The effects of historical land use on plant diversity in semi-natural grasslands

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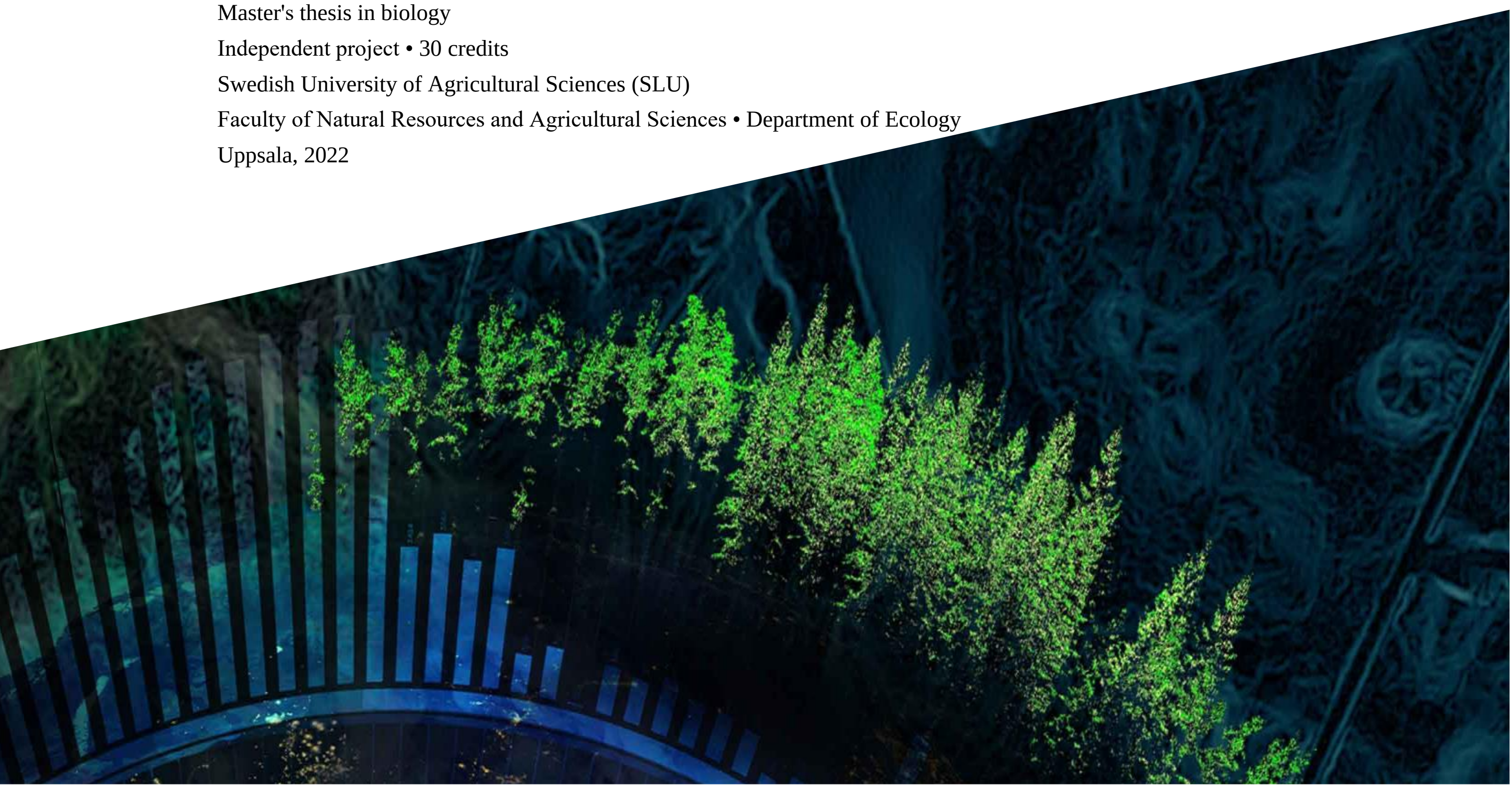

Ängen… är något av det vackraste märkligaste och mest sinnrika av allt som vi människor hann skapa medan vi ännu vårdade jorden på dess egna villkor, så som den borde vårdas om livet skall kunna gå vidare.

- Peter Nilsson (Nilsson, 1995, p. 14).

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For in the end, we will conserve only what we love,
we will love only what we understand, and we will
understand only what we are taught.
- Baba Dioum

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Abstract

During the last two centuries, large-scale administrational and technological reforms have drastically changed the agricultural landscape in Sweden. The meadows and semi-natural grasslands that once played a central role in the agricultural landscape have been reduced with up to 95%.
This has entailed large losses of habitat for vascular plants that rely on traditional management practises, and a decrease in the overall plant species richness of managed landscapes. Yet, traces of historical land use, so-called legacy effects, often remain and influence the present-day distribution of plants. How such historical land use affects the species richness we have today and how these changes in land use affect the diversity of vascular plants are investigated here. In this study, I inventoried a total of 97 different grassland and afforested grassland plots in two locations and related the plant species richness and specialist plant occurrence to historical land uses with the help of historical land-use maps obtained from a project by Cousins (2009). The results indicate that legacy effects of historical land use influence present-day plant communities but that these vary across the different locations, probably due to site-specific effects. The results seem to be contradictory to each other in the two locations that were included.

Keywords: semi-natural grasslands, land-use sequences, diversity in vascular plants.

Sammanfattning

Under de senaste två århundradena har storskaliga administrativa och tekniska reformer drastiskt förändrat jordbrukslandskapet i Sverige. De ängar och naturbetesmarker som en gång spelade en central roll i livsmedelsproduktion systemet är idag reducerade med upp till 95%. Detta har inneburit stora förluster av livsmiljöer för kärlväxter som är beroende av traditionella skötselmetoder, vilket har resulterat i en minskning av den totala växt/artrikedomen i landskapet. Ändå finns ofta spår av historisk markanvändning, så kallade arvseffekter, kvar och påverkar den nuvarande utbredningen av växter.

Hur den historiska markanvändningen påverkar artrikedomen vi har idag och hur förändringarna i markanvändningen påverkar mångfalden av kärlväxter undersöks här.

Det gjordes en inventering av två landskap med totalt 97 olika platser. Artrikedomen och förekomsten av specialistarter relaterades till historiska markanvändningskartor som erhölls från ett projekt av Cousins (2009).

Resultaten tyder på att arvseffekter av historisk markanvändning påverkar dagens växtsamhällen men att dessa varierar mellan olika platser, troligen på grund av platsspecifika effekter. I denna avhandling visade sig resultaten vara motsägande i de två platserna som ingick i studien.

Table of contents

List of tables

List of figures

Abbreviations

LUS	Land use sequences
SNG	Semi- natural grasslands
SLU	Swedish University of Agricultural Sciences

1. Introduction

The growing human population is facing challenges with the changing climate and the need to feed the world (IPCC, 2018). This is affecting how the land is used and what the landscape looks like, affecting biodiversity and raising questions about the consequences of land use (Foley et al., 2005).

Semi-natural grasslands (SNG) constitute habitat for numerous species of plants, insects, and birds (Eriksson, 2021) and play a crucial part in maintaining overall landscape diversity and ecosystem functions (Bengtsson et al., 2019) However, the proportion of actively maintained grasslands has decreased drastically over the last two centuries as a consequence of past and ongoing land-use changes (Bardgett et al., 2021; Cousins, 2009). During this time, our methods of agriculture have intensified with industrialisation, often with an economic gain in focus (Walden, 2018). For example, in only five years between (1951-1956) 75,000 farms smaller than 10 ha disappeared in Sweden (Harrison, 2017) and during the same time the mechanisation and intensification of remaining agricultural areas increased a lot (ibid). With the change to intensified and monocultural land use, many of the traditionally managed grasslands have been abandoned or converted into cultivated grasslands (Cousins, 2009). It is estimated that the area of managed grasslands in Sweden and Europe has declined as much as 95% over the two last centuries (Eriksson, 2021), and semi-natural grasslands are now a relatively unusual part of most Swedish landscapes.

As many vascular plants rely on traditional non-intensive farming practises of grasslands to reproduce and disperse, the loss of semi-natural grasslands is a major threat to plant diversity (e.g. plant species richness) in Swedish landscapes (Cousins et al., 2007; Ekstam & Forshed 1992).

When a traditionally managed grassland is abandoned and enters secondary succession and overgrowth, many species reliant on regular grazing or cutting are quickly outcompeted by faster-growing plants (Ekstam & Forshed, 1992, p. 16-17; Craine et al., 2013). With time the area will be increasingly overgrown and eventually also fully afforested (Ekstam et al., p. 92, 1988; Cousins et al., 2007; Milberg et al., 2019), and only fragments of the original grassland flora remain. Similarly, when semi-natural grasslands are directly converted to forest or to cultivated grasslands (i.e. grasslands that are regularly sown, ploughed, and/or fertilised), much of the local species pool is quickly lost (Cousins & Eriksson, 2002). Despite this, there is often an observable delay in the decline of grassland specialist plants that are difficult to reconcile with the impacts of changed land use or land abandonment (Gustavsson et al., 2007). This could be due in part to the slow response of plants to changes in their habitat, creating a so-called “extinction debt” of future plant losses if the habitat changes are not reversed (Tilman et al, 2017), but also due to the presence of legacy effects of previous land uses that remain an influential factor centuries after they changed (Valls Fox et al., 2015; Gustavsson, 2007). In Sweden, a unique set of cadastral maps from the 1700th and 19th-centuries that depict land use have created good opportunities to infer land-use changes over time and relate this to present-day plant species richness and composition (Cousins 2009, Gustavsson et al. 2007). In this way, the relative impacts of legacy effects and the possible extent of extinction debt can be estimated in order to better shape conservation practises in a rapidly changing world. This is an important area to study as humans depend heavily upon the diversity of plant species that are connected to more complex ecological symbiosis (Eliasson, 2021). The knowledge we can get from the effects of historical land use on the diversity of plant species today can help us change accordingly for a good sustainable development of land use into the future. In this master thesis project, I collected data on plant species richness in 97 vegetation plots located across a number of grasslands or afforested previous grasslands in two landscapes in Södermanland in South-eastern Sweden, and related the present-day species richness and specialist composition of vascular plants to historical land-use maps derived from a previous project by Cousins (2009) in order to infer impacts of legacy effects and land abandonment and overgrowth since the 1950s.

2. Aim

The aim of the thesis is to examine the impacts of historical land use on the present-day richness and specialist occurrence of vascular plants.

The research questions are:

- How do historical land use effects (legacy effects) shape present-day species richness and composition of vascular plants?

- How does the species richness and diversity of vascular plants in semi-natural grasslands change during successional stages of overgrowth since the 1950's?

In relation to these questions, I have worked with the following two hypotheses:

- Legacy effects have tangible effects on present-day plant communities, where historical management of traditional semi-natural grasslands has a positive effect on species richness today.

- Both species richness as well as the within-community diversity of plant communities decrease with increasing succession.

3. Background

3.1 Historical perspective

The way humans have cultivated the land has been changing throughout history, and traces of past land use, sometimes as far back as centuries or millennia after their change, continue to shape the richness and distribution of plant species in grasslands (Milberg et al., 2020; Cousins, 2009).
During the last two centuries, perhaps the most impactful event when it comes to land-use change in Sweden is related to the drastic decrease of meadows and semi-natural grasslands. Between 1870 and 1945 there was a 10-fold reduction of meadows from 2.5 million hectares to an estimated 250 thousand hectares (Lennartsson & Westin, 2017). A further reduction of the semi-natural grasslands down to the around 8000 hectares in Sweden today are thought to be related to grassland abandonment and afforestation (ibid). In addition, many of the managed pastures in today's agricultural landscape are heavily fertilised, which leaves only a few areas as semi natural grasslands. In Södermanland a province in Southeastern Sweden, approximately 15% of the farmland is used for pasture but only a third of these grazed areas were semi-natural grasslands in 2007 (Cousins et al. 2007).

At Hemsta and Långmaren, the two areas of focus in this study, the landscape has been formed by cattle, managed by humans, grazing the landscape from around the bronze age (Cousins & Eriksson, 2002). The landscapes in this part of Sweden consisted of valley-like areas with clay soil in between areas of bare or covered bedrock (ibid). The start of using the grasslands for winter fodder (hay) to the animals are believed to have started around 2500 years ago (ibid).

The management with grazing and hay production resulted in species-rich meadows and semi-natural grasslands. In this context, meadows are areas that were, and also some places still are, used for hay production, and a common definition posits that a meadow is “a hayfield that has not been fertilised, cultivated or sown with alien species” (The Swedish board of agriculture see Svensson & Moreau, 2012). An SNG is similar to the meadow in definition with the addition that also includes areas for grazing (Eriksson, 2020). However, it is not a simple task to describe the exact differences between SNGs, meadows and other grasslands, especially when one considers them as habitats and defines them according to the species they contain. Urban Ekstam writes that the original environment and many other conditions affect the vegetation in a meadow. He writes that each meadow has its own identity and characteristics and that the conditions like the soil, water conditions and surroundings are determining factors for which species that will be present and thrive in the meadow (1988, p.10). The management and land use are also factors which affect both meadows and SNG (Bonari et al., 2017).

An example of how the land use and extent of grassland in the agricultural landscape has changed over time can be seen in figure 1 and figure 2 below. By using historical land-use maps spanning over centuries of mapped land uses, it is possible to track changes in land use over the centuries. The particular maps used to infer land-use changes in this thesis derive from a previous project by Cousins (2009). They are categorised in different colours according to land-use type and show how these change in the two locations (Hemsta and Långmaren) in Södermanland that were chosen for this project over four time steps that coincide with large-scale landscape changes described in the introduction above: at the 1700s, at the early 1900s, 1950 and 2009.

