Arable Plant Diversity on Gotland, Sweden

Rebecca Örnberg

Degree project in biology, Bachelor of science, 2023
Examensarbete i biologi 15 hp till kandidatexamen, 2023
Biology Education Centre, Uppsala University, and Swedish University of Agricultural Sciences SLU
Ecology centre
Supervisors: Alexander Menegat and Darwin Hickman
**Table of contents**

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>TABLE OF CONTENTS</td>
<td>1</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>2</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>2</td>
</tr>
<tr>
<td>1.1 AGRICULTURE AND ARABLE PLANTS</td>
<td>2</td>
</tr>
<tr>
<td>1.2 DIVERSITY IN ARABLE PLANTS</td>
<td>3</td>
</tr>
<tr>
<td>1.3 PLANT SURVEYS</td>
<td>4</td>
</tr>
<tr>
<td>1.4 THE AIMS OF THIS STUDY</td>
<td>4</td>
</tr>
<tr>
<td>2. METHODS AND MATERIALS</td>
<td>5</td>
</tr>
<tr>
<td>2.1 DATA COLLECTION</td>
<td>5</td>
</tr>
<tr>
<td>2.2 DATA MANAGEMENT</td>
<td>5</td>
</tr>
<tr>
<td>2.3 STATISTICAL ANALYSES</td>
<td>6</td>
</tr>
<tr>
<td>2.4 LIMITATIONS OF THE STUDY</td>
<td>7</td>
</tr>
<tr>
<td>3. RESULTS</td>
<td>7</td>
</tr>
<tr>
<td>3.1 BRIEF SUMMARY</td>
<td>7</td>
</tr>
<tr>
<td>3.2 TEMPORAL COMPARISONS</td>
<td>7</td>
</tr>
<tr>
<td>3.3 DIVERSITY ANALYSIS</td>
<td>7</td>
</tr>
<tr>
<td>3.4 HEAT MAPS</td>
<td>11</td>
</tr>
<tr>
<td>3.4 PRINCIPAL COMPONENT ANALYSIS</td>
<td>11</td>
</tr>
<tr>
<td>4. DISCUSSION AND CONCLUSION</td>
<td>12</td>
</tr>
<tr>
<td>4.1 THE DATASET</td>
<td>12</td>
</tr>
<tr>
<td>4.2 EFFECT OF FIELD SIZE</td>
<td>13</td>
</tr>
<tr>
<td>4.3 EFFECT OF SOIL TEXTURE</td>
<td>13</td>
</tr>
<tr>
<td>4.4 EFFECT OF CROP TYPE</td>
<td>14</td>
</tr>
<tr>
<td>4.5 EFFECT OF MANAGEMENT SYSTEM</td>
<td>14</td>
</tr>
<tr>
<td>4.6 A NOTE ON FUNCTIONAL DIVERSITY AND STATISTICS</td>
<td>14</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>15</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>15</td>
</tr>
</tbody>
</table>
Arable plant diversity on Gotland, Sweden

Abstract
Arable plant species diversity has been on a decline, with many species dependent on arable land becoming threatened. At the same time, attempts at defining the drivers of arable plant diversity have proven difficult and results are often contradictory. Much of the available data come from surveys that are small-scale and with great variability in methodology, leading to difficulties comparing them. In this study, I have used survey data from Gotland to examine how arable plant diversity is influenced by management, field size, soil texture and standing crop. I found a negative trend of diversity with increasing field size, and a suggested effect of management and soil texture on the presence of red listed arable plants. This study also evaluates the use of small datasets when examining plant diversity, and the limitations associated with it. It shows that while a small dataset cannot be analysed to the extent a more comprehensive one can, it is possible to identify trends and patterns with it, which may inform further studies.

