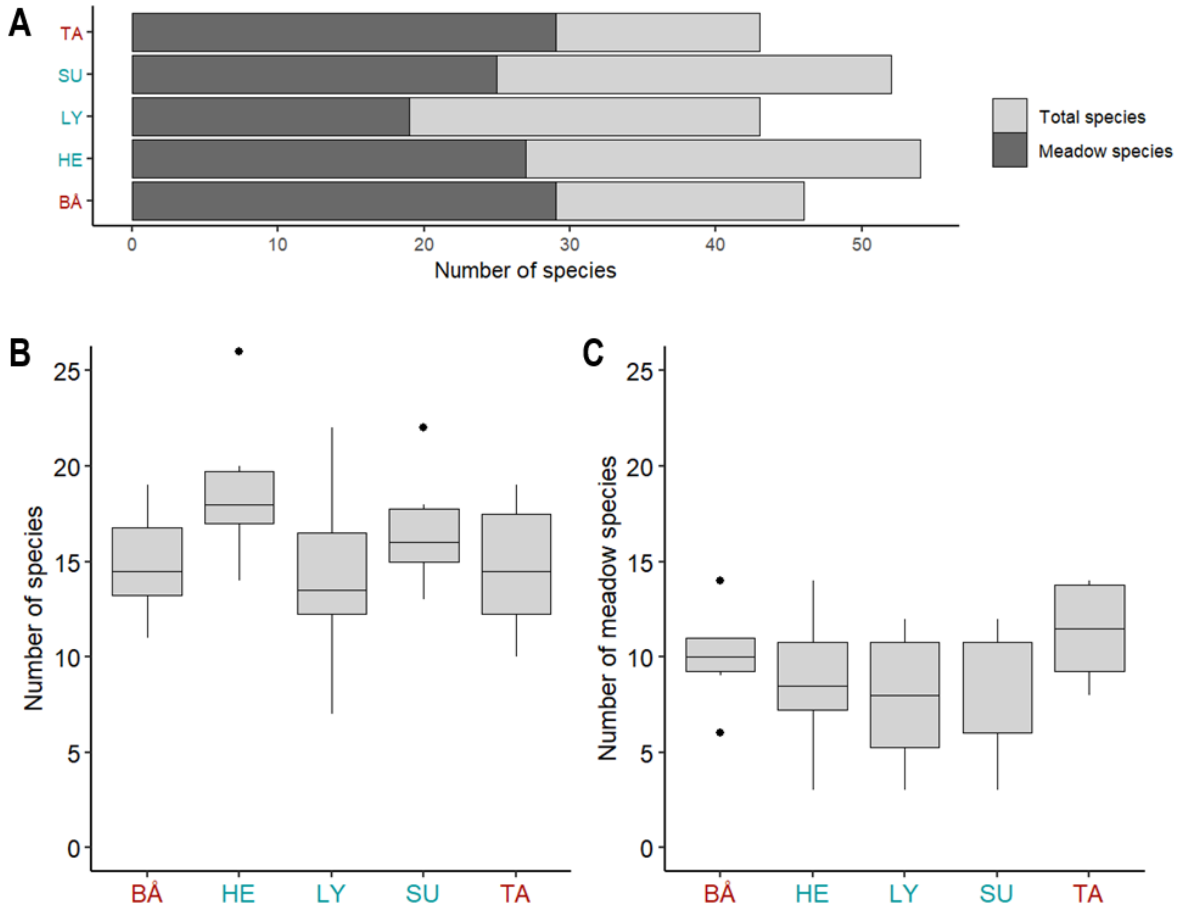

Figure 6 *Total species richness (A) and distributions the number of all species (A) and meadow species (B) per site. (A) shows the species richness per meadow with total number of species (whole bar) and meadow species (dark hue). (B) and (C) shows two boxplots with x-axes showing the five different sites: BÅ (Bånnåsen), HE (Helleberget), LY (Lysthusåsen), SU (Sundjordet) and TA (Tangen). Donor sites are in red text and receptor sites in blue.*

Table 1 *Differences and p-values from the post hoc test based on the ANOVA testing species richness and meadow species richness between two and two sites. Numbers show the difference in species richness between each receptor site and its associated donor meadow. Significant p-values are indicated by asterisks (*p < .05, **p < .01, ***p < .001).*

	Species richness		**Meadow species richness**	
Comparison	**Difference**	**P adj**	**Difference**	**P adj**
HE-BÅ	3.5	.134	-2.5	.300
LY-BÅ	-1.0	.959	-3.3	.089
SU-BÅ	1.6	.807	-3.7	.043 *
TA-HE	-3.7	.100	1.6	.718
TA-SU	-1.8	.731	2.8	.198

Table 2 *Results from the t-tests comparing species richness and meadow species richness between different sites or halves of sites. The first five comparisons are between a given donor meadow and an associated half of a receptor site in which the donated hay went to. Lysthusåsen was only tested against Bånnåsen since that was the only hay placed there (Figure 2-B). The latter two comparisons test each half of a single receptor site to see whether hay origin makes a difference. Significant p-values are indicated by asterisks (*p < .05, **p < .01, ***p < .001).*

	Species richness			**Meadow species richness**		
Comparison	**Mean at donor**	**Mean at receptor half**	**P-value**	**Mean at donor**	**Mean at receptor half**	**P-value**

BÅ vs. BÅ-half of SU	14.80	15.50	.556	11.30	7.17	.036 *
TA vs. TA-half of SU	14.60	17.75	.129	10.40	8.25	.214
BÅ vs. BÅ-half of HE	14.80	17.00	.147	11.30	9.25	.113
TA vs. TA-half of HE	14.60	19.17	.041 *	10.40	8.50	.297
BÅ vs. BÅ-half of LY	14.80	13.80	.541	11.30	8.00	.020 *
BÅ-half of SU vs. TA-half of SU	15.50	17.75	.248	7.17	8.25	.595
BÅ-half of HE vs. TA-half of HE	17.00	19.17	.303	9.25	8.50	.680

3.1.2 Species composition

The NMDS ordination plots show a clear divide between donor meadows (circles on the right) and receptor meadows (triangles on the left) in Figure 7-A. There are slightly shorter distances from Sundjordet and Helleberget to the donors (specifically Bånnåsen) than between Lysthusåsen and the donor meadows. This correlates well with observations of species at Lysthusåsen differing greatly from other sites. More meadow species (blue) are concentrated on the right side of the species GNMDS plot (Figure 7-B), which corresponds to where the donor meadows are located in Figure 7-A.

The CCA tests showed that both sites and treatments (donor and receptor) were significantly different in total species composition and in meadow species composition (Table 3). When comparing only two sites at a time, one donor and one receptor, all comparisons produce significant differences in species composition (Table 3), i.e. that each meadow has its own unique composition of vascular plant species and of meadow species.