Looking at these maps, we see at Hemsta how in the 1700s large areas of grasslands dominated the landscape with a few arable fields located close to the living area. In the next time step, in the early 1900s, a number of grassland areas have been converted to arable fields, and the residential built area has increased. The change in the landscape often mirrors other changes like in this case, the increased arable land is reflecting a growing population and an increased need for food. The rocky terrain displayed in the map appears to have been used as grassland at this time, probably due to the need for utilising all the available land, with more people living in the area (bigger living area). Even more drastic changes to the land uses occurred following from the agricultural revolution in the early 1900's, as can be seen in the next consequential map from the 1950's. Here, the remaining grassland areas are shown with different levels of tree coverage, indicating that they are undergoing secondary succession following abandonment or less active management. The new land-use category of forests that has replaced large areas of grasslands give another indication of this, as it has been either actively planted on remnant grasslands, or passively afforested abandoned SNGs. Only a few relatively small areas of grasslands remain in the proximity of the built areas. Finally, in 2009, which constitutes the final time step here as the maps derived from the Cousins (2009) project was done in that year, the proportion of grasslands with no or only low forest coverage has disappeared, and only grasslands in later stages of overgrowth (i.e. containing higher amounts of trees) are left. Instead, there are areas that are fertilised, in the form of cultivated grasslands and arable fields.

The grassland areas that are found at inconvenient and less fertile locations are often abandoned first (Aune, et al., 2018) and as we can see on the maps the result will often be that they will be passively afforested during secondary succession. The forests are growing in and taking over the grasslands and pasture areas if these areas are no longer managed and kept open. As this happens, the conditions that make SNGs suitable habitat for numerous species of vascular plants also disappear as the habitat and landscape slowly transforms. Examples of some of these species that are expected to disappear with the cessation of well-managed SNGs are *Leucanthemum vulgare, Primula veris, Helianthemum nummularium, Arnica montana and Antennaria dioica*.

Many of these species are now red-listed and threatened to go locally or regionally extinct as a consequence of the changing landscape and abandonment of SNG.

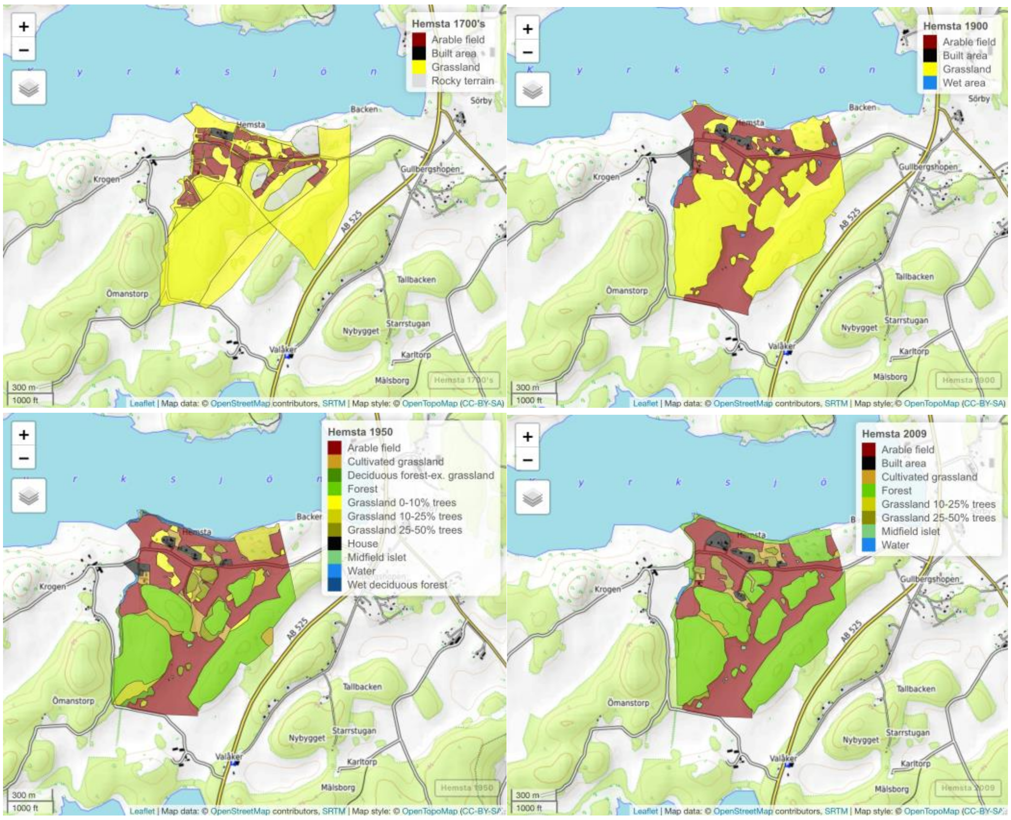

Figure 1. Shows maps of the land-use categories (LUS) at Hemsta from the 18th century (top left), 1900 (top right), 1950 (bottom left) and 2009 (bottom right).

At Långmaren similar changes in the landscape across the four time steps seen at Hemsta can be observed, but with some crucial differences. Also here, grasslands are the dominating form of land use in the 1700s, and also here, large proportions of these have been converted to forest already by the early 1900s. However, the true extent of this early grassland-to-forest transformation is uncertain due to the forest category used in the maps from 1900 often included shrubland or only partly afforested grasslands (Cousins, 2009). However, in 1950 and 2009 the categorisation clearly shows that the forests are growing in and have been taking over more and more of the area, with more or less trees depending on the grasslands' stage of overgrowth. At Långmaren, there is nevertheless a considerable amount of well-preserved SNG left today, and this is a crucial difference to the landscape at Hemsta which is characterised by a more wide-scale grassland abandonment.

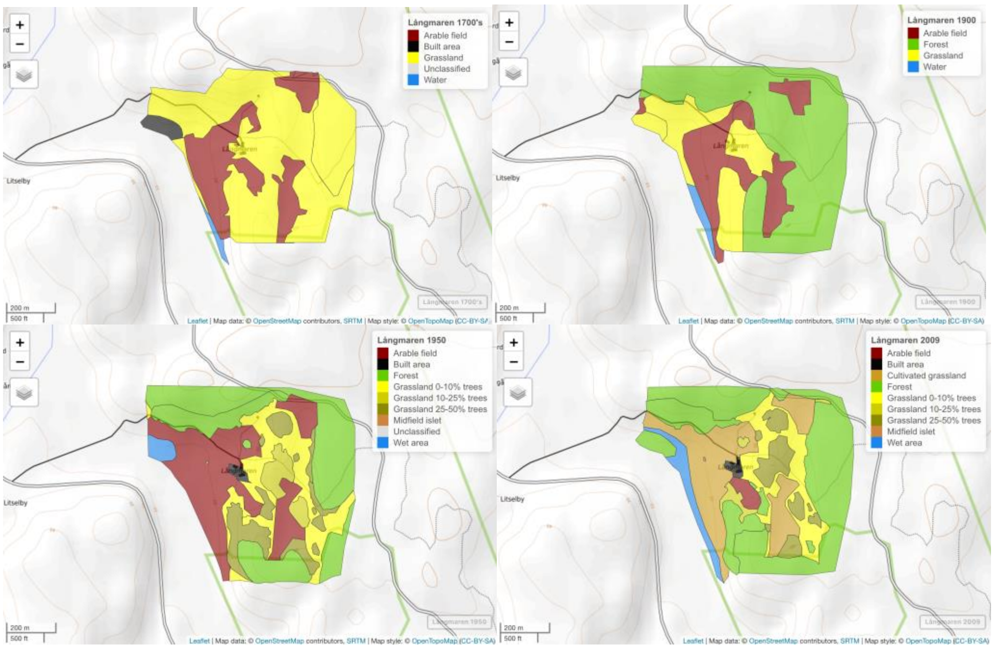

Figure 2. Shows maps of the land use series (LUS) categories at Långmaren from the 18th century (top left), 1900 (top right), 1950 (bottom left) and to 2009 (bottom right).

Well preserved semi-natural grasslands harbour a large amount of biodiversity. In Sweden these are some of the most species-rich habitats we have in terms of vascular plant diversity and their associated fauna (Karlsson, 2014; Humbert et al., 2009). The drastic reduction of these habitats has therefore also resulted in one of the most acute threats to biodiversity nationwide as well as regionwide (Gerstner et al., 2014).

3.2 Factors and conditions

Different plants have different preferences in terms of conditions and requirements for habitat. The land-use practices and management with which we maintain and change habitats therefore have big effects on how well plants thrive and disperse, and in prolongation also on the overall species richness in the landscape. However, apart from the management factors, several environmental, or edaphic, factors also influence the distribution and dispersal of plants. For example, soil type, pH, macronutrient availability, moisture, and elevation are some of the environmental factors that exert at strong influence on what plants thrive and reproduce at a given site (Cingolani et al., 2007). In addition, so-called landscape factors, such as landscape configuration, habitat connectivity, and landscape fragmentation, act as a filter of what plants ultimately occur up where (Gaujour et al., 2011).

The timing and management of grass and hay harvest in farming have changed a lot over time. Prior to the agricultural revolution in the 19th century, the hay harvest was mainly manual labour over a longer period of time (Cserhalmi, 1998, Lennartsson & Westin, 2017), where the hay was cut with a scythe, normally in between mid-July to mid-August, depending on location and weather (Lennartsson & Westin, 2017). Plants differ in relation to how they grow, how and when they multiply and set seed. This means that different types of management practices will affect different species differently (Lennartsson et al., 1997). Some species might be able to handle management with for example an earlier grazing, while another species that flower early might suffer with such an early disturbance (ibid). An example of two different species that flower at different times, in the region of focus here are *Leucanthemum vulgare* and *Ranunculus auricomus*. *Ranunculus auricomus* flowers already in May while *Leucanthemum vulgare* matures in late July (Dahlström et al, 2008, see Lennartsson & Westin, 2017, p. 53).

3.3 Fertilisation

Traditionally, meadows and SNGs receive no or very little manure/fertiliser apart from the manure left by grazing animals. This leads to often low-fertility grasslands on shallow soils where nutrients are constantly removed with the grass/ hay leaving the field (Lennartsson & Westin, 2017). These "lean" conditions are a factor that is beneficial for many typical species in meadows and SNGs (Foster & Gross, 1998; ibid.). As mentioned earlier not many areas are left unfertilised today and additionally it is known that we have a lot of nitrogen in the atmosphere that comes down with the rain and becomes an unwanted fertilisation in semi-natural grasslands, affecting the conditions for the species (Bobbink et al., 1998). In this thesis the areas that have been or still are fertilised are referred to as *cultivated grasslands.* Another term that will be used in this thesis is arable land which refers to an area that is completely different to a meadow or a semi-natural grassland as it has been or still is ploughed.

3.4 Indicators/specialists

Since different plant species are tightly connected to different habitats, edaphic conditions, and management types, many species are used as indicators of the conditions in place. Some specialist plants with very specific niche requirements are especially good indicators, while other species with more general niche preferences might be able to grow in several different conditions and thereby less precise as indicators of habitat quality.

Species that traditionally indicate a well-managed semi natural grassland in landscapes like Södermanland include, among others, *Lathyrus linifolius, Polygala vulgaris, Antennaria dioica,* and *Helianthemum nummularium*. These species among others are good indicators as they are some of the first species that disappear in an SNG where management stops or decreases (Eriksson, 2007; Ekstam & Forshed, 2000; Ekstam & Forshed, 1992). Another community-based indicator of a well-managed SNG is that there are many species in the same area with high evenness, i.e. without one species being overly representative (Ekstam & Forshed, 2000, p.132-133). Many species, including specialist and indicator species, will still be present a few years after the area has been abandoned. Ekstam writes that an abandoned grassland can contain a high diversity of species if it has not been abandoned for a long time (Ekstam, Aronsson & Forshed, 1988, p. 96). Gradually, however, the abandoned grassland will be taken over little by little by strong competitor species like *Pteridium aquilinum* and *Deschampsia flexuosa* (Bengtsson & Claesson, n.d.). Other species that are indicators for abandonment and too little management are for example *Anemone nemorosa* and *Prunus spinosa* (Elmhag, 2019).

Due to the intrinsic link between vascular plant communities and grassland habitat and management, Ekstam and Forshed (1992) use a system of four categories for the succession patterns when the management in an area is changed that will be adopted in this thesis when examining the effect of grassland abandonment and secondary succession on plant communities. Species in the first category (A) are very sensitive to competition and strongly favoured by active management, which means that they most likely will disappear in three to five years in a situation where management stops. Examples of species in this category (A) are *Polygala vulgaris, Antennaria dioica, Trifolium arvense, Briza media, Plantago lanceolata* and *Trifolium repens* (Ekstam & Forshed, 1992).

In the next category (B) we find the species that are less sensitive to management cessation and that are often found up to a decade or so into secondary succession. Examples of species in category B are: *Helianthemum nummularium, Rumex acetosella, Dianthus deltoides, Luzula campestris, Plantago media* and *Anthoxanthum odoratum* (ibid). The species included in category C are indicators for far-advanced secondary succession and overgrowth. The occurrence of species found in this category, along with a strong absence of category A and B species, is a clear indication of a SNG that has not been managed for around/up to 18 years, depending on site conditions. Examples of species in category C are: *Calluna vulgaris*, *Prunus spinosa*, *Galium verum L.*, *Dactylis glomerata*, and *Prunella vulgaris* (ibid). In the last category (D), we find the species frequently found in late-successional stages of overgrowth, and include *Pteridium aquilinum*, *Calamagrostis arundinacea*, *Convallaria majalis*, *Deschampsia flexuosa*, and *Filipendula ulmaria L.* Examples of the habitats containing the different stages of succession in the Hemsta and Långmaren areas can be seen in figures 3A-D below.