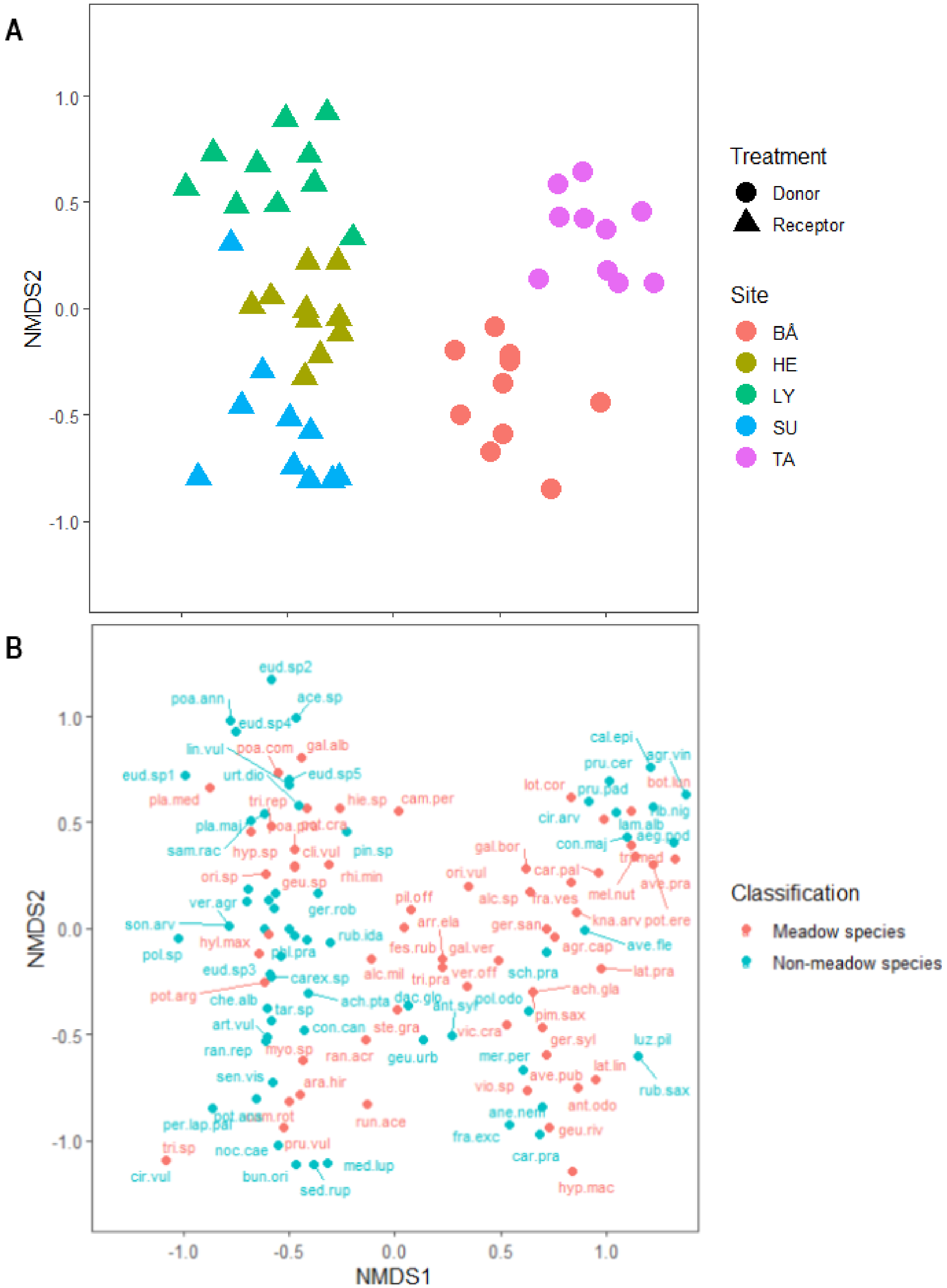

Figure 7 *GNMDS plots showing (A) the five sites and their treatment in an ordination space, and (B) each species found through the vegetation analyses. In (A), each point represents the species composition of a single plot. The locations are as following: BÅ (Bånnåsen), HE (Helleberget), LY (Lysthusåsen), SU (Sundjordet) and TA (Tangen). In (B), the species placement in the plot relates to the placement of the sites in (A). Full scientific names of the species can be found in Table S1.*

Table 3 *Degrees of freedom, ChiSquare, F-statistic and P-value for CCA-analyses testing the effect site and treatment has on species composition and meadow species composition. Significant p-values are indicated by asterisks (*p < .05, **p < .01, ***p < .001).*

Response variable	Explanatory variable	Df	ChiSquare	F	Pr(>F)
Species composition	Site	4	1.99	3.04	0.001 ***
	Treatment	1	0.82	4.62	0.001 ***
Meadow species composition	Site	4	1.72	3.49	0.001 ***
	Treatment	1	0.69	5.05	0.001 ***
Species composition	Site SU and BÅ	1	0.91	4.16	0.001 ***
	Site SU and TA	1	0.84	2.73	0.001 ***
	Site HE and BÅ	1	0.91	4.04	0.001 ***
	Site HE and TA	1	0.78	2.55	0.001 ***
	Site LY and BÅ	1	0.83	4.20	0.001 ***

3.1.3 *Vegetation cover*

The cover of vegetation layers varied greatly between sites (Figure 8). When comparing the vegetation layers between the two treatments overall, donor sites and receptor sites, there was a significantly higher field cover at the donor sites than at the receptor sites and vice versa for ground cover (Table 4). The three meadows Helleberget (HE), Sundjordet (SU) and Tangen (TA) had a higher spread in their vegetation covers, especially so for Helleberget (HE). No significant differences in vegetation layers could was found between Tangen and Helleberget, nor between Tangen and Sundjordet.

The T-test showed significant differences between Lysthusåsen and its associated donor site Bånnåsen, both in field cover and ground cover (Table 4). Lysthusåsen (LY) stood out as very low in field cover (mean=8.0%), and high in ground cover, consisting mainly of bare ground but also some litter, including hay. Bånnåsen (BÅ), on the other hand, was significantly higher in field cover compared to all receptor sites with an average as high as 88.1%.

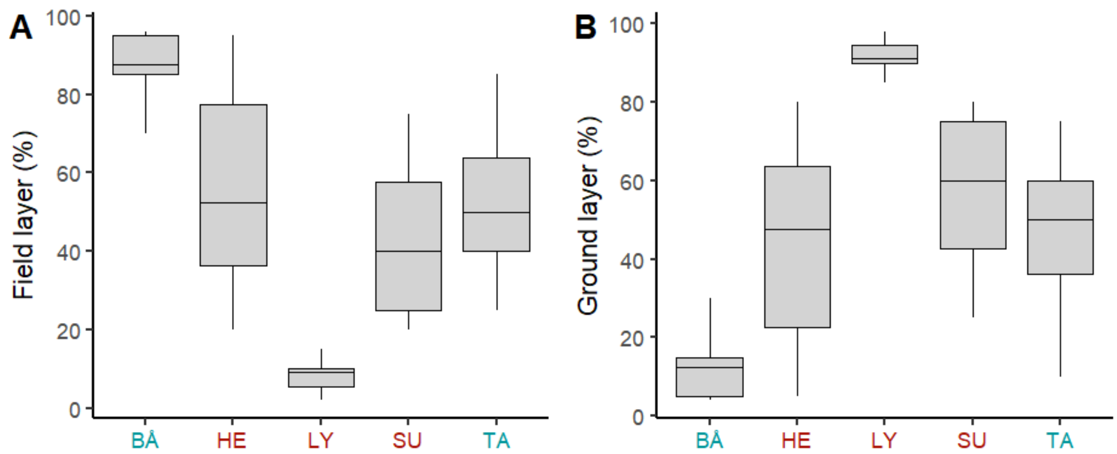

Figure 8 *Vegetation layers. The coverage of different vegetation layers per meadow. Donor meadows are shown with blue text on the x-axis whereas receptor meadows are written in red. The x-axes show the five different sites: BÅ (Bånnåsen), HE (Helleberget), LY (Lysthusåsen), SU (Sundjordet) and TA (Tangen).*

Table 4 *Receptor sites HE (Helleberget), LY (Lysthusåsen) and SU (Sundjordet) were tested in field and ground cover against their associated hay donor site BÅ (Bånnåsen) and TA (Tangen). The difference between treatments, that being donor or receptor, was also tested. Significant p-values are indicated by asterisks (*p < .05, **p < .01, ***p < .001).*

	Field cover			Ground cover		
Comparison	**T**	**Df**	**p-value**	**T**	**Df**	**p-value**
SU vs. BÅ	6.61	11.80	<.001***	-6.61	11.80	< .001 ***
SU vs. TA	-1.06	18.00	.303 *	1.09	18.00	.290
HE vs. BÅ	3.80	10.76	.003 **	-3.80	10.76	.003 **
HE vs. TA	0.34	17.05	.737	-0.29	17.36	.777
LY vs. BÅ	28.50	13.03	<.001***	-28.50	13.03	< .001 ***
Donor vs. receptor	4.77	44.93	<.001***	-4.78	44.75	< .001 ***

3.2 Effect of hay litter

The ANOVA showed a significant difference in cover of hay litter between the three receptor sites (Table 5**Error! Reference source not found.**). Post-hoc tests showed that the biggest differences were between SU and HE (13.4) and SU and LY (10.8) (Table 6). LY and HE were more similar in hay cover (2.6). The cover of hay litter was never above 50% for a plot (
Figure **9**). The lowest amounts of hay were 3%, 5% and 7% respectively, all found at Helleberget (HE). Helleberget showed a large variability in hay cover. Sundjordet (SU) contained the most amount of hay litter overall.

Table 5 *Degrees of freedom, Sum Square, Mean Square, F-value and P-value for an ANOVA testing hay litter cover between three receptor sites, Sundjordet (SU), Helleberget (HE) and Lysthusåsen (LY). Significant p-values are indicated by asterisks (*p < .05, **p < .01, ***p < .001).*

	Df	**Sum Sq**	**Mean Sq**	**F value**	**Pr(>F)**
site	2	1010	504.9	3.39	0.049 *
Residuals	27	4018	148.8		

Table 6 *Difference and P-value from the post hoc-test testing hay cover between three receptor sites.*

Comparison	**Difference**	**p adj**
LY-HE	2.6	.883
SU-HE	13.4	.053
SU-LY	10.8	.137

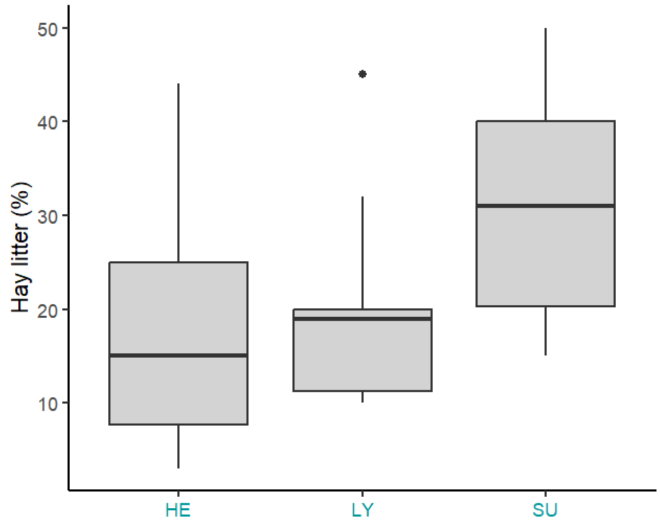

Figure 9 *Boxplots showing the cover of hay litter observed at each receptor site. The x-axis shows the three receptor sites: HE (Helleberget), LY (Lysthusåsen) and SU (Sundjordet).*

Overall, there was a significant negative correlation between hay litter cover and species richness (Table **7**). The less hay, the more species were present across the field. When testing each receptor species separately however, the opposite trend was seen for Sundjordet: generally, the more hay observed, the more species (Figure 10,
Table **7**). Regarding meadow species, the trend was overall positively significant: the more hay, the more meadow species, but differed for all three receptor sites (Table 7). A negative correlation was found between hay cover and meadow species richness at Helleberget. At Lysthusåsen, more hay was correlated with a higher amount of meadow species. For Sundjordet, no significant correlation was found.

Overall, the GLM returned a significant negative correlation between field cover and hay litter cover (Figure 11; Table 7). The more hay, the lower field layer cover. The same pattern was seen when each receptor meadow was tested separately.

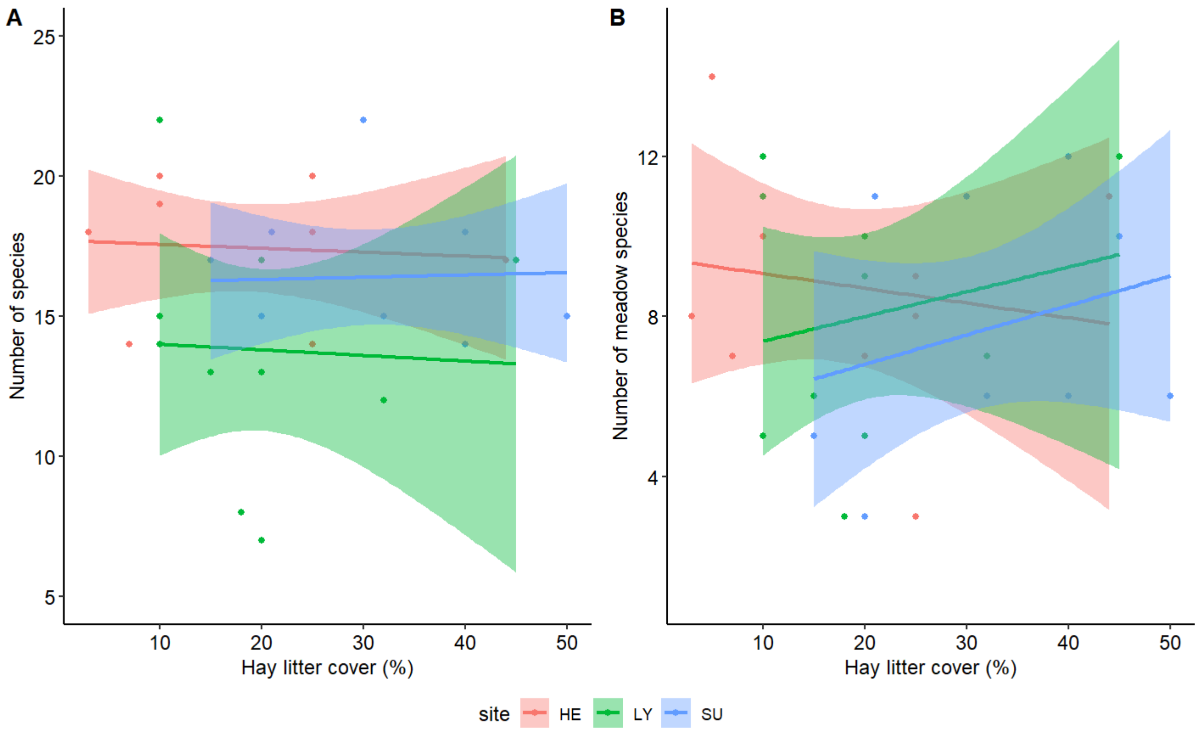

Figure 10 *Generalised linear models showing the correlations between species richness at three receptor sites. HE (Helleberget), LY (Lysthusåsen) and SU (Sundjordet)**.** A) Number of species, and B) Number of meadow species. The regression lines have confidence intervals of 95%.*

Table 7 *GLMs performed on hay litter cover (response variables) and species richness, meadow species richness and field cover (%). Significant p-values are indicated by asterisks (*p < .05, **p < .01, ***p < .001).*

Response variable	Location	Intercept	Slope	Std. Error	T-value	Pr(>|t|)
Species richness	All receptor sites	16.91	-0.03	1.46	11.61	<.001 ***
	Sundjordet (SU)	16.15	0.01	2.38	6.78	<.001 ***
	Helleberget (HE)	19.77	-0.08	1.91	10.33	<.001 ***
	Lysthusåsen (LY)	14.20	-0.02	3.17	4.48	.002 **
Meadow species richness	All receptor sites	7.93	0.01	1.14	6.96	<.001 ***
	Sundjordet (SU)	5.33	0.07	2.71	1.96	.086 .
	Helleberget (HE)	9.44	-0.04	1.72	5.48	<.001 ***
	Lysthusåsen (LY)	6.76	0.06	2.28	2.96	.018 *
Field cover (%)	All receptor sites	43.14	-0.33	10.19	4.23	<.001 ***
	Sundjordet (SU)	52.94	-0.32	18.04	2.94	.019 *
	Helleberget (HE)	73.43	-1.00	12.94	5.68	<.001 ***
	Lysthusåsen (LY	7.62	0.02	2.81	2.72	.026 *