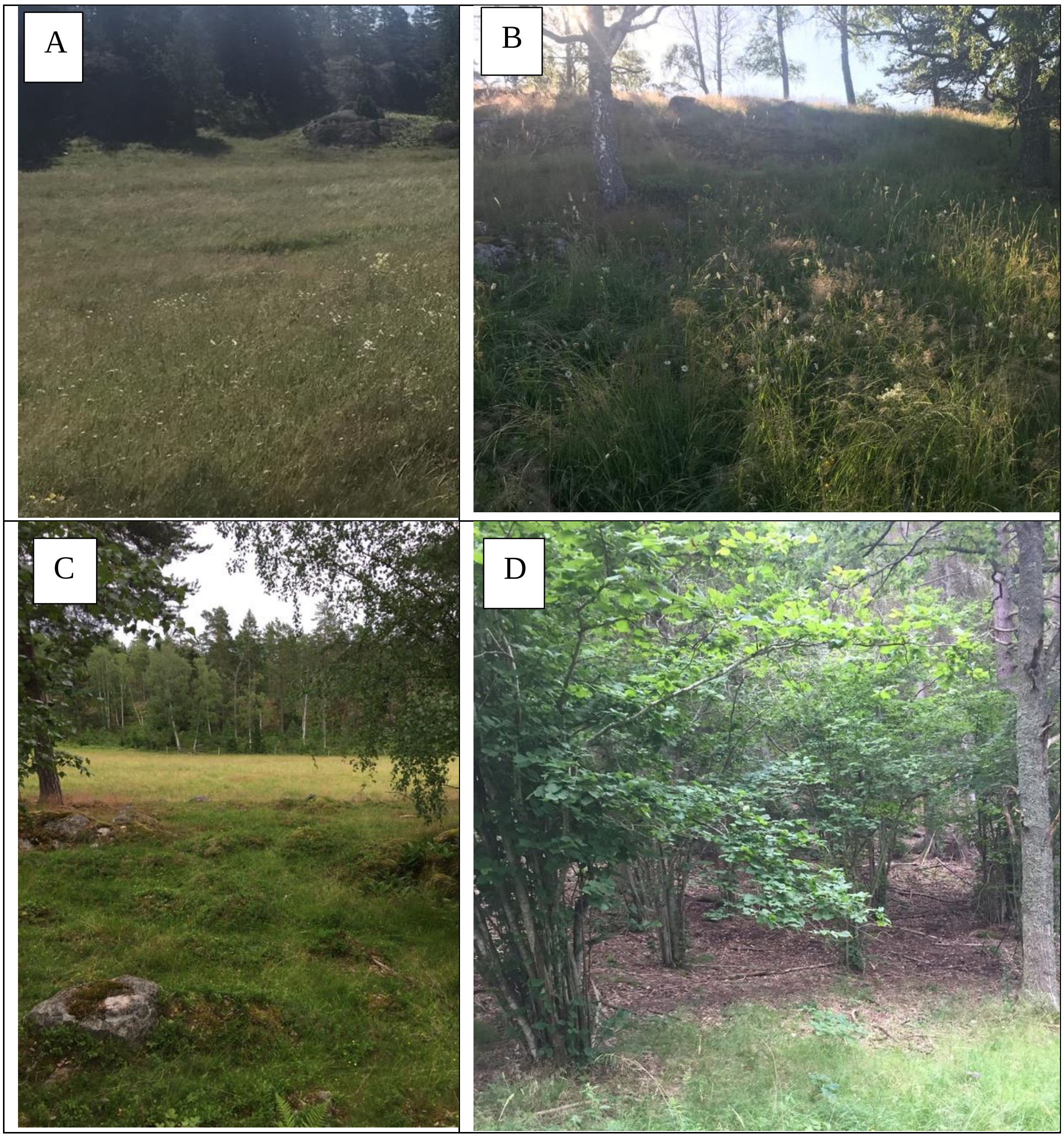

Figure 3. Shows four pictures of different land-use categories at Långmaren. Picture A = category grassland 0-10% trees. This area consists of species typical for a well-managed grassland.

Examples of species that can be found are, among others, Polygala vulgaris, Plantago lanceolata, Filipendula vulgaris and Lotus corniculatus. Picture B = example of grassland category with 10-25% trees, this area consists of more trees and example of species that can be found here are: Leuchanthemum vulgare, Hypericum maculatum and Phleum pratense. Picture C = the category of grassland with 25-50% trees, showing species more connected to a forest habitat like Pteridium aquilinum, Vaccinium vitis-idaea, Fragaria vesca and Deschampsia flexuosa. Picture D = category deciduous forest ex. grassland, here with hazel trees shadowing the ground, examples of other species found in this kind of habitat were Calamagrostis arundinacea and Hepatica nobilis.

4. Methods

4.1 Locations

The grassland and forest plots examined in this project were included in and retrieved from a project by Cousins, *"the soil properties effect on grassland decline and species richness in rural landscapes"* (2009), which mapped the grassland decline, soil fertility, and plant species richness in 12 rural landscapes in Södermanland. The methodology and background material needed to construct the historical land use maps are described closer in Cousins' study and will not be discussed further here. Except for the google map below (figure 4), showing the locations of Hemsta and Långmaren in a national context, all maps in this study were created from the GIS-files obtained from Cousins (2009) using the map view package in R (v.4.0.5.). It should be noted that the maps from 2009 that are used as present-day land-use maps in this study, are a decade old. This means that significant changes in the vegetation community during the time between 2009 and present time (2021) could have occurred depending on the management practices put in place. Therefore, all plots were visually inspected prior to inventory, and any plots that were deemed to have changed drastically since 2009 were excluded from the analyses.

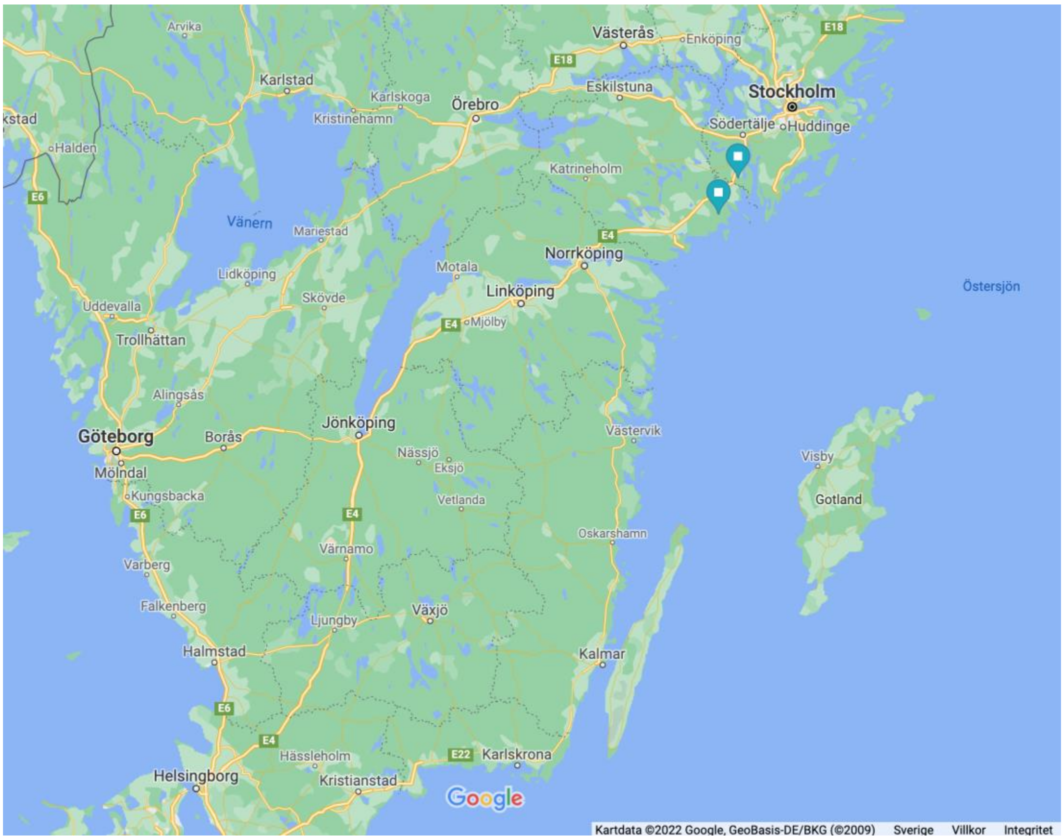

Figure 4. A map over southern Sweden (in northern Europe) shows where the two locations are placed, southeast in the country, close to Östersjön (Google maps, 2022).

4.1.1 Hemsta

Hemsta is an area located in Södermanland, just outside Hölö (59.00255'N, 17.57479'E) in southeastern Sweden. The area consists mostly of clay soil, some parts with more rocks and stones (Cousins, 2009). Overall, the vegetation is characterised by a high degree of spontaneous overgrowth (figure 6).

The inventory at Hemsta comprised a total of 47 plots, of which a few were subsequently discarded from the final analyses (see classification in part 2.3.). The Hemsta location with its 2009 land-use classifications can be seen in figure 5 below.

Figure 5. Showing an overview map on the Hemsta area as of 2009.

Figure 6. Two pictures showing high vegetation at Hemsta, indicating grassland abandonment in the process of secondary succession.

4.1.2 Långmaren

Långmaren (58.83427’N, 17.40297’E), is characterised as a well-preserved cultural landscape integrated in a ~5,000 ha nature reserve since 1971 (Länsstyrelsen, n.d.). The area has a rich flora and fauna, and include both forests, cultivated grasslands, and well-preserved SNG. The area was managed according to traditional management practices by Ivar Karlsson until 1967 and is today a museum farm under the management of Södermanlands region (Nynässlott, n.d.). An unusual thing about the farm is that the land never has been fertilised with artificial fertilisers. Until 1967, no tractor was used at the farm, instead the field work was done with oxen and the grass was cut with a scythe (Sormlands museum, 2014). At Långmaren a total of 50 different plots were inventoried (Fig. 7).

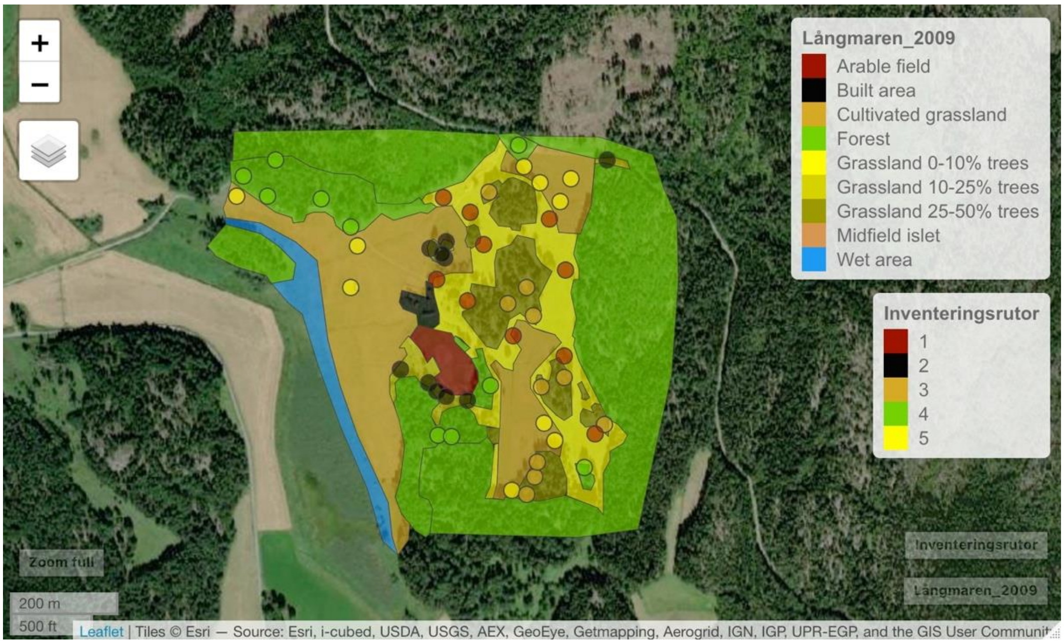

Figure 7. Shows an overview of the Långmaren area along with the inventory plots (coloured points) as of 2009.

Figure 8. Shows a SNG at Långmaren characterised by traditional grazing management.

4.2 Inventory

The inventory work took place between the 10th of June and the 15th of August, 2021. I used the square method to identify vascular plants to species level and determine species-area curves in every plot, along with total plant species richness. The inventory method followed the one proposed by Ekstam and Forshed (1996), where an area of $1m^2$ is inventoried and followed by an adjacent similar square, and then two more, so that by the end a total area of $4m^2$ is inventoried in four steps. For this purpose, a steel frame, of $1m^2$, was used, put down on the ground, for marking the square. When all the species from the first $1m^2$ were noted, the frame was flipped to the corresponding area, edge to edge with the first square. This was repeated until all four m^2, one by one, were assessed (figure 9). Species that were found in the second, third and fourth square were added only if they were not found in the previously occurring squares.

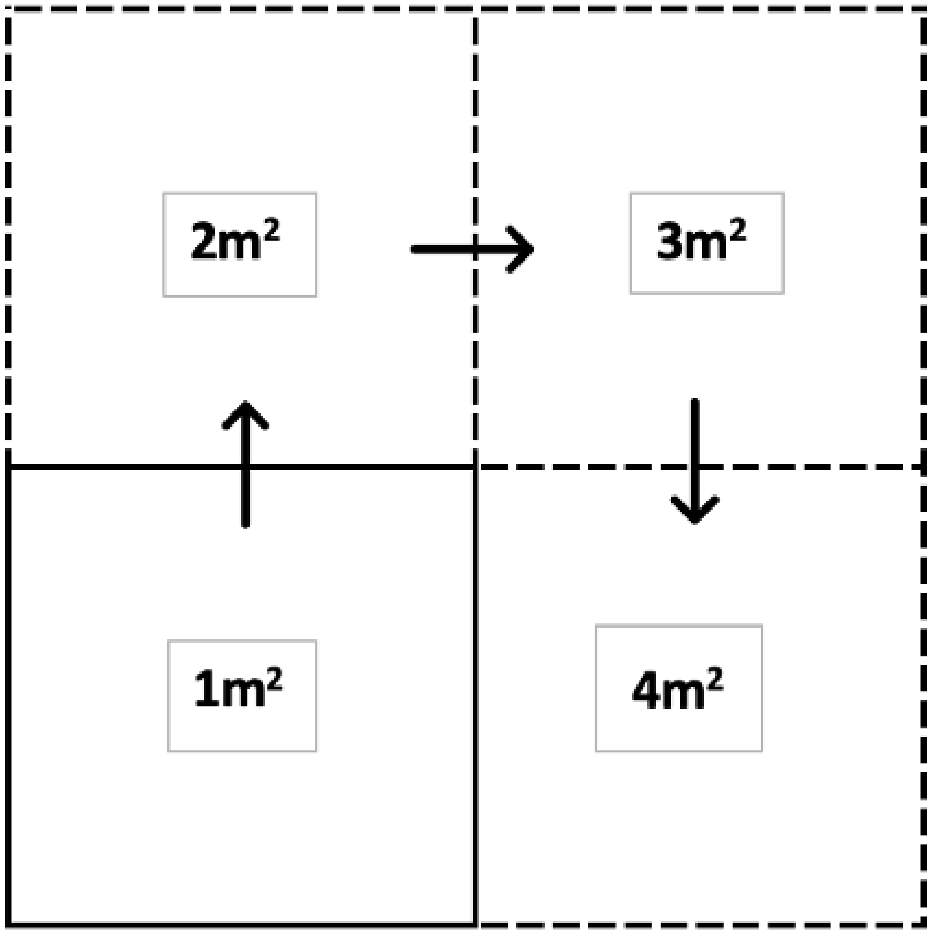

Figure 9. Shows the squares that were inventoried. The inventory was made in the order of the square placement, following the arrows.

From this, species-area curves (Ekstam & Forshed, 1996) were used to assess how well the plant richness in the grassland was captured by inventorying using $1m^2$ squares, in addition to giving an indication about the structuring of the plant communities at the site. Thus, the shape and steepness of the slope linking species richness to the successively larger area inventoried give an indication of the patchiness and structure the plant distribution as in the examples shown in figure 10 below. For example, if the area is found to have an even distribution like the first example figure 10A, the slope of the species richness- area curve plateaus early as no additional species are found after three or four squares. In this case, relatively few replicates suffice to sufficiently capture the total richness of the area. In the examples shown in figure 10B, the plant community is unevenly structured and new species are found even after high replication effort.

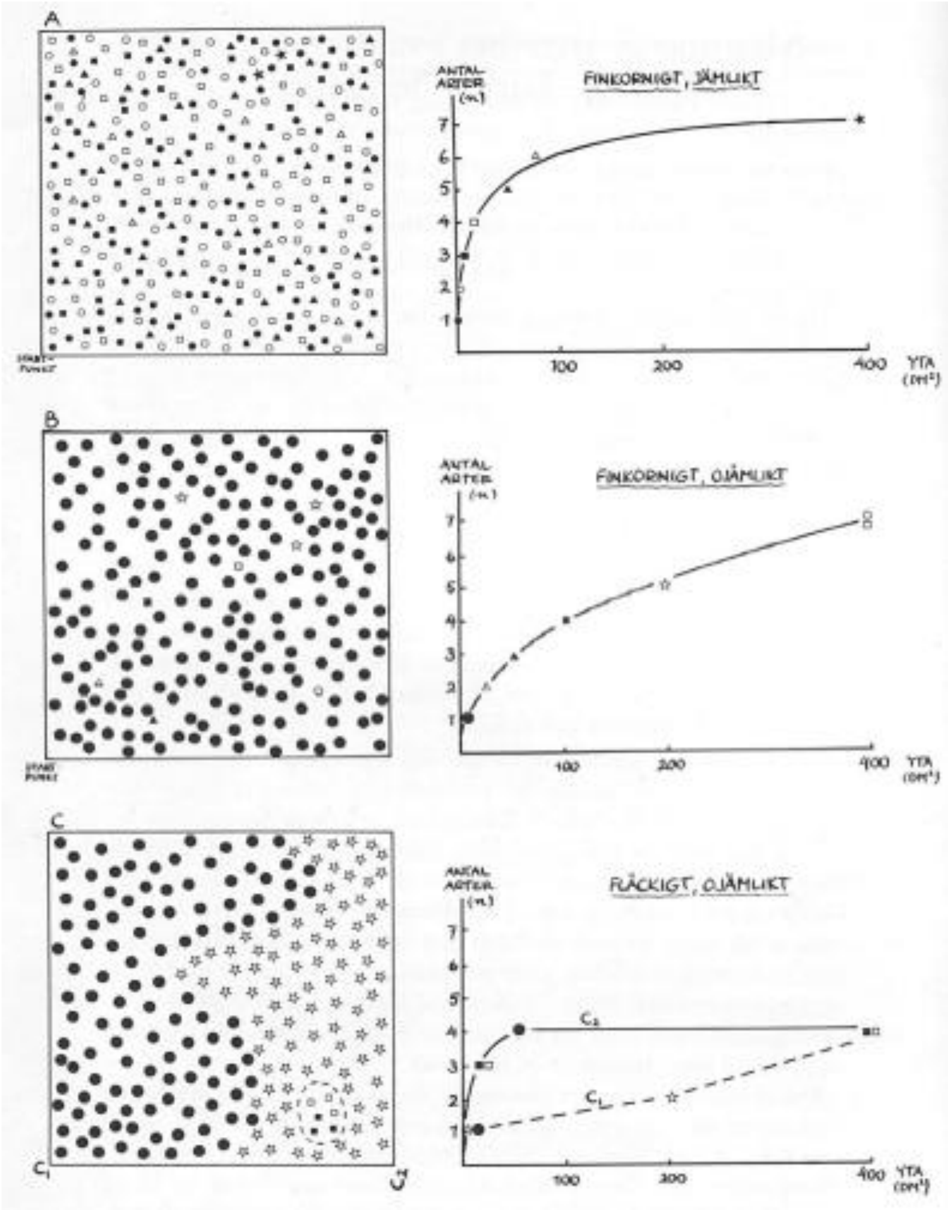

Figure 10. Shows examples on how the species/area- curves indicate the structure in different plant communities (Ekstam & Forshed, 1996, p. 216). The graph at the top shows a curve indicating a community of species with a uniform dispersal over the area. The graph in the middle shows a more uneven dispersal, while the graph at the bottom shows a community with different areas/spots of species requiring a bigger inventory area to cover a representative number of species.

4.2.1 Assessing SNG specialist occurrence

To assess the changes in plant communities in abandoned and overgrowing grasslands, all species found in the present-day land-use categories were matched against the indicator species developed by Ekstam & Forshed (1992) and described above. A list of all the specialist species (categories A & B) noted are found in Appendix 2. The occurrences of specialist species characterising well-managed SNGs were compared across land-use categories to examine how the management today affects the species.

4.2.2 Materials

A 1x1m steel frame was used to delineate the inventory site. For plant identification, I relied on the *Svensk Fältflora* (Mossberg & Stenberg, 2021), in addition to *Nordens Flora* (Mossberg & Stenberg, 2018). I used an Iphone S6 to retrieve coordinate locations using GoogleMaps.

4.3 Land-use classifications

To address the research questions posed in this thesis, I worked with two different notions of land use that will be expanded upon more below. For the question of species richness in overgrowing grasslands, I relied on the present-day land-use categories found in the 2009 land-use maps and visually confirmed to agree with present-day land use in the field. These land-use categories show grasslands in different stages of secondary succession (i.e. with differing degrees of tree cover), in addition to the categories of cultivated grassland and forests on plots that historically harboured grasslands (figures 5 & 7). To address the question of how historical land-use effects affect present-day plant communities, I further constructed land-use series (LUS) by combining different land-use categories across the time steps of the historical maps. This step required some re-classifications of the original land-use categories at each time step, as will be explained more below.

4.3.1 The land-use categories

All present-day land-use categories can be seen in table 1 and 2 for Långmaren and Hemsta respectively. Since this project aimed at evaluating grassland flora in different stages of succession, only the grassland (i.e., grasslands with any % of trees, cultivated grasslands), forest categories were included in the analyses of present-day species richness between different land-use categories.

The land-use categories inherent in each map were subsequently grouped and harmonised to larger land-use categories in order to determine historical legacy effects by constructing LUS. The harmonisation procedure is described briefly below, and all re-classifications made in the construction of LUS are found in Appendix 1.

4.3.2 The LUS classification

The method of constructing land-use series spanning over chronological steps of land-use categories across time was used drawn from a similar study aiming at determining historical land-use effects on plant communities in Västra Götaland (Gustavsson et al. 2007).

Thus, LUS were constructed by first simplifying and harmonising the land-use categories inherent in each historical land-use map. The land-use categories were put into combinatorial sequences that show land-use change over time. Combinations of four letters, one letter for each stage in time. For example if a site was categorised as grassland (G) in the 18th century, Arable field (A) in 1900, cultivated grassland (C) in 1950 and forest (F) in 2009, the shortened combination of LUS would look like: G-A-C-F. Due to the many and similar land-use categories, in each of the historical maps (Cousins, 2009), it was necessary to first simplify and harmonise these categories into broader meaningful categories that allowed for more LUS replicates. Categories that were found compatible were combined, this was done to get fewer more solid groups of categories.

Table 1. Shows the categorisation and the changes made in the categories for the different mapping times at Långmaren. The categorisation is divided into four: the 18th century, 1900, 1950 and 2009. The category that is written on the left side of each = shows what the categories were before they were changed. What they were changed to can be seen on the right side of each = sign.

18th century			**1900**		
Original		**Changed to**	**Original**		**Changed to**
Outskirt areas for grazing	=	Grassland	Arable fields	=	Arable fields
Grassland	=	Grassland	Coniferous forest	=	Grassland
Arable fields	=	Arable fields	Grassland	=	Grassland
			Other open area impediment	=	Grassland
			Deciduous forest ex. grassland	=	Grassland
			Arable fields	=	Arable fields
1950			**2009**		
Original		**Changed to**	**Original**		**Changed to**
Deciduous forest ex grassland	=	Forest	Deciduous forest-ex. grassland	=	Forest
Forest	=	Forest	Grassland 0-10% trees	=	Grassland
Arable fields	=	Arable fields	Grassland 10-25% trees	=	Grassland
Grassland 0-10% trees	=	Grassland	Grassland 25-50% trees	=	Grassland
Grassland 10-25% trees	=	Grassland	Cultivated grassland	=	Cultivated-grassland
Grassland 25-50% trees	=	Grassland			
Midfield islet	=	Grassland			

Table 2. Shows the categorisation and the changes that were made in the categories for the different years at Hemsta. The categorisation is divided into four: the 18th century, 1900, 1950 and 2009. The category that is written on the left side of each = shows what the categories were before they were changed. What they were changed to can be seen on the right side of each = sign.

18th century			**1900**		
Original		**Changed to**	**Original**		**Changed to**
Arable fields	=	Arable fields	Arable fields	=	Arable fields
Grassland	=	Grassland	Coniferous forest	=	Grassland
Outskirt areas for grazing	=	Grassland	Grassland	=	Grassland
			Other open area impediment	=	Grassland
			Deciduous forest	=	Grassland

1950			**2009**		
Original		**Changed to**	**Original**		**Changed to**
Arable fields	=	Arable fields	Cultivated grassland	=	Cultivated grassland
Deciduous forest ex. grassland	=	Forest	Deciduous forest-ex. grassland	=	Forest
Forest	=	Forest	Grassland 0-10% trees	=	Grassland
Grassland 0-10% trees	=	Grassland	Grassland 10-25% trees	=	Grassland
Grassland 10-25% trees	=	Grassland	Grassland 25-50% trees	=	Grassland
Grassland 25-50% trees	=	Grassland			
Midfield islet	=	Grassland			

4.3.3 Construction of land-use sequences LUS

Hemsta

At Hemsta the total number of different LUS combinations were 13. A few of these combinations only included one or two replicates which made them unsuited for statistical analyses. I therefore decided to narrow down the combinations from 13 to 5, excluding combinations with only one or two replicates. These five LUS combinations, along with their number of replicates, can be seen in table 3.

Table 3. Shows the five LUS groups and the number of coordinates that were in each LUS group. This was data used in the statistics for Hemsta.

LUS	**Number of replicates**
G-A-A-G	5
G-A-G-G	4
G-G-G-G	13
G-A-A-C	5
G-G-G-F	9

Långmaren

At Långmaren, a total of 11 different LUS combinations were found. Similar to at Hemsta, I discarded all combinations containing only one or two replicates to increase the statistical power of the comparisons. As a consequence, a final total of 5 LUS combinations were used at Långmaren (Table 4).

Table 4. Shows the number of plots in the different LUS groups that were used at Långmaren.

LUS	**Number of replicates**
G-G-G-G	21
A-A-A-C	6
G-G-F-F	6
G-G-F-G	4
G-G-G-F	4

4.4 Statistics

One-way analysis of variance (anova) was used to determine the effects of historical land use and successional stages of overgrowth on plant species richness and occurrence of specialist plants. In the case of significant results ($p < 0.05$) a post-hoc test (Tukey's HSD) was used to examine differences between groups. All tests and graphs were done using Minitab (version 19.2020.1.0).

4.5 Literature

The books Ängar (Ekstam et al., 1988) and Svenska naturbetesmarker (Ekstam & Forshed, 2000) were read as a start for writing this thesis. Additional literature and articles were read when needing more information on specific areas. They were found by searches in databases such as google scholar and the SLU library (libris). For the part about specialists the book “*If grassland management ceases: vascular plants as indicator species in meadows and pastures”* by Ekstam & Forshed (1992) was a good support.

5. Results

5.1 Species richness

Overall, the Långmaren area was characterised by a higher species richness than Hemsta (Figs. 11 & 12). The constructed species-area curves show how the number of species increased with increasing inventory area (Figs. 11 & 12). Based on these curves, the plant communities appear to be quite unevenly structured, and a larger sampling effort is probably required to better capture the true occurrences and distribution of plants at both areas.