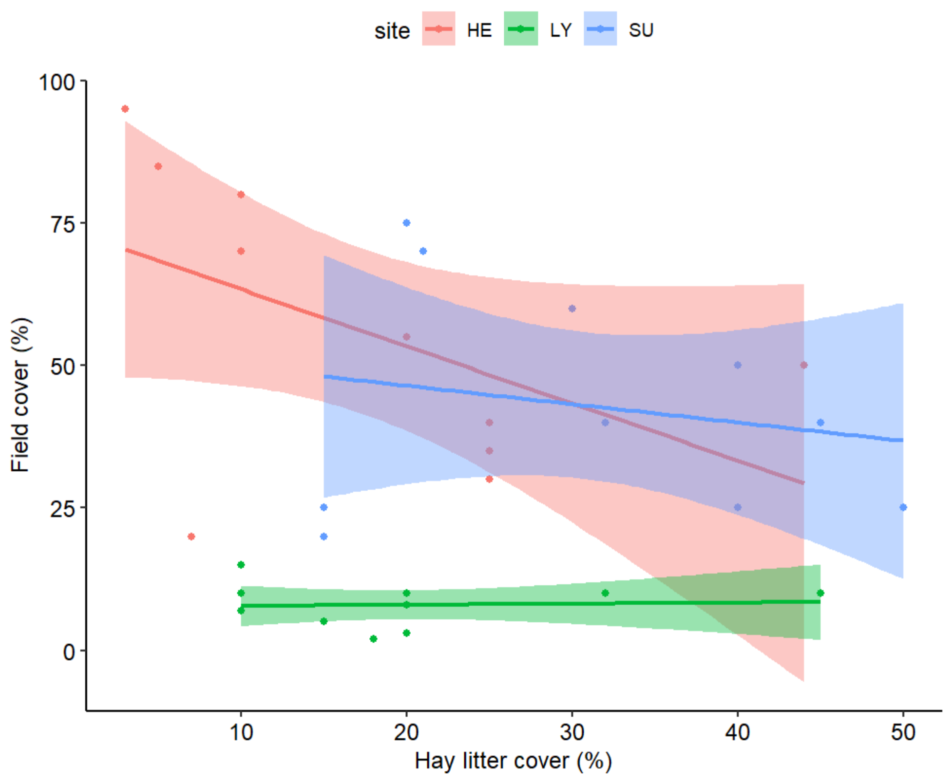

Figure 11 *Generalised linear models showing the correlations between field layer cover and hay cover at three receptor sites. HE (Helleberget), LY (Lysthusåsen) and SU (Sundjordet)**.** The regression lines have confidence intervals at 0.95.*

3.3 Effect of surrounding vegetation

The GLMs showed significant correlations between a species' abundance in the receptor meadow and their closest distance in the surroundings for all three meadows (Table 8). Generally, the more abundant a species is in a receptor meadow, the closer it can be found in the surroundings (Figure 12).

Some meadow species were found both at the receptor sites and in their surroundings. This includes *Festuca rubra, Fragaria vesca, Galium boreale, Galium verum, Poa compressa, Ranunculus acris, Stellaria graminea* and *Trifolium pratense*.

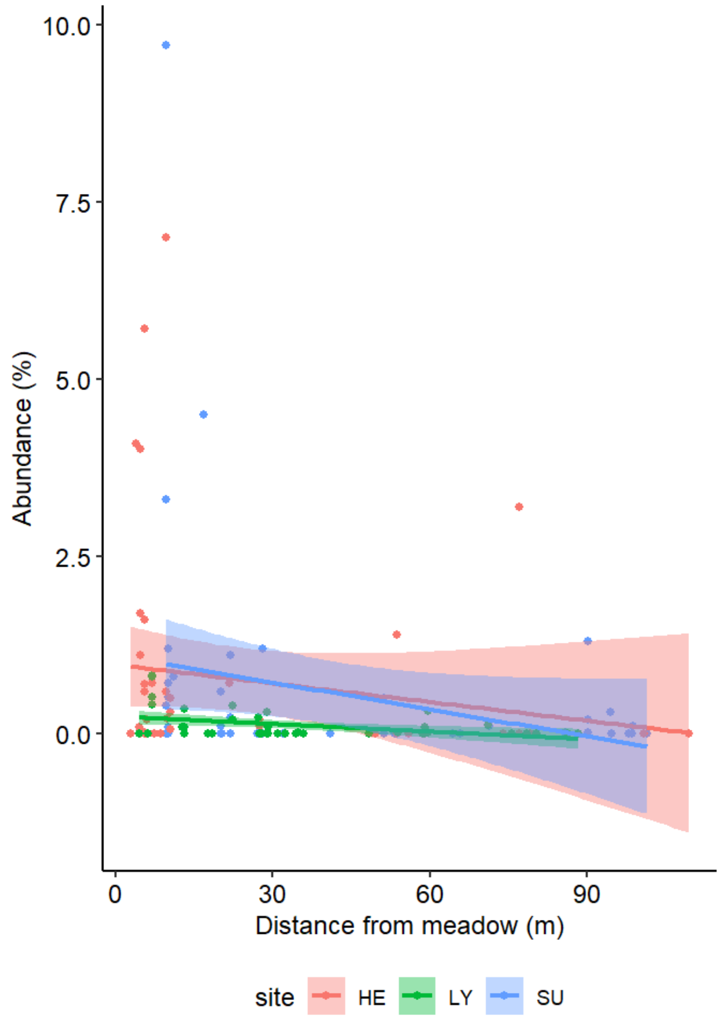

Figure 12 *Relationships between species abundance and its distance to the receptor meadow in a 100 m radius. Each colour represents a receptor site: Sundjordet (SU), Helleberget (HE) and Lysthusåsen (LY). The regression lines have confidence intervals at 95% (desaturated colours).*

Table 8 *GLMs testing for significant correlations between distance from receptor meadow and species abundance within a receptor meadow. All three receptor meadows had significant negative correlations. Significant p-values are indicated by asterisks (*p < .05, **p < .01, ***p < .001).*

Site	**Intercept**	**Slope**	**Std. Error**	**T-value**	**Pr(>|t|)**
Sundjordet (SU)	1.10	-0.013	0.38	2.93	.005 **
Helleberget (HE)	0.98	-0.009	0.30	3.22	.002 **
Lysthusåsen (LY)	0.24	-0.004	0.05	4.56	<.001 ***

4 Discussion

With an increasing expansion of urban land, understanding and improving urban ecosystems is becoming increasingly important (Elmqvist et al., 2019). Replacing urban lawns with local-sourced flower meadows, as was done in Porsgrunn, may directly increase urban plant diversity (Marshall et al., 2023; Sehrt et al., 2020), which supports other organisms and improves ecological function (Paudel & States, 2023).

4.1 Evaluation of restoration success

In Porsgrunn, no difference in total species richness between new meadows and donor meadows was found. This contradicts the hypothesis that donor meadows would have a higher species richness than the receptor meadows. In fact, many studies point out that urban areas are more species rich than their rural counterparts (Kühn & Klotz, 2006; McKinney, 2009), possibly because cities are often located in biodiversity hotspots (Kühn et al., 2004). My study found however that the new meadows contained a lower number of meadow species than the donor sites, which confirms the second part of my first hypothesis. Even though the number of meadow species at the receptor sites were lower than the donor sites, there was still a decent amount of meadow species, leading to an evaluation score of *medium* for Sundjordet and Helleberget, and *low* for Lysthusåsen (Table 9).

Since less meadow species were found at the receptor sites than at the donor sites, but there were overall the same number of species, there must be a higher number of non-meadow species at the receptor sites. This pattern is also visible when comparing the two ordination plots. Many of these non-meadow species, such as *Artemisia vulgaris*, *Conyza canadensis, Linaria vulgaris* and *Senecio viscosus* are ruderal species, a type of pioneer species that are adapted to effectively colonise human-modified land, such as construction sites and road verges (Ranđelović & Jovanović, 2023). Such areas are analogous to the open ground present after lawn removal in Porsgrunn which may explain why so many ruderal species were present.