Interestingly, the most managed plots at each location appeared to be most evenly structured (Figs. 11 & 12), which indicates that active grassland management maintains not only diversity but also the evenness and structure of the plant communities which agrees with what Ekstam & Forshed have written (1996, p. 215).

At Långmaren, there was a clear indication of open and managed grasslands being diverse habitats in terms of vascular plant species richness. The grassland category seems to have the most uniform number of species between the squares, but also this category has an increase with one more species in the last square. The form of the curve, according to Ekstam and Forshed, is a mix between both A and B (Figs. 10 and 11) indicating that this particular category is somewhere in between having an even distribution and having an uneven distribution of species over the $4m^2$ inventoried here (Ekstam and Forshed 1996, s. 216).

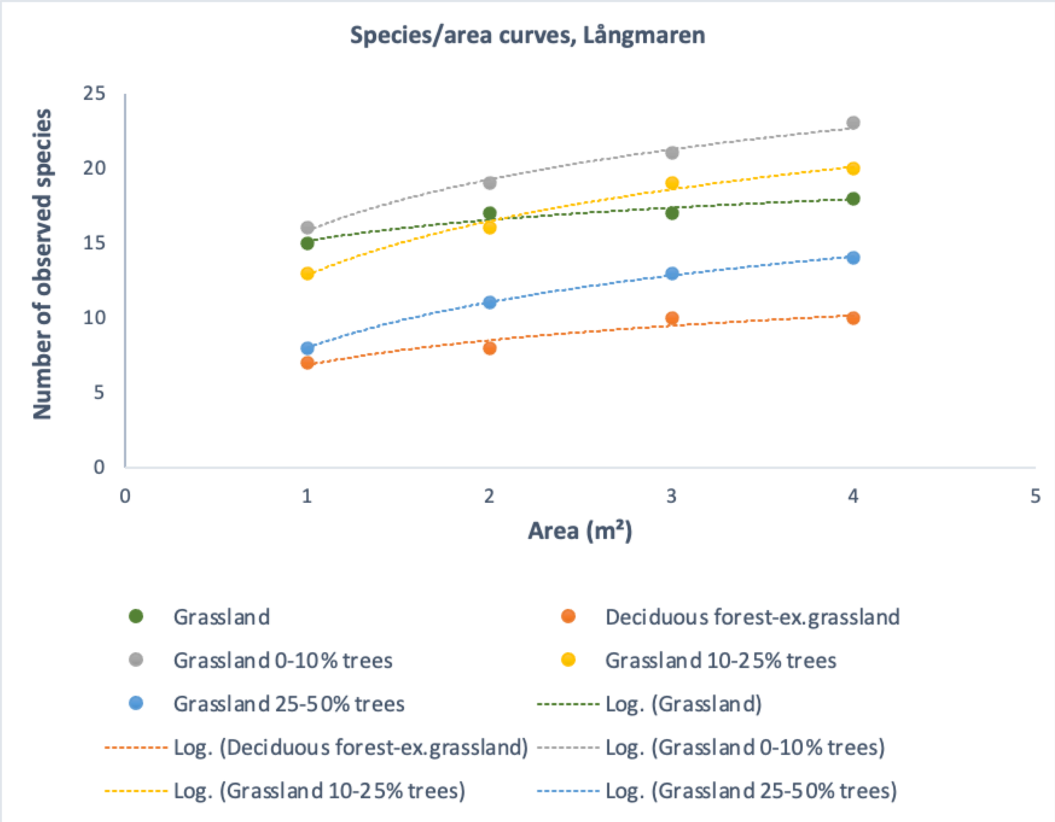

Figure 11. The graph is constructed with the number of species on the y-axis and the four squares that were inventoried placed at the x-axis. The graph shows the average number of species, in the different categories, at Långmaren.

At Hemsta (fig. 12), there were smaller differences between the present-day land-use categories than at Långmaren. These results also shows that the category of grassland 10-25% trees and cultivated grassland has a linear form making it be somewhere in between the uniform structuring and the uneven structuring over the squares compared with the other categories (fig.12).

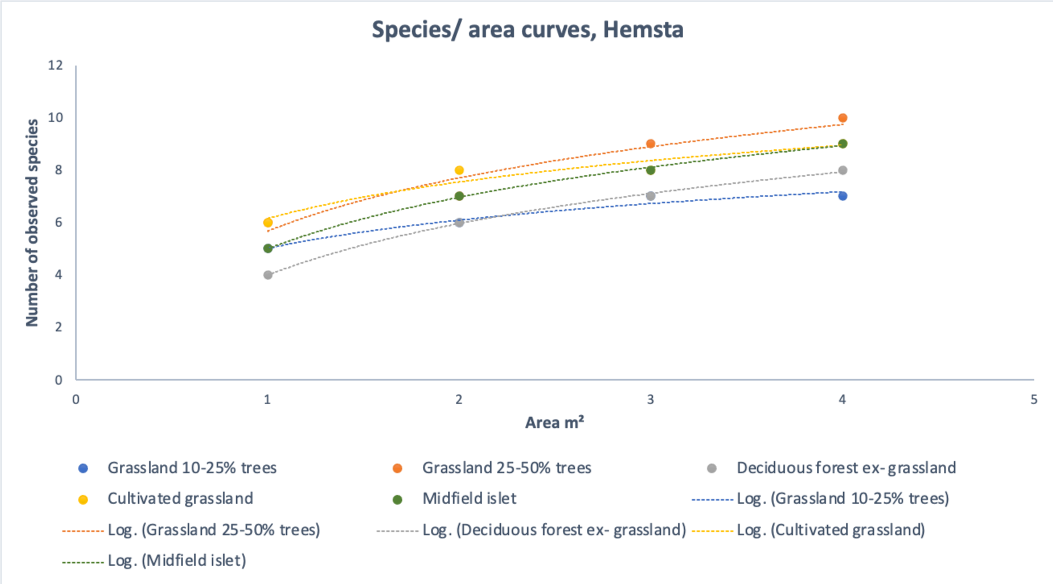

Figure 12. Shows the average number of species found with increasing inventory area (1-4m^2) in the different land-use categories at Hemsta.

5.2 Plant species richness in present-day land-use categories

At Långmaren, the forest plots standing on remnant historical grassland harboured the highest number of species on average (Fig. 13), whereas the cultivated grasslands appeared to be the poorest in terms of species richness. However, none of the differences were statistically significant in this area (see Table 5 for the outcome of all global one-way anova tests).

This was in stark contrast to the Hemsta area, in which the cultivated grasslands harboured significantly higher number of species than the afforested grasslands (Fig. 14, Tukey's HD, $P < 0.05$).

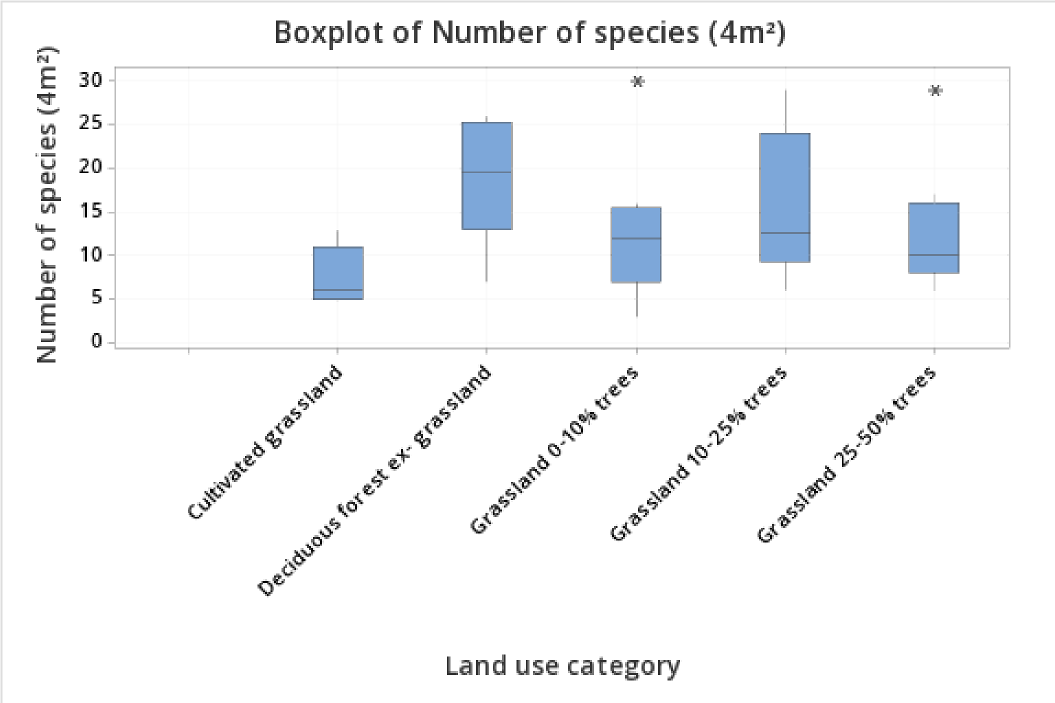

Figure 13. Shows the number of species (4m^2), versus the land-use categories, in the area of Långmaren.

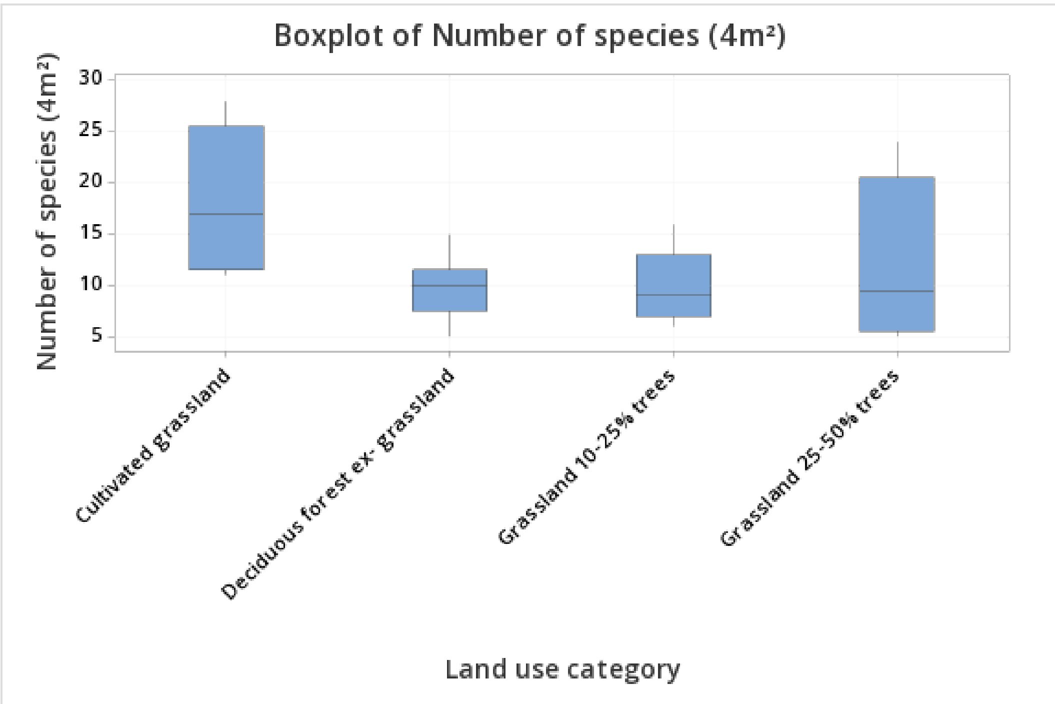

Figure 14. Shows the number of species (4m^2) versus the land-use categories, in the area of Hemsta.

Table 5. Shows the results of a one-way anova on the number of species between different land categories at both locations. It also shows the results of a one-way anova on species richness versus LUS.

Factor	Number of species		
	MS	F	P
Land use 2009, Långmaren	116.73	2.25	0.83
Land use 2009, Hemsta	91.87	3.31	<0.05
LUS, Långmaren	177.50	3.92	<0.05
LUS, Hemsta	91.87	3.47	<0.05

5.3 Specialist plant occurrence

The presence of specialist species indicating a well-managed grassland (succession categories A and B) can be seen in figs. 15-16. In line with the predictions, the occurrence of these plants dropped sharply between the managed grasslands (0-10% tree cover) and the more overgrown grasslands (25-50% tree cover) and fully afforested plots (significant, Tukey's HD, $p < 0.05$) at Långmaren (Fig. 15). At Hemsta, there were overall much fewer specialist plant occurrences, and these did not differ significantly between the grasslands in different stages of secondary succession (Fig. 16).

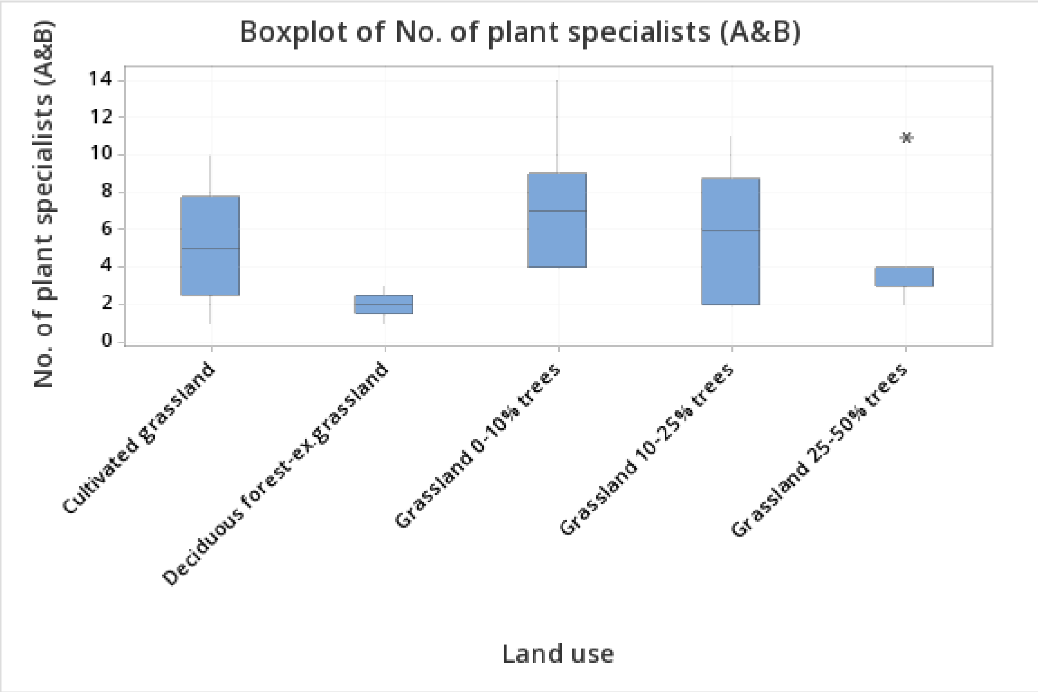

Figure 15. A boxplot showing the total number of specialist species (category A&B) that were found at Långmaren in the different land-use categories (4m^2).