Together, the pioneer species and the meadow species at the receptor sites contribute to a similar total species richness as the donor meadows have. Typically, diversity increases gradually through the successional stages (Donahue & Lee, 2008). The species richness of the new Porsgrunn meadows would unlikely be as high if no species were transferred through the hay, seeing as many restoration projects on arable land benefit from diverse seed introduction (Van der Putten et al., 2000). It is likely, that by transferring additional species through hay, the meadow species got a head start on the competition with other species. Unlike pioneer species, meadow species are not adapted for rapid colonisation of non-vegetated land. By introducing later-successional plant species may shorten the first successional stages (Van der Putten et al., 2000), leading to faster recovery for obtaining a stable meadow.

There were more meadow species in the new meadows than successfully transferred species, creating a group of potentially successfully transferred species. The successfully transferred species derived from the donated hay, but it is uncertain whether the other meadow species derived from. They might have come from the hay, dispersed from the surroundings or if they were already present in the seedbank. These meadow species include *Festuca rubra* and *Fragaria vesca*, which shares generalist traits, being able to thrive in a wide range of external conditions (Davies et al., 2012). They were found in the surroundings of the receptor sites and are typical to find in urban green areas, such as parks. I find it likely that all three paths of origin possibilities are occurring simultaneously: some individuals may have been transferred through the hay, others dispersed from the surroundings whereas a few sprouted from the seedbank.

Meadow species that were successfully transferred to the new meadows include *Campanula persicifolia, Carex pallescens, Galium boreale, Origanum vulgare, Rumex acetosa, Stellaria graminea,* and *Trifolium pratense*. Low numbers of transferred meadow species gave the success rate of *low* for Sundjordet and *very low* for Helleberget and Lysthusåsen. Parallel to the potentially successfully transferred species in the previous paragraph, some of the successful transferred species do also have more generalist strategies, such as *Stellaria graminea* and *Trifolium pratense*. Other successful transfers, such as *Campanula persicifolia* and *Origanum vulgare* are more specialised to hay meadow conditions. Hay meadow specialists requires external stresses like low nutrient content and frequent mowing to avoid being outcompeted by fast-growing plants (Svalheim, 2022), such as generalists or ruderal species. It is likely that over a longer time span, and with adequate management, meadow species may increase in number at the three receptor sites.

The origin of hay did not seem to influence meadow species richness. A similar number of meadow species was found at Sundjordet and Helleberget independent of which donor meadow the hay was derived from. Even though the two donor meadows were composed of different species, they were similar in terms of meadow species richness, which may explain why hay origin did not affect meadow species richness. However, the data applied in these t-tests were flawed, meaning this claim should be conceived with caution. The hay applied at Sundjordet and Helleberget was originally distributed in three with hay from both donor sites in the middle, as illustrated in Figure 2-B. In the t-tests, instead, the two receptor sites were divided down the middle and each half was assigned a hay origin (Tangen or Bånnåsen), excluding the stripe in the middle with hay from both donor sites. While it could have been beneficial to use an ANOVA rather than a t-test, allowing for all three hay locations to be tested, the sample size would have been too low (3-4 plots per location) for any statistically significant evidence.

Since the donor sites contained significantly more meadow species than the receptor sites, I would expect to also find that each donor site would contain more meadow species than the receptor half of where their hay was assigned. This was found between Bånnåsen and Lysthusåsen and between Bånnåsen and its respected half at Sundjordet. The fact that there were no significant differences between Tangen and the Tangen-half of Sundjordet, Tangen and the Tangen half of Helleberget, nor Bånnåsen and the Bånnåsen half of Helleberget was surprising. It is possible that less meadow species were transferred at these halves, but this seems less likely as it contradicts with the statement in the previous paragraph that the hay origin did not affect meadow species richness. It is also important to keep in mind here that the meadow species richness does not equal to successful transfers. A more plausible cause is therefore that some meadow species may have derived from the surroundings of the receptor sites since the surroundings also contained a decent amount of meadow species. Because of this, the number of meadow species between donor sites and some receptor halves does not vary as much.

As expected, the two treatments were vastly different in plant species composition, confirming my second hypothesis. All five sites had a distinct plant composition. Naturally, meadow species were more abundant at the donor sites. The donor sites were the most similar to each other, and the receptor sites the most similar to other receptor sites. The fact that the receptor sites were not more similar to the donor sites than the donor sites were to each other, indicates that the new meadows are vastly different from hay meadows, resulting in a very low success score for species composition all three sites (Table 9). Since cities are highly heterogeneous consisting of mosaics of multiple habitats (Forman, 2014), it was expected that the receptor sites located in the city would be more different in species composition to each other than the donor meadows were to themselves. This trend was not found, however. Bånnåsen, located in the city centre, was the most similar donor meadow to the receptor meadows, possibly because similar locations provide similar external conditions which yields a more similar composition.

When establishing the three new meadows in Porsgrunn, the lawn was removed to ease sprouting of transferred seeds and to lower competition of existing plants. The lawn removal eliminated all vegetation including field cover and plant species. Plants that sprouted at the receptor sites could therefore only derive from seeds or propagules from a) the hay used, b) the soil's seed bank, including the added sand, or c) spread in from the surroundings during or after meadow establishment. The lawn removal however did not involve removing all soil. Although non-vegetated, this type of nudation initiates secondary succession. In contrast to primary succession, secondary succession occurs when there are still soil and seed bank present (Hull, 2008). More specifically, it can be categorised as old field succession, which occurs after human disturbances (Hull, 2008). This also correlates with the type of vegetation observed, which were mostly vascular plants, rather than mosses or lichens (Pandolfi, 2008).

Considering that this was the first year after lawn removal, it was expected that the field cover at the new meadows would be significantly lower than the donor meadows. However, many plants have colonised and grown, and takes up a considerable proportion of field layer, relatively to the reference sites. Sundjordet and Helleberget are the most similar to the donor sites in field cover, thus scoring *medium* in field cover (Table 9). Lysthusåsen is considerably lower in field cover and receiving a success score of *low.* It is clear that the new urban meadows have not reached a stage of stabilisation, as they contain a much lower field cover than the donor meadows. Many of the plants observed at the receptor sites were small in size and there were many small patches of non-vegetated area. However, looking at the total number of plant species observed, a distinction between the two treatments was not seen. This means that even though field cover is lower at receptor sites, there are still as many species overall as are found in the donor sites. Hay meadows have been forged through several hundred years (Hejcman et al., 2013), thus establishing a comparable meadow requires more time than the single year (Austad & Rydgren, 2014) the Porsgrunn Pollinator Project has been running. It is likely that field cover will even out with time when the meadows are maturing into more stable systems.

Below is a summary of the four parameters used to evaluate the restoration success of the three receptor meadows (
Table **9**). The levels applied go from *very low* to *low*, *medium*, *high* and *very high*. Keep in mind that the source of reference are the two donor meadows, and seeing as none of the parameters are at the same level as the donor meadows, none of them reaches very high.

Estimating the average of the four parameters gives us the total restoration success of each receptor meadow. From this we see that Sundjordet was the most successful of the three, followed by Helleberget and lastly, Lysthusåsen. Each parameter was combined to see the success score of all receptor sites combined. For field cover and species composition, an average of the three meadows was used. For the number of meadow species and successful transfers, the total number for all three meadows were used. Interestingly, when these numbers were combined, the total success score increased for these two parameters. This indicates that the three urban meadows combined give a greater outcome in terms of meadow species richness and successful transfers. It is not impossible, that in the future, three new meadows can interact with each other by allowing gene flow.