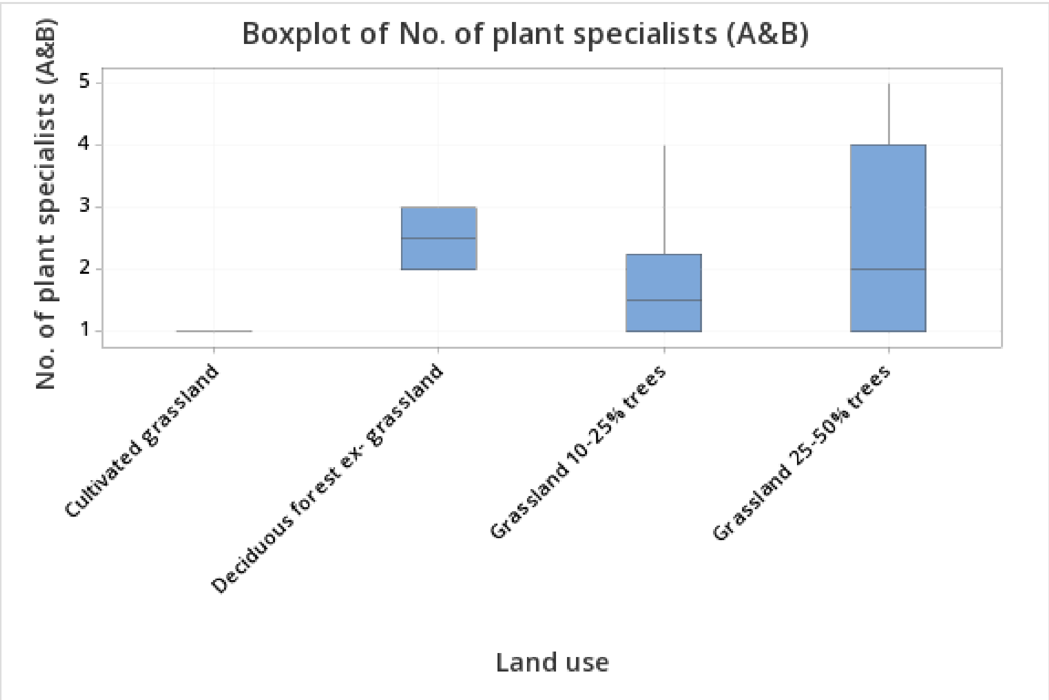

Figure 16. Shows a boxplot of the total number of species (in category A&B) that were found at Hemsta in the different land-use categories (4m^2)

5.4 Legacy effect of historical land use

There was evidence of legacy effects from historical land use on the present-day plant communities at both locations (Table 5). At Långmaren, plots with a LUS including arable land (i.e. land that has been/is ploughed and used for cropping) had significantly lower number of plant species (Tukey's HD, $p < 0.05$) than plots with a LUS comprising forest in different stages back in history (not including forest categorised in 2009 /today) (fig. 17).

Interestingly, the effects were somewhat opposite at Hemsta, with the LUS ending in present-day cultivated grassland management having the overall highest number of species, and significantly higher richness than present-day grasslands with grasslands that were used as arable fields in the early 1900s and then reconverted (Fig. 18, Tukey's HD, $p < 0.05$).

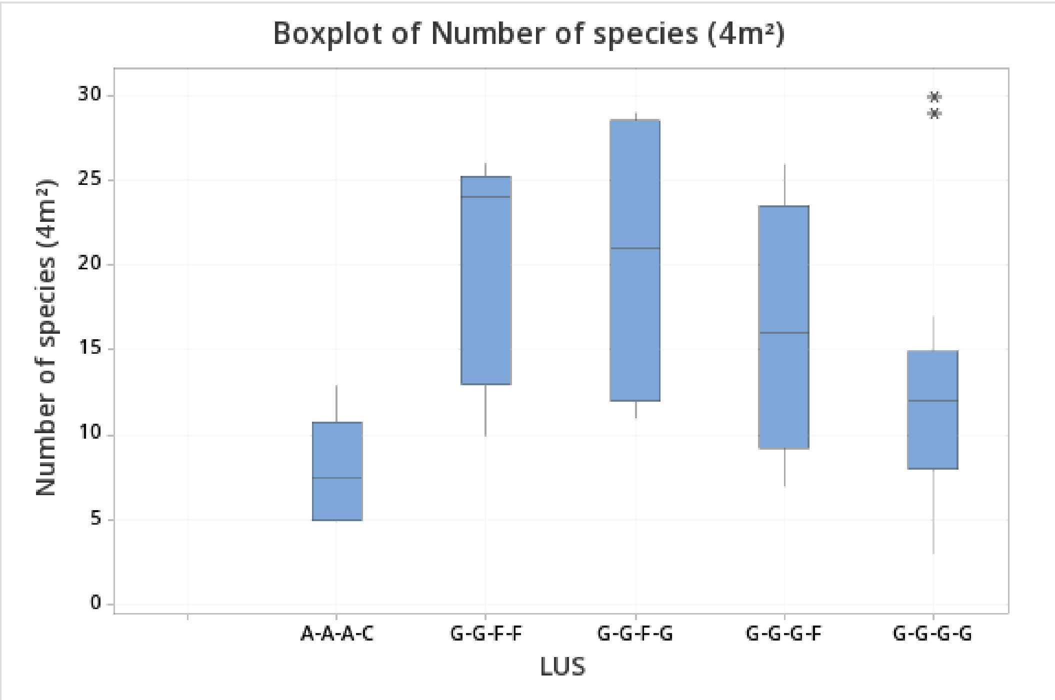

Figure 17. Shows a boxplot of the number of species ($4m^2$) on the y axis versus the LUS (land-use sequence) combinations (one letter from each categorisation year) on the x- axis, at Långmaren. A= arable land, C= cultivated grassland, F= forest, G= grassland. Outliers indicated by stars.

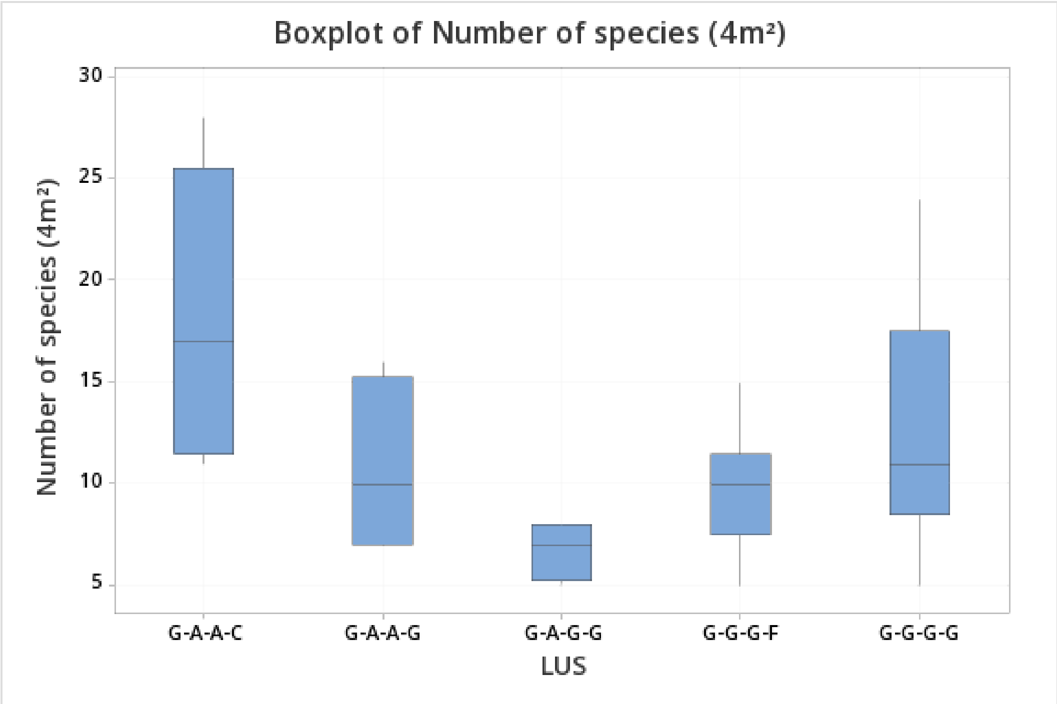

Figure 18. Shows a boxplot of the number of species (4m^2) on the y axis, versus the LUS (land-use sequence), on the x-axis, in the area of Hemsta. A= arable land, C= cultivated grassland, F= forest, G= grassland.

6. Discussion

6.1 Species richness in the landscape

As mentioned, the species area curves from Ekstam and Forshed (1996) will take different forms depending on the species density and the structure in the vegetation at a specific location. The species-area curves produced in this study showed that most of the categories include a steadily-increasing number of species in the second, third and fourth square at both locations. This indicates that a) the plant communities are unevenly structured, and b) that increasing sampling effort (i.e. more replicate squares) are necessary to adequately capture the true plant occurrences in the landscape (Ekstam & Forshed, 1996).

At Långmaren, the grasslands under active management appear to be more evenly structured than abandoned or afforested grasslands (Fig. 11), in line with the succession theory of Ekstam and Forshed (1996). At Hemsta, all grasslands as well as the fully afforested areas appeared to be similarly and quite evenly structured (Fig. 12), which is perhaps not surprising given the absence of active management and contrasts between well-managed and abandoned grasslands in the area. The use of species-area curves has been criticised for providing poor data for statistical treatments, compared to e.g. using index-based values (Karlsson, 2014). A patchy and uneven vegetation might occur locally only due to stochastic or uneven distribution of disturbances, and the inability to capture these local patches could result in a flat species-area curve and indicate that the area is spotty and in a later succession stage which would be correct, but it might on the other hand not be representative for the site (ibid).

In the present thesis, the heterogeneity of the different land use categories were compared solely in relation to Ekstam's description of the species area curves.

(Ekstam & Forshed, 1996, p. 216). For a better view of the community heterogeneity in the different land-use categories it would have been good to look at the differences across as well as within the different habitats.

6.2 Site specific differences

Already while conducting the inventory out in the field, it was clear that the overall species richness differed between the Hemsta and Långmaren areas independently of the land-use category examined, and this was further corroborated when examining the species-area curves at each area (Figures 11 & 12). A possible explanation for this could be that the management at Långmaren has remained stable and continuous over a long time. Management continuity is an important factor behind a stable and diverse plant community, as the different species have had the time to adapt to the specific management as well as to the location (Lennartsson & Westin, 2017). In this context, the plots at Hemsta are characterised by larger habitat transformations which is also evident in the relative proportion of historical grassland that has been lost in both areas since the 1700s (Cousins 2009, Figures 1 & 2). While different landscapes have different plant communities for a range of reasons, some of which are not directly related to management (Hulshof et al., 2020) plant species richness in a given plot is also directly related to landscape factors such as habitat connectivity and fragmentation (Gaujour et al., 2011). Which have probably undergone larger shifts in Hemsta than at Långmaren. It is therefore possible that the species at Hemsta in comparison have not had the possibility to adapt to a changing management depending on the time and the people responsible. In particular, different soil conditions might also be a factor that possibly has affected the results. pH (Schuster & Diekmann, 2003), fertility, soil structure and microbial population (Beylich et al., 2010; Young & Ritz, 2000; Liu et al., 2020) are all factors affecting the structuring, dispersal, and plant richness of a grassland habitat. As none of these soil edaphic properties or landscape factors were measured, it is difficult to speculate more precisely on the reasons for the overall higher plant diversity at Långmaren compared to Hemsta. However, I would like to suggest that the long continuity of management at Långmaren, as well as the relatively less fertile soil there could be a key here. Less fertile soil typically results in the microbes affecting the plants more through higher levels of root symbioses compared to fertile soils where plants are less reliant on microbial symbioses to obtain nutrients (Liu et al., 2020). A higher diversity of soil and plant microbes therefore typically correlate with a higher plant diversity (ibid). Soil microbes are also affected by the soil structure and decrease under heavy soil compaction (Beylich et al., 2010; Young & Ritz, 2000; Liu et al., 2020). A speculation is therefore whether the soil at Långmaren could be less compacted due to the prolonged absence of heavy machinery in its management history, in contrast to Hemsta. It would in any case have been beneficial for this type of research project to collect soil samples and more information on the soil structure as this might have explained some of the differences between the locations.

According to Chapman (2001) the disturbances created by a well-balanced density of livestock gives the optimal balance between different species resulting in optimal diversity. At Hemsta there were no grazing animals seen, apart from some wildlife. When being out in the field at Hemsta the question of what the areas were used for came to mind, as much of the areas seemed to be in later successional stages due to abandonment and/or inactive management. Figure 14 show that Hemsta does not have well-managed grasslands (category grassland with 0-10% trees) at the present time compared to Långmaren (fig. 13). This might have impacts beyond the actual grasslands being grazed, as grazing animals also maintain the overall landscape connectivity and act as dispersal agents for a range of vascular plants (Tälle et al., 2016; Auffret, 2013).