Table 9 *Evaluation of restoration success of the three receptor meadows using the four parameters for evaluating restoration success.*

	Field cover	**Number of meadow species**	**Number of successful transfers**	**Species composition**	**Total restoration success**
Sundjordet (SU)	Medium	Medium (25)	Low (11)	Very low	Medium
Helleberget (HE)	Medium	Medium (27)	Very low (8)	Very low	Low
Lysthusåsen (LY)	Very low	Low (19)	Very low (7)	Very low	Very low
All receptor sites	Medium	High (37)	Medium (19)	Very low	Medium

4.2 Effect of hay litter

Less hay was correlated with a higher cover of field layer. It may seem as though less hay allowed for more plant cover, possibly because r-strategists from the surroundings can colonise and grow with less obstacles. Species dispersed from the surroundings likely grow faster than species transferred through the hay, resulting in a higher field layer cover. Here, it would have been interesting to test whether less hay was correlated with the cover of species also found in the surroundings. It was found that less hay was correlated with a higher total species richness, which again highlights that less hay may lead to easier colonisation from outsiders. Considering that hay is a seed source, it may appear as counterintuitive that hay leads to less species, but the hay likely protects against colonisers.

I expected that more hay would lead to more meadow species, as the donated hay is firstly a seed source for meadow species. This trend, however, was only found at Lysthusåsen. At Helleberget, a negative correlation was found between hay cover and species richness of meadow species. However, Helleberget showed a large variability in hay cover likely due to a high incline pulling mass downwards, leaving little hay litter on the upper parts of the field and a lot on the lower parts. This may have skewed the results. At Sundjordet, even though the correlation between meadow species and hay cover was positive, there was no significance relationship.

A considerable amount of hay is needed to transfer meadow seeds. Additionally, a high amount of hay may make it harder for outside seeds to colonise, lowering the competition for transferred plants. Sufficient hay is also beneficial because it protects the ground from external forces like wind and sun exposure. Seeds are less likely to blow away from the desired location and the ground is kept moist, increasing chance of germination. However, too much hay may also inhibit the growth from transferred hay meadow seeds. It is therefore thought that there exists an optimum of hay application ratio. The literature recommends different hay to area ratios, ranging from 1:1 (Kiehl 2006, Kiehl 2010, Edwards 2007) to 3:1 (Rydgren 2010). In Porsgrunn, the intention was to use a 2:1 ratio, but in reality less hay was applied, approximately a ratio of 1.5:1. It is difficult to compare this hay ratio to the hay cover data gathered in 2022, because the hay cover data was gathered the year after the hay was spread, meaning hay could have blown away or decayed since the autumn of 2022. However, comparing hay cover and meadow species may give an indication. Since Helleberget may be skewed by the incline and Lysthusåsen contained very low hay cover, the data from Sundjordet is the only reliable for testing for a potential optimal hay ratio. It would have been interesting to test this in future investigations. Based on the success scores given, the hay ratio used in Porsgrunn (>2:1) seems like an adequate ratio. Considering the positive correlation found between hay litter cover and meadow species at Lysthusåsen, it appears as though more could have been put into use here. For the other receptor sites, using more hay could have been beneficial to reduce colonisation from the surroundings.

Many meadow species at the new meadows were also found in their surroundings, lowering the chance that they were arrived there from the transferred hay. Lower number of successful transferred species could have several causes, such as insufficient hay, or that the hay used contained few viable seeds. Seeds were stored under roof during winter, and there is a possibility that some seeds did not undergo overwintering to break seed dormancy. Other external causes are also possible, such as drought, of which is likely at Lysthusåsen where hay cover was low.

4.3 Effect of surrounding vegetation

Plant species located in the closer surroundings of the receptor meadows were generally more abundant in the meadows. This indicates that many plants have derived there not only due to hay transfer, but also through dispersal from the surroundings. Many of the species found both in the surroundings and at the receptor sites were typical generalists and ruderal specialists, such as *Plantago major* and *Poa annua*, that are adapted to frequent human intervention.

Additionally, many meadow species were found both in the surroundings and at the receptor sites. Many of these were likely present in the lawn before establishment. This includes typical lawn grasses like *Festuca rubra* and *Lolium pratense*, but also forbs like *Achillea millefolium, Alchemilla sp*., *Ranunculus repens* and *Taraxacum sp*. Many of these species are included on the meadow species list, such as *Festuca rubra* and *Achillea millefolium*, which makes colonisation by these species is desirable. Colonisation by non-native and problematic species, however, is not desirable. Non-native species tend to be more abundant in urban and suburban areas than in more natural landscapes (Forman, 2014). Since dispersal is more likely at close distances, it is a good idea to check the near surroundings for unwanted species before establishing meadows and remove them as needed.

4.4 Study limitations and recommendations

Juvenile plants are difficult to identify, because the cotyledons, the first leaves, are often indistinguishable from another. Sometimes, it was not possible to identify plants further than it being a dicot rather than a monocot. Other juveniles at the receptor meadows were identified to genus, rather than species, such as *Geum sp.* and *Hypericum sp*., whereas these were specified to the species level at the donor sites. This could potentially mean that the number of species at the receptor sites was under-recorded.

As previously stated, species recorded at the receptor sites may have derived from several origins. It is not possible to know for a certain whether meadow species have been transferred through the hay or dispersed from the surroundings. The meadow species list contains many species with generalist traits and are common in urban areas. A more restrictive meadow species list could have been selected, containing only species that is endemic to hay meadows, but this would have been unreasonable considering generalist meadow species are also needed for obtaining a biodiverse meadow habitat.

Using traditional hay meadows as a reference ecosystem is not always as relevant when establishing new meadows. Urban areas are exposed to so many disturbances and contain a different climate than what may occur in rural areas (Elmqvist et al., 2008). In this sense, since Bånnåsen is located within the city centre, it may more suitable as a reference ecosystem than Tangen which is located near a residential area. Austad and Rydgren (2014) suggest that it takes much more than a year to create a hay meadow, but that it is possible to obtain biodiverse habitats. I believe that hay meadows would require decades or perhaps centuries of careful management, which is unlikely to be happening in urban areas where new construction projects appear frequently. The objective should therefore not to be create hay meadows with identical plant composition as the donor meadows. A more realistic goal would be to rather pursue rich and local-sourced plant compositions, that includes typical meadow species but also other native forbs. This is not only a more tangible goal but may increase the likelihood of obtaining self-sustainable plant populations.

The process of establishing local-sourced biodiverse meadows by using dry hay transfer required a considerable amount of time and effort. Removing lawn, adding sand and distributing hay were among the tasks that needed participation from various agencies. In Porsgrunn, the scores of the four restoration criteria seem promising taking into consideration that this was the first year of flowering after establishment. If the establishment phase is done thoroughly, minimal work is needed to do the following years. Weeding problematic or non-native species in the new meadows can be useful, however, these did not constitute a prominent problem in Porsgrunn. Some weeding was done late summer of 2022, and it is worth paying attention for such species in the future. Apart from annually or biannually mowing, minimal supplementary management practices are needed.

It is recommended to further monitor the Porsgrunn meadows, preferably looking at the development over years, using system such as ordination regression-based approach (ORBA) (Rydgren et al., 2019). Monitoring makes it possible to follow the successional stages of the Porsgrunn meadows, that being the changes in vegetational composition over time (Hull, 2008).

4.5 Meadow establishment techniques

Using dry hay from donor meadow for introducing species is only one of several methods to consider when establishing a new flower meadow. The easiest way is to nothing at all, by simply reducing the frequency of lawn mowing, thereby increasing plant diversity (Chollet et al., 2018). However, this is not a very effective method in obtaining meadow species specifically. Therefore, it is common to remove the lawn, either in its entirety or in parts, and add seeds. The most typical method to establish a meadow is to use commercially sold seed mixes (Bretzel et al., 2016). This method is very commonly seen in parks and private gardens, due to its practicality, simplicity, low cost, and availability. A disadvantage of using commercial seeds, however, is that the seeds are rarely local, often originating from another country, and may even include non-native species that can outcompete or hybridise with native flora (Kendle & Rose, 2000). Even if all species are native, commercially produced seeds have a tendency to undergo genotypic selection resulting in introduction of new genotypes to the local gene pool (Dyer et al., 2016). To avoid this, it is possible to pick your own local seeds, or attempt to find local seed mixes. However, such local seed mixes hardly exist, and if they do, can be quite expensive (Schaub et al., 2021). Picking your own seeds is a very time-consuming activity and requires trained personnel. An easier method is to obtain threshed seeds from local hay meadows (Fischer et al., 2013), or to simply use seed-containing hay straws, as was applied in Porsgrunn. Austad and Rydgren (2014) found no large differences regarding species establishment between the usages of dry hay, fresh hay, or threshed seeds. All three materials had quick meadow establishment and reached 60% field coverage after three years. In this regard, choosing dry hay when establishing urban flower meadows in Porsgrunn was a convenient and fruitful choice. Green hay transfer is, however, regarded as especially successful (Starr-Keddle, 2022) and is thought to have a slightly faster establishment rate than dry hay, because less seeds detach from the hay when fresh (Jones, 1995). Additionally, Martensson (2017) found that covering the ground with hay protects seeds from drying out during establishment, ultimately proving to be more successful than using threshed seeds alone. Taking note of this, it may be wise to choose green hay as a seed source in future meadow establishment projects.