6.3 Species richness and presence of specialist species under present land use

At Långmaren, plant species richness did not differ between present-day land uses. This result did not agree with the hypothesis in this thesis, that plant species richness would decrease with increasing succession, as it was expected that the well-managed grassland categories (i.e. low percentage of tree cover) would have had a higher number of species compared to for example the fully afforested grasslands and the grasslands in later successional stages (Uchida et al., 2018). However, when examining the number of specialist indicator species associated with well-managed SNGs (i.e. species in succession categories A and B), I found that these followed the expected pattern of gradual disappearance with increasing tree cover (Fig. 15). This suggests that, at Långmaren, the composition of plant communities might undergo significant changes despite the overall plant species richness remaining more or less constant across land-use changes. This could be of importance in the context of grassland restoration, as a focus only on maintaining plant species richness would not necessarily lead to good outcomes for plant species that require a high level of active management (i.e. grazing) to thrive. At Hemsta, the results were more surprising. Here, the only grassland category being actively managed was cultivated grasslands, and these were on average more species-rich than the fully afforested plots with a history of grassland management (Fig. 14, Table 5) but did not differ significantly from the other grassland categories. When looking at the number of indicator species, however, I found that the cultivated grasslands acted as poor habitat for these. This result deviates from the results obtained for Långmaren, as well as from succession stages by Ekstam & Forshed (1992) and from similar results found in other studies (Aune et al.,2018; Öckinger et al., 2006; Uchida et al., 2018).

The presence of more indicator species in the grasslands characterised by high overgrowth and in the fully afforested plots suggest that active management at Hemsta is perhaps a more important factor shaping both the species richness and the community composition of plants in this area. The effects of management for grassland biodiversity can vary depending on both management type and site factors (Tälle et al., 2016) and both species richness and community composition is ultimately best described by considering local management and environmental factors jointly (ibid). At Hemsta, both environmental factors (although not measured here) and management differs a lot from the situation at Långmaren, and it is perhaps not surprising that the drivers of plant communities differ between the areas. Millberg et al. (2020) recently found evidence of site factors being more important as drivers of grassland indicator species than management factors across more than 300 grassland plots in Southern Sweden, with site productivity and soil moisture acting as the main environmental filters of indicator plant occurrences. Managing grasslands to preserve threatened indicator species is therefore clearly a better option in low-productivity areas such as Långmaren compared to the more nutrient-rich area of Hemsta.

Another question arising from these results is why the category of cultivated grassland contain such a high number of specialist species even though the (possible) disturbance of ploughing is believed to decrease biodiversity (Uchida et al., 2018). A possible explanation for this could be found in the mediating factor of legacy effects. Typically, cultivated grasslands used for growing ley and animal fodder today are situated on more fertile soil than grazed grasslands (Cousins 2009), and this means that they are also likely to have been used as arable fields and ploughed in earlier times. In a study from Norway (Austrheim & Olsson, 1999), it was found that some specialist plant species that are normally found exclusively in uncultivated (i.e. unploughed) grasslands, could in fact benefit from historical ploughing if this had not occurred too close in time.

On the other hand, agreeing with Uchida et al. (2018) the study also found that when the ploughing had occurred closer than 12 years to present inventory, the effect might be the opposite resulting in decreased plant diversity (Austrheim & Olsson, 1999). This means that possible explanations to the results for Långmaren can be factors like legacy effects and management.

6.4 Legacy effects of historical land use

Semi-natural grasslands in Sweden cannot be understood without also considering the history of the landscape (Eriksson & Cousins, 2014). Gustavsson et al. (2007) found that land-use changes going from extensive to more productive systems often entail negative legacy effects for many grassland specialist species, whereas areas that have been kept in the same land use, like some semi-natural grasslands, over a longer timespan harbour a greater overall diversity and diversity of endangered species. In this study, I also found evidence of legacy effects of historical land use on the present-day plant communities in the areas examined. Interestingly, however, the legacy effects were inconsistent between the areas, pointing again to the importance of local site effects. At Långmaren, the results again agreed well with my initial hypothesis that a continuity of SNG management would create positive legacy effects for present-day plant species richness. Here, the LUS including arable land as a part of their land-use history had significantly fewer plant species than plots with a long-term SNG management (Fig. 17, Table 5), which is in line with the results obtained by Gustavsson et al. (2007). These legacy effects could be a direct effect of arable system practices such as ploughing, as discussed above in the context of Norwegian grasslands (Austrheim & Olsson, 1999). They could also be related to the intensification of the system, with more intensive land-use practices generally leading to sharper legacy effects on present-day plant communities (Valls Fox et al., 2015). At Hemsta, however, the fact that the LUS ending with a cultivated grassland management harboured higher species richness than the LUS classified as continuous grassland since the 1900's (Fig. 18, Table 5) is probably an indication of present-day management being more important than historical legacy effects at this site. In this context, legacy effects of historical land-use might be important only as long as the management is continuous and extensive but overshadowed by present-day management effects in grasslands that are abandoned or intensively managed (Cousins et. al., 2007).

To isolate and explain exactly what it is that cause legacy effects of historical land use is difficult, and it is therefore also difficult to disentangle when they cause differences in present-day plant communities and when they do not. Often, intensive or continuous management practices create permanent and irreversible effects in the soil physico-chemical properties and the soil biota (Dupouey et al., 2002), and these can cause effects on the plant communities long after the land use has changed (Cuddington, 2012; Heinen et al., 2020). In this context, the results at Långmaren fall in line with the general theory of more intensive practices (arable cropping systems instead of extensive grazing systems) creating legacy effects that negatively impact plant communities. However, there is also research suggesting that most soil variables impacted by land-use change only create transient legacy effects that cease after about 15 months from the disturbance (Jongen et al., 2021), depending on the time the system has to recover. It would therefore be interesting to examine the environmental factors at Hemsta and Långmaren more to see if these could be tied to the legacy effects observed here.

Possible sources of error

- The fact that I did not have any experience in the field of inventory work might be the biggest possible error of influence. This should be taken into consideration. The area of Långmaren was the first to be inventoried and Hemsta was done last. This means that I had more experience when I came to Hemsta. It is therefore possible that I did a better job and could find more of the species at Hemsta than I did at Långmaren.

- There were animals grazing the areas at Långmaren which made it more challenging to identify some of the more popular species at times. This can have affected the results.

- The statistical results would have been stronger if more locations had been included, this was not possible due to the time frame for this project.

Scope for future research

There is so much that would be important to research further. The many factors influencing grassland species richness and composition such as habitat quality, soil type, mycorrhizal and fungi interactions, different management practices and ecological symbioses are some examples that would be interesting to examine further. It would be interesting if it was possible to include many of the factors mentioned above in the same model system and follow it over a longer time. The challenge with this might be the difficulty in retrieving results with many factors being present. The time aspect can also be a challenge as Liu et al., (2007) writes, the ecological consequences from the impact of human life and management are hard to research because of the time for the effects to show (ibid). Using historical land-use maps as I did here, is one way to get around this but it relies on many assumptions in the classification of old maps. It seems like much research in this area end up with contradictory results, which makes the field intriguing but also interesting to research further.

Examples of questions that could be researched further are:

- How does legacy effects and habitat fragmentation affect plant diversity in semi-natural grasslands?
- What are the Legacy effects of different managements on plant diversity in different land use categories?
- What are the effects of former land use on soil physico- chemical composition, and how does this affect plant diversity?

7. Conclusion

The coupling between human and nature is something varying and changing over time. The previous mapping and earlier categorisation from back in time has made it possible to compare the results and by doing that it has been possible to see how the areas changes, how the density of species is affected by different land use and by how much overgrowth that has happened and is happening over time.

The result in this project proposes that legacy effects of historical land use appear to be highly site specific with many factors involved. Factors like soil edaphic properties, habitat connectivity and fragmentation are examples of site-specific factors among other that might heavily modify or steer legacy effects.

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Popular science summary

Plant diversity in relation to land use and legacy effects

Did you know that the land use in Sweden have drastically changed during the last two centuries?
Large-scale administrational and technological reforms have changed the agricultural landscape. Following an increase in the intensive monocultural land use there has been a decrease in areas that harbour biodiversity. A loss of traditional non-intensive areas like semi-natural grasslands and meadows result in many species decreasing or going instinct as they don't have suitable conditions to grow, reproduce, and disperse.

In this thesis I investigated how the changes in land use affect the diversity of vascular plants and if there is an impacts of historical land use on the species richness today.

Historical maps from four different times back in history was used to see how the land use has changed over time. Additional to this, 97 different plots at two different locations, in south-eastern Sweden, were inventoried. All the present species of vascular plants that were found were noted down and used in statistical analysis.

The results suggests that legacy effects of historical land use influence present-day plant communities but that these vary across the different locations. The results in this project seemed to be inconsistent to each other in the two locations that were included. The legacy effect of historical land use appears to be very site specific with many different factors most likely affecting the results.

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Appendix 1

Reclassifications of land-use categories

Changes in the land use categorizations at Långmaren

The changes that were made on the land use categories at Långmaren can be seen in table 2.

In the 18th century the “outskirt area for grazing” was changed to “grassland”. The argument behind the change (same as for Hemsta) was that an outskirt area for grazing included land with grass and therefore it fitted best in the grassland category.

The changes in the 1900 categorisation were that the two categories for forest, “deciduous forest” and “coniferous forest”, were changed into grassland. This change was, similar to the change for Hemsta, done due to the information from Cousins that in that time they tended to see the grasslands as forests (Cousins, 2021, personal communication). Another change in the categorisation for 1900 was that the “other open area impediment” were changed into grassland, this was done thinking that open areas fit into the category of some type of grassland.

The changes in the categorization for 1950 were that the grasslands divided into different percentages of trees and the midfield islet were changed into the grassland category. As mentioned earlier in the part about Hemsta this change was done since these categories fit best into the grassland category. In the 1950 year's categorisation the deciduous forest ex. grassland category was changed to forest. This is unlike the categorisation in the 18th century. The difference between the years is that “deciduous forest ex. grassland” are a type of forest and therefore fit into the forest category, the exception to this, in 1900, is already previously described.

In the 2009 categorisation the same changes as previous years were made. The grasslands with different percentages of trees were changed to grassland. Like in 1900 the category of "deciduous forest ex. grassland" was changed into "forest".

Changes in the land use categorizations at Hemsta

The Hemsta area land-use categories were changed according to table 1.

HEMSTA: In the mapping from the 18th century the following changes were made on the categorization: "open area around field", "stony slopes", and "Rocky terrain" were included in the category of "grasslands". This was done since all those categories fit into a wider definition of grasslands. Historically these areas were used as pastures which makes them suitable for the grassland category. Hilly and stony habitats such as some pastures and permanent meadows sometimes were, can be defined as grasslands according to Fuller et al., (2017).

The "outskirt grazed forest" [Utmarks område/skogsbete] category was changed into being just forest. This was done because even though the forest sometimes was used for grazing it still is a forest and therefore fits into the forest category.

In 1900 the "wetland" category was changed into "grassland". This seemed like a suitable choice since there are wetlands that are defined as a type of grassland (Lennartsson & Westin, 2017). Also, the wetlands were categorised as grassland in the previous categorisation (1700) and midfield islet or grassland in the categorisation that followed in 1950. Another change in the categorisation of 1900, was that all the "grazed forest" were changed to "grassland". This change was done according to Cousins since the categorisation at that specific time tended to see the grasslands as forests (Cousins, 2021, personal communication).

In 1950 the three different grassland categories with various percentages of trees and the midfield islet were all included in the grassland category. Another change in the 1950 land use was the category "house". This category was deleted from the data series because it is difficult to know exactly how the area around a specific house was utilised.

In 2009 the categories were changed in the same way as in the previous years. The grassland with different percentages of trees and the midfield islet were changed to be included in grassland.

At the inventory in 2021 a few coordinates placed on a lawn outside a house were excluded from the data. The lawn was cut constantly with a robotic lawnmower which made it incommensurate for inventorying. One coordinate was left out because it was not found as it was missing in the coordinate GPS system.

The conclusion on the changes in the categories at Hemsta is that the categories of for example grassland and forest had to be widened to include more different types of habitats. The changes were made to get fewer categories in the statistical data.

Appendix 2

Specialist species

Information on the number of specialist species, in succession category A&B that were found at Långmaren.

Långmaren

Name in swedish	**Succession category**	**Name in latin**
Backlök	B	*Allium oleraceum L.*
Backnejlika	B	*Dianthus deltoides L.*
Bergssyra	B	*Rumex acetosella*
Betesdaggkåpa	B	*Alchemilla monticola Opiz*
Blåsuga	B	*Ajuga pyramidalis*
Bockrot	B	*Pimpinella saxifraga L.*
Brunven	B	*Agrostis canina*
Darrgräs	A	*Briza media*
Fårsvingel	B	*Festuca ovina*
Groblad	A	*Plantago major*
Gråfibbla	B	*Hieracium pilosella*
Gullviva	B	*Primula veris L.*
Gökärt	B	*Lathyrus linifolius*
Harklöver	A	*Trifolium arvense*
Höstfibbla	A	*Scorzoneroides autumnalis*
Jungfrulin	A	*Polygala vulgaris*
Knippfryle	A	*Luzula campestris (L.)*
Käringtand	B	*Lotus corniculatus*
Liten blåklocka	B	*Campanula rotundifolia*
Majsmörblomma	B	*Ranunculus auricomus L.*
Majveronica	A	*Veronica serpyllifolia*
Nattviol	B	*Platanthera bifolia*
Ormrot	B	*Bistorta vivipara (L.) Gray*
Prästkrage	B	*Leucanthemum vulgare*

Revfingerört	B	*P. Reptans*
Rosettjungfrulin	A	*Polygala amarella Cr.*
Rödklöver	B	*Trifolium pratense*
Rödkämpe	B	*Plantago media*
Rödsvingel	B	*Festuca rubra*
Sammetsdaggkåpa	B	*Alchemilla vulgaris*
Slåtterfibbla	A	*Hypochaeris maculata L.*
Småborre	B	*Agrimonia eupatoria*
Småfingerört	A	*P. Verna*
Smörblomma	B	*Ranunculus acris*
Solvända	B	*Helianthemum nummularium*
Sommarfibbla	B	*Leontodon hispidus*
Spåtistel	A	*Carlina vulgaris L.*
Svartkämpe	A	*Plantago lanceolata*
Teveronica	B	*Veronica chamaedrys*
Veronica	B	*Veronica L.*
Vitklöver	A	*Trifolium repens*
Vittåtel	A	*Aira caryophyllea*
Vårbrodd	B	*Anthoxanthum odoratum*
Äkta Johannesört	B	*Hypericum perforatum*
Ängsklocka	B	*Campanula patula L.*
Ärenpris	B	*Veronica officinalis*
Ängsvädd	B	*Succisa pratensis*

The number of observed specialist species in category A&B that were found at Hemsta.