A reoccurring issue is the lack of successful establishment of rare meadow species (Austad & Rydgren, 2014). Meadow species have more narrow ecological requirements than other species and may require several years of hay meadow management before establishing. Starr-Keddle (2022) therefore recommends supplementing the hay transfer method by sowing additional seeds or planting plug plants from meadow rare donor species. In Porsgrunn, locally picked daisy seeds, *C. leucanthemum*, were sowed to ensure flower-containing meadows. Another method for supplementing is to pre-cultivate and transplant plug plants. This technique, together with sowing seeds, is much more controlled because you only obtain the species you yourself choose to set out. The benefit with plug plants is that since the plants have already sprouted and grown when transplanted out, they get a head start on the weeds. As such, they have a higher survival rate than other methods (Martensson, 2017). Growing plug plants has been tried both with and without mycorrhiza and is regarded as more successful than using threshed seeds (Fischer et al., 2013). However, it is a very costly method because it requires time and space to grow the seedlings before transplantation. Even though the most important goal when establishing a flower meadow is to obtain a high diversity of species, including meadow species, the cost and the effort required is additional consideration. The simpler and cheaper, the more likely the project is to be implemented by stakeholders.

5 Conclusions

Even though the new meadows differed from the hay meadows in terms of species composition, meadow species richness and field cover, many species were successfully transferred. The new meadows contained a varied flora of meadow species, pioneers, and generalists. The restoration success of the three new meadows, Sundjordet, Helleberget and Lysthusåsen, were rated as *medium, low,* and *very low*, respectively. It was evident that dispersal had occurred from the surroundings to the new meadows, and that species close to the meadows were more abundant. Less hay seemed to result in more colonisation from pioneer species, whereas more hay overall led to more meadow species. The amount of hay used in Porsgrunn seemed to be adequate, or not enough, especially so for Lysthusåsen where meadow species richness increased with hay litter cover.

One year is not sufficient to create hay meadows, but it is possible to transfer some meadow species and obtain a relatively plant diverse habitat. The establishment phase requires considerable work, but minimal effort is needed after establishment except for regular maintenance. Relative to the short time span the Porsgrunn Pollinator Project has been running, it seems as though the meadows are on the right track, however, future monitoring of the development of plant composition is useful and recommended.

As a result of this project, it is likely that Porsgrunn city has increased in plant diversity, which in the future sustains habitat and food for pollinators. Another benefit has been the use of hay from current hay meadows which can be a win-win situation to conserve local flora and genetics. Hopefully, the new urban meadows contribute to recreational value and spark a curiosity about the importance of biodiverse greenspace.

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7 Supplementary data

Table S1 List of all species found through vegetation analysis in the five meadows, including abbreviation, full scientific name and whether the species was selected as a meadow species or not.

	Scientific abbreviation	Full scientific name	Norwegian name	Meadow species
1	ace.sp	*Acer sp.*	lønn sp.	no
2	ach.pta	*Achillea ptarmica*	nyseryllik	no
3	aeg.pod	*Aegopodium podagraria*	skvallerkål	no
4	agr.cap	*Agrostis capillaris*	engkvein	yes
5	agr.vin	*Agrostis vinealis*	bergkvein	no
6	ach.gla	*Alchemilla glaucescens*	fløyelsmarikåpe	yes
7	alc.mil	*Achillea millefolium*	ryllik	yes
8	alc.sp	*Alchemilla sp.*	marikåpe sp.	yes
9	ane.nem	*Anemone nemorosa*	kvitveis	no
10	ant.odo	*Anthoxanthum odoratum*	gulaks	yes
11	ant.syl	*Anthriscus sylvestris*	hundekjeks	no
12	ant.vul	*Anthyllis vulneraria*	rundbelg	yes
13	ara.hir	*Arabis hirsuta*	bergskrinneblom	yes
14	arr.ela	*Arrhenatherum elatius*	hestehavre	yes
15	art.vul	*Artemisia vulgaris*	burot	no
16	ave.fle	*Avenella flexuosa*	smyle	no
17	ave.pra	*Avenula pratensis*	enghavre	yes
18	ave.pub	*Avenula pubescens*	dunhavre	yes
19	bet.pub	*Betula pubescens*	bjørk	no
20	bot.lun	*Botrychium lunaria*	marinøkkel	yes
21	bun.ori	*Bunias orientalis*	russekål	no
22	cal.epi	*Calamagrostis epigejos*	bergrørkvein	no
23	cam.per	*Campanula persicifolia*	fagerklokke	yes
24	cam.rot	*Campanula rotundifolia*	blåklokke	yes
25	car.pal	*Carex pallescens*	bleikstarr	yes
26	car.pra	*Cardamine pratensi*	engkarse	no
27	carex.sp	*Carex sp.*	starr sp.	no
28	cer.glo	*Cerastium glomeratum*	veiarve	no
29	che.alb	*Chenopodium album*	meldestokk	no
30	che.maj	*Chelidonium majus*	svaleurt	no
31	cir.arv	*Cirsium arvense*	åkertistel	no
32	cir.vul	*Cirsium vulgare*	veitistel	no
33	cli.vul	*Clinopodium vulgare*	kransmynte	yes
34	con.can	*Conyza canadensis*	hestehamp	no
35	con.maj	*Convallaria majalis*	liljekonvall	no
36	dac.glo	*Dactylis glomerata*	hundegras	no
37	des.ces	*Deschampsia cespitosa*	sølvbunke	no
38	ely.rep	*Elytrigia repens*	kveke	no
39	epi.sp	*Epilobium sp.*	mjølke sp.	no
40	eud.sp1		tofrøblad forveda sp.	no
41	eud.sp2		tofrødblad (bilde)	no
42	eud.sp3		tofrøblad sp.	no
43	eud.sp4		tofrøblad sp. Lysegrønt hjarte	no
44	eud.sp5		tofrøblad sp. Mørkegrøn oval	no
45	fes.rub	*Festuca rubra*	raudsvingel	yes
46	fra.exc	*Fraxinus excelsior*	ask	no
47	fra.ves	*Fragaria vesca*	markjordbær	yes
48	gal.alb	*Galium album*	stormaure	yes
49	gal.bor	*Galium boreale*	kvitmaure	yes
50	gal.ver	*Galium verum*	gulmaure	yes
51	ger.rob	*Geranium robertianum*	stankstorkenebb	no
52	ger.san	*Geranium sanguineum*	blodstorkenebb	yes
53	ger.syl	*Geranium sylvaticum*	skogstorkenebb	yes
54	geu.riv	*Geum rivale*	enghumleblom	yes
55	geu.sp	*Geum sp.*	humleblom sp.	yes
56	geu.urb	*Geum urbanum*	kratthumleblom	no
57	hel.ann	*Helianthus annuus*	solsikke	no