Hemsta

Name in swedish	**Succession category**	**Name in latin**
Backlök	B	*Allium oleraceum L*
Bergsyra	B	*Rumex acetosella*
Betesdaggkåpa	B	*Alchemilla monticola Opiz*
Bockrot	B	*Pimpinella saxifraga L.*
Brunven	B	*Agrostis canina L.*
Fårsvingel	B	*Festuca ovina*
Groblad	A	*Plantago major*
Gullviva	B	*Primula veris*

Gökärt	B	*Lathyrus linifolius*
Harklöver	A	*Trifolium arvense*
Höstfibbla	A	*Scorzoneroides autumnalis*
Liten blåklocka	B	*Campanula rotundifolia L*
Majsmörblomma	B	*Ranunculus auricomus L.*
Rosett jungfrulin	A	*Polygala amarella Cr.*
Rödklöver	B	*Trifolium pratense*
Sammetsdaggkåpa	B	*Alchemilla vulgaris*
Småborre	B	*Agrimonia eupatoria*
Smörblomma	B	*Ranunculus acris*
Solvända	B	*Helianthemum nummularium*
Teveronica	B	*Veronica chamaedrys*
Veronica	B	*Veronica L.*
Vitklöver	A	*Trifolium repens*
Vårbrodd	B	*Anthoxanthum odoratum*
Äkta Johannesört	B	*Hypericum perforatum*
Ärenpris	B	*Veronica officinalis*

Appendix 3

Following is the total number of species that were found in the inventory at Långmaren and Hemsta.

List of species found at Långmaren

Name in swedish	**Name in latin**
Asp	*Populus tremula*
Backlök	*Allium oleraceum L.*
Backnejlika	*Dianthus deltoides L.*
Bergslok	*Melica nutans*
Bergssyra	*Rumex acetosella*
Betesdaggkåpa	*Alchemilla monticola Opiz*
Bindvide	*Salix aurita L.*
Björk	*Beutula*
Blekstarr	*Carex pallescens*
Blodrot	*Potentilla erecta*
Blåbär	*Vaccinium myrtillus*
Blåklocka	*Campanula persicifolia*
Blåsippa	*Anemone hepatica*
Blåsuga	*Ajuga pyramidalis*
Bockrot	*Pimpinella saxifraga L.*
Brudbröd	*Filipendula vulgaris*
Brunven	*Agrostis canina*
Brunört	*Prunella vulgaris*
Brännässla	*Urtica dioica*
Darrgräs	*Briza media*
Ek	*Quercus robur*
En	*Juniperis communis*
Fibbla	*Crepis*
Fyrkantig johannesört	*Hypericum maculatum*
Fårsvingel	*Festuca ovina*
Förgetmigej	*Myosotis scorpioides*
Getrams	*Polygonatum odoratum*
Gran	*Picea abies*

Grodblad	*Plantago major*
Gråfibbla	*Hieracium pilosella*
Gräs	*Poaceae*
Grässtjärnblomma	*Stellaria graminea*
Gullklöver	*Trifolium aureum*
Gullviva	*Primula veris L.*
Gulmåra	*Galium verum*
Gulvial	*Lathyrus pratensis*
Gårdsskräppa	*Rumex longifolius*
Gökärt	*Lathyrus linifolius*
Hallon	*Rubus idaeus*
Harklöver	*Trifolium arvense*
Harkål	*Lapsana communis*
Hassel	*Corylus avellana*
Humleblomst	*Geum rivale*
Hundkäx	Anthriscus sylvestris
Hundäxing	*Dactylis glomerata*
Häckvicker	*Vicia sepium*
Höstfibbla	*Scorzoneroides autumnalis*
Jungfrulin	*Polygala vulgaris*
Knapptåg	*Juncus conglomeratus*
Knippfryle	*Luzula campestris (L.)*
Knylhavre	*Arrhenatherum elatius*
Krustistel	*Carduus crispus L.*
Kruståtel	*Deschampsia flexuosa*
Krypvide	*Salix repens L.*
Kråkvicker	*Vicia cracca*
Käringtand	*Lotus corniculatus*
Kärleksört	*Hylotelephium telephium*
Kärrfibbla	*Crepis paludosa (L.) Moench*
Kärrgröe	*Poa trivialis*
Liljekonvalj	*Convallaria majalis*
Lingon	*Vaccinium vitis-idaea*
Liten blåklocka	*Campanula rotundifolia*
Ljung	*Calluna vulgaris*
Luddhavre	*Helictotrichon pubescens h.*
Lundslok	*Melica uniflora*
Majsmörblomma	*Ranunculus auricomus L.*
Majveronica	*Veronica serpyllifolia*
Maskros	*Taraxacum*
Midsommarblomst	*Geranium sylvaticum*

Nattviol	*Platanthera bifolia*
Nyponros	*Rosa dumalis*
Ormbär	*Paris quadrifolia*
Ormrot	*Bistorta vivipara (L.) Gray*
Oxel	*Sorbus intermedia*
Piggstarr	*Carex spicata*
Piprör	*Calamagrostis arundinacea*
Plister	*Lamium*
Prästkraage	*Leucanthemum vulgare*
Revfingerört	*P. Reptans*
Rosettjungfrulin	*Polygala amarella Cr.*
Rödklint	*Centaurea jacea*
Rödklöver	*Trifolium pratense*
Rödkämpe	*Plantago media*
Rödsvingel	*Festuca rubra*
Rödven	*Agrostis capillaris*
Röllika	*Achillea millefolium L*
Rönn	*Sorbus aucuparia*
Rörflen	*Phalaris arundinacea*
Sammetsdaggkåpa	*Alchemilla vulgaris*
Skogsfibblor	*Hieracium L. sect. Hieracium*
Skogsfräken	*Equisetum sylvaticum*
Skogsklöver	*Trifolium medium*
Skogskovall	*Melampyrum sylvaticum*
Skogssallat	*Lactuca muralis*
Skogstry	*Lonicera xylosteum*
Skogsvicker	*Vicia sylvatica L.*
Skogsviol	*Viola riviniana*
Skräppa	*Rumex*
Slidstarr	*Carex vaginata Tausch.*
Slån	*Prunus spinosa*
Slåtterfibbla	*Hypochaeris maculata L.*
Smultron	*Fragaria vesca*
Småborre	*Agrimonia eupatoria*
Småfingerört	*P. Verna*
Smörblomma	*Ranunculus acris*
Solvända	*Helianthemum nummularium*
Sommarfibbla	*Leontodon hispidus*
Spåtistel	*Carlina vulgaris L.*
Stensöta	*Polypodium vulgare*
Stjärnstarr	*Carex echinata*

Stor blåklocka	*Campanula persicifolia*
Storgröe	*Poa remota Forselles*
Strängstarr	*Carex chordorrhiza L. f.*
Styvfibblor	Hieracium L. sect. Tridentata.
Styvmorsviol	*Viola tricolor*
Svartkämpe	*Plantago lanceolata*
Sälg	*Salix caprea*
Tall	*Pinus sylvestris*
Teveronica	*Veronica chamaedrys*
Timotej	*Phleum pratense*
Tistel	*Cirsium*
Träjon	*Dryopteris filix-mas (L.) Schott*
Tuvtåtel	*Deschampsia cespitosa*
Vanlig smörblomma	*Ranunculus acris*
Veronica	*Veronica L.*
Vitklöver	Trifolium repens
Vitmåra	*Galium boreale*
Vitsippa	*Anemone nemorosa*
Vittåtel	*Aira caryophyllea*
Vårbrodd	*Anthoxanthum odoratum*
Vårtbjörk	*Betula pendula*
Väddklint	*Centaurea scabiosa*
Åkerförgätmigej	*Myosotis arvensis*
Åkertistel	*Cirsium arvense*
Åkerveronika	*Veronica agrestis*
Äkta Johannesört	*Hypericum perforatum*
Älggräs	*Filipendula ulmaria L.*
Älgört	*Filipendula ulmaria*
Älväxing	*Sesleria caerulea*
Ängsfryle	*Luzula multiflora*
Ängsfräken	*Equisetum pratense*
Ängsgröe	*Poa pratensis*
Ängshavre	*Helictotrichon pratense*
Ängskavle	*Alopecurus pratensis*
Ängsklocka	*Campanula patula L.*
Ängssvingel	*Festuca pratensis*
Ärenpris	*Veronica officinalis*
Ängssyra	*Rumex acetosa L.*
Ängsvädd	*Succisa pratensis*
Örnbräken	*Pteridium aquilinum*

List of species found at Hemsta

Name in swedish	**Name in latin**
Ask	*Fraxinus excelsior*
Asp	*Populus tremula*
Backlök	*Allium oleraceum L*
Baldersbrå	*Tripleurospermum perforatum*
Bergslok	*Melica nutans*
Betesdaggkåpa	*Alchemilla monticola Opiz*
Bergsyra	*Rumex acetosella*
Björk	*Betula L*
Blåbär	*Vaccinium myrtillus L.*
Blåsippa	*Anemone hepatica*
Bockrot	*Pimpinella saxifraga L.*
Brunven	*Agrostis canina L.*
Brunört	*Prunella vulgaris*
Brännässlor	*Urtica dioica*
Ek	*Quercus robur*
En	*Juniperus communis*
Fyrkantig Johannesört	*Hypericum maculatum*
Fårsvingel	*Festuca ovina*
Gran	*Picea abies*
Groblad	*Plantago major*
Grå al	*Alnus incana*
Gräddmåra	*Galium album x verum*
Grässtjärnblomma	*Stellaria graminea*
Gröe	*Poa*
Gullviva	*Primula veris*
Gulmåra	*Galium verum L.*
Gulvial	*Lathyrus pratensis*
Gökärt	*Lathyrus linifolius*
Hagtorn	*Crataegus L*
Harklöver	*Trifolium arvense*
Harkål	*Lapsana communis L.*
Hartsros	*Rosa villosa L*
Hundkäx	*Anthriscus sylvestris*
Hundäxing	*Dactylis glomerata*
Häckvicker	*Vicia sepium*
Hägg	*Prunus padus*

Höstfibbla	*Scorzoneroides autumnalis*
Kamomill	*Matricaria chamomilla*
Knylhavre	*Arrhenatherum elatius*
Kruståtel	*Deschampsia flexuosa*
Kråkvicker	*Vicia cracca*
Kvickrot	*Elytrigia repens L.*
Kärleksört	*Hylotelephium telephium*
Liljekonvalj	*Convallaria majalis*
Liten blåklocka	*Campanula rotundifolia L*
Lundbräken	*Dryopteris dilatata*
Lönn	*Acer platanoides*
Majsmörblomma	*Ranunculus auricomus L.*
Maskros	*Taraxacum*
Midsommarblomst	Geranium sylvaticum
Murgröna	*H. Helix*
Måbär	*Ribes alpinum L.*
Måra	*Galium*
Nejlikrot	*Geum urbanum*
Nyponros	*Rosa dumalis*
Rosett jungfrulin	*Polygala amarella Cr.*
Rundhagtorn	*Crataegus laevigata*
Rödklöver	*Trifolium pratense*
Rödven	*Agrostis capillaris*
Röllika	*Achillea millefolium L.*
Rönn	*Sorbus aucuparia*
Sammetsdaggkåpa	*Alchemilla vulgaris*
Skogsbräken	*Dryopteris carthusiana*
Skogsfibblor	*Hieracium L. sect. Hieracium*
Skogsklöver	*Trifolium medium*
Skogsvinbär	*Ribes spicatum*
Skräppa	*Rumex longifolius*
Slidstarr	*Carex vaginata Tausch.*
Slån	*Prunus Spinosa*
Smultron	*Fragaria vesca*
Småborre	*Agrimonia eupatoria*
Smörblomma	*Ranunculus acris*
Solvända	*Helianthemum nummularium*
Sparvvicker	*Vicia tetrasperma*
Spetshagtorn	*Crataegus rhipidophylla Gand*
Stensöta	*Polypodium vulgare*
Stor blåklocka	*Campanula persicifolia L.*

Stormåra	*Galium album*
Svingel	*Festuca*
Tall	*Pinus sylvestris*
Teveronica	*Veronica chamaedrys*
Timotej	*Phleum pratense*
Tistel	*Cirsium*
Träjon	*Dryopteris filix-mas*
Tuvtåtel	*Deschampsia cespitosa*
Veronica	*Veronica L.*
Vildapel	*Malus sylvestris*
Vit fetknopp	*Sedum album L*
Vitklöver	*Trifolium repens*
Vitmåra	*Galium boreale*
Vitsippa	*Anemone nemorosa*
Vårbrodd	*Anthoxanthum odoratum*
Vägtistel	*Cirsium vulgare*
Åkertistel	*Cirsium arvense*
Äkta Johannesört	*Hypericum perforatum*
Äkta ängsviol	*Viola canina ssp.*
Älggräs	*Filipendula ulmaria*
Ängskavle	*Alopecurus pratensis L.*
Ängssvingel	*Festuca pratensis*
Ärenpris	*Veronica officinalis*
Örnbräken	*Pteridium aquilinum*

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