58	hie.sp	*Hieracium sp.*	sveve sp.	yes
59	hyl.max	*Hylotelephium maximum*	smørbukk	yes
60	hyp.mac	*Hypericum maculatum*	firkantperikum	yes
61	hyp.per	*Hypericum perforatum*	prikkperikum	yes
62	hyp.sp	*Hypericum sp.*	perikum sp.	yes
63	kna.arv	*Knautia arvensis*	raudknapp	yes
64	lam.alb	*Lamium album*	dauvnesle	no
65	lat.lin	*Lathyrus linifolius*	knollerteknapp	yes
66	lat.pra	*Lathyrus pratensis*	gulskolm (gulflatbelg)	yes
67	leu.vul	*Leucanthemum vulgare*	prestekrage	yes
68	lin.vul	*Linaria vulgaris*	lintorskemunn	no
69	lot.cor	*Lotus corniculatus*	tiriltunge	yes
70	luz.pil	*Luzula pilosa*	hårfrytle	no
71	med.lup	*Medicago lupulina*	sneglebelg	no
72	mel.nut	*Melica nutans*	hengjeaks	yes
73	mer.per	*Mercurialis perennis*	skogbingel	no
74	myo.sp	*Myosotis scorpioides*	forglemmegei	yes
75	noc.cae	*Noccaea caerulescens*	vårpengeurt	no
76	ori.sp	*Origanum/Clinopodium*	mynte sp.	yes
77	ori.vul	*Origanum vulgare*	bergmynte	yes
78	per.lap.pal	*Persicaria lapathifolia subsp. Pallida*	grønt hønsegras	no
79	phl.pra	*Phleum pratense*	timotei	no
80	pil.off	*Pilosella officinarum*	hårsveve	yes
81	pim.sax	*Pimpinella saxifraga*	gjeldkarve	yes
82	pin.sp	*Pinus sp.*	furu sp.	no
83	pla.maj	*Plantago major*	groblad	no
84	pla.med	*Plantago media*	dunkjempe	yes
85	poa.ann	*Poa annua*	tunrapp	no
86	poa.com	*Poa compressa*	flatrapp	yes
87	poa.pra	*Poa pratensis*	engrapp	yes
88	poaceae	*poaceae*	gras sp.	no
89	pol.odo	*Polygonatum odoratum*	kantkonvall	no
90	pol.sp	*Polygonum aviculare*	tungras	no
91	pot.ans	*Potentilla anserina*	gåsemure	no
92	pot.arg	*Potentilla argentea*	sølvmure	yes
93	pot.cra	*Potentilla crantzii*	flekkmure	yes
94	pot.ere	*Potentilla erecta*	tepperot	yes
95	pru.cer	*Prunus cerasus*	kirsebær	no
96	pru.pad	*Prunus padus*	hegg	no
97	pru.vul	*Prunella vulgaris*	blåkoll	yes
98	ran.acr	*Ranunculus acris*	engsoleie	yes
99	ran.rep	*Ranunculus repens*	krypsoleie	no
100	rhi.min	*Rhinanthus minor*	småengkall	yes
101	rib.nig	*Ribes nigrum*	solbær	no
102	ros.sp	*Rosa sp.*	rose sp.	no
103	rub.ida	*Rubus idaeus*	bringebær	no
104	rub.sax	*Rubus saxatilis*	teiebær	no
105	run.ace	*Rumex acetosa*	engsyre	yes
106	sam.rac	*Sambucus racemosa*	raudhyll	no
107	sch.pra	*Lolium pratense*	engsvingel	no
108	sed.rup	*Petrosedum rupestre*	broddbergknapp	no
109	sen.vis	*Senecio viscosus*	klistersvineblom	no
110	son.arv	*Sonchus arvensis*	åkerdylle	no
111	ste.gra	*Stellaria graminea*	grasstjerneblom	yes
112	tar.sp	*Taraxacum sp.*	løvetann	no
113	tri.med	*Trifolium medium*	skogkløver	yes
114	tri.pra	*Trifolium pratense*	raudkløver	yes
115	tri.rep	*Trifolium repens*	kvitkløver	yes
116	tri.sp	*Trifolium sp.*	kløver sp.	yes
117	urt.dio	*Urtica dioica*	stornesle	no
118	ver.agr	*Veronica agrestis*	åkerveronika	no
119	ver.off	*Veronica officinalis*	legeveronika	yes
120	ver.ser	*Veronica serpyllifolia*	snauveronika	no
121	vic.cra	*Vicia cracca*	fuglevikke	yes

122	vio.sp	*Viola sp.*	fiol sp.	yes

Table S2 *Meadow species found at receptor sites. The table shows the list of meadow species, and at which receptor sites they were found.*

Full scientific name	**Sundjordet (SU)**	**Helleberget (HE)**	**Lysthusåsen (LY)**
Agrostis capillaris		x	
Achillea millefolium	x	x	x
Alchemilla sp.	x	x	x
Arabis hirsuta	x	x	
Arrhenatherum elatius		x	
Campanula persicifolia	x	x	
Campanula rotundifolia	x	x	
Carex pallescens	x		
Clinopodium vulgare		x	
Festuca rubra	x	x	x
Fragaria vesca		x	x
Galium album			x
Galium boreale	x	x	x
Galium verum	x	x	
Geranium sanguineum			x
Geum sp.	x	x	x
Hieracium sp.	x		x
Hylotelephium maximum	x	x	
Hypericum sp.	x	x	x
Leucanthemum vulgare	x	x	x
Lotus corniculatus			x
Myosotis scorpioides	x	x	
Origanum vulgare	x	x	
Pilosella officinarum			x
Plantago media			x
Poa compressa	x	x	x
Poa pratensis	x		x
Potentilla argentea		x	
Potentilla crantzii		x	x
Prunella vulgaris	x		
Ranunculus acris	x	x	
Rhinanthus minor		x	
Rumex acetosa	x	x	
Stellaria graminea	x	x	
Trifolium pratense		x	
Trifolium repens	x	x	x
Total meadow species found	**25**	**27**	**19**

Table S3 *Meadow species found at the donor meadows through vegetation analysis.*

Abbreviation	Full scientific name	Tangen (TA)	Bånnåsen (BÅ)
ach.gla	*Alchemilla glaucescens*	x	
ant.odo	*Anthoxanthum odoratum*	x	
ant.vul	*Anthyllis vulneraria*		x
ave.pra	*Avenula pratensis*		x
ave.pub	*Avenula pubescens*	x	x
bot.lun	*Botrychium lunaria*		x
ger.syl	*Geranium sylvaticum*	x	x
geu.riv	*Geum rivale*	x	
kna.arv	*Knautia arvensis*	x	x
lat.lin	*Lathyrus linifolius*	x	
lat.pra	*Lathyrus pratensis*	x	x
mel.nut	*Melica nutans*		x
pim.sax	*Pimpinella saxifraga*	x	
pot.ere	*Potentilla erecta*	x	x
tri.med	*Trifolium medium*		x
ver.off	*Veronica officinalis*	x	
vic.cra	*Vicia cracca*	x	
vio.sp	*Viola sp.*	x	

Table S4 *Successful transfers in the three receptor meadows. Successful transfers are meadow species that were observed both in the donor sites and the receptor sites but not in the surroundings of the receptor sites.*

Abbreviation	Scientific name	Sundjordet (SU)	Helleberget (HE)	Lysthusåsen (LY)
arr.ela	*Arrhenatherum elatius*		x	
cam.per	*Campanula persicifolia*	x	x	
car.pal	*Carex pallescens*	x		
fes.rub	*Festuca rubra*	x		
fra.ves	*Fragaria vesca*		x	
gal.bor	*Galium boreale*		x	
gal.ver	*Galium verum*	x	x	
ger.san	*Geranium sanguineum*			x
geu.sp	*Geum sp.*			x
hie.sp	*Hieracium sp.*	x		x
lot.cor	*Lotus corniculatus*			x
ori.vul	*Origanum vulgare*	x	x	x
pil.off	*Pilosella officinarum*			x
poa.com	*Poa compressa*	x		
poa.pra	*Poa pratensis*	x		x
ran.acr	*Ranunculus acris*		x	
run.ace	*Rumex acetosa*	x	x	
ste.gra	*Stellaria graminea*	x		
tri.pra	*Trifolium pratense*	x		
Total number of meadow species found:		**11**	**8**	**7**

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