1. Introduction

1.1 Agriculture and arable plants
The rise of agriculture some 12,000 years ago allowed human population to grow exponentially to this day. In Sweden in 2019, 6.14 million tonnes of cereals were produced, and both production and yield of individual fields have been on a steady increase since 1800 (Karlsson 2020). Due to the space, nutrients and other resources available in an agricultural field, they are attractive hosts for a wide range of non-crop plant species. These plants, also referred to as arable plants, may have spread there from the surroundings by wind, water, animals and agricultural machinery, or been introduced with crop seeds as contaminants (Bernes 2011). Arable plants may be a major limiting factor for crop production why they are most often generalised as weeds (Oerke 2006). In contrast, arable plants also maintain important ecosystem functions. They provide nectar and pollen for insects and other pollinators, like bees and butterflies, and they serve as both a direct and indirect food source for birds through seeds, and the insects they attract. Arable plants are also culturally important; many of them are also national and regional symbols in Sweden and other countries (Sundberg et al. 2021). Despite efforts of farmers to remove these plants in favour of their crop, arable plants have remained as much a part of the agricultural landscape as the crops themselves – to the point that some of these plants today cannot survive outside of the fields tended by humans (Sundberg et al. 2021).

With the rise of new, more effective management methods, herbicides and fertilisers, many arable plants have come under new threat. Many, like Scandix pecten-veneris, have become threatened and put on the IUCN red list (a list of categories to indicate the status and health of a population) because of the increased pressure (Bernes 2011). Yet, the so-called weeds are not all equally threatened. We can also see a parallel to antibiotic resistance in agriculture: resistance to herbicides is on the rise and some have developed into veritable “super weeds”. These “super weeds”, such as Alopecurus myosuroides or Lolium multiflorum, are likewise a threat to biodiversity as they outcompete more ecologically important plants (Sundberg et al.
Other management methods applying specific types of disturbance can similarly select for weeds which can tolerate them.

1.2 Diversity in arable plants
Measuring diversity can be complicated and often comes down to a trade-off between ease-of-interpretation and limiting information loss. A well-known way of measuring biodiversity has been to look at species richness, abundance, and community composition, often employing diversity indices such as Shannon’s or Simpson’s indices of diversity (Morris et al. 2014). There is, however, an argument to be made for an alternative approach – measuring functional diversity (Bengtsson 1998). This is especially the case for plants, where the definition of what constitutes as an individual is often vague and blurry. Should, for example, a group of young trees originating from the same root system as root-shoots, and hence are essentially genetic clones, be considered one or several individuals? Likewise, does an oak sapling contribute as much to ecosystem diversity as does a 15 meter tall, 100 year old oak tree? Grime (1974) proposed that plant life-history traits can be organised in a three-cornered continuum. In one corner of this triangle are the competitors (‘C’), who thrive in crowded places where disturbance is rare, in one are the stress-tolerators (‘S’), that can withstand biotic and abiotic stresses. In the last are the ruderals (‘R’), which thrive where disturbance is high – for example in an agricultural field. This is commonly referred to as Grime’s CSR triangle (Begon & Townsend 2020). This implies that in an agricultural field, the (non-crop) arable plants would be predominantly ruderal (MacLaren et al. 2020). It also raises the question about functional diversity. A field that is always managed the same way would benefit a narrower range of traits, and a field with a high species richness may still have a very low functional diversity. Nevertheless, species diversity still has the benefit of being easier to understand and measure even for the inexperienced, and is easier to use and identify in the field.

Numerous attempts have been made to identify the drivers of diversity and composition of arable plant communities, with varying and often contradictory results. This may vary substantially by location, for instance according to the role of crop (Lososová et al. 2004), or scale (Hawes et al. 2010). This is indicative of the complex interplay of different factors that is behind diversity, and suggests that the main components are random field- and farm-level factors, especially when it comes to appearance of rare species (Rotchés-Ribalta et al. 2015). Landscape complexity has been proposed as a main driver for diversity and richness (Gabriel et al. 2005, Roschewitz et al. 2005). Yet others have found limited effects from landscape (Marshall 2009). Soil texture and character have limited effects on diversity, but still is deciding factor in what species are found in a site (Andreasen et al. 1991, Gabriel et al. 2005). Crop type in a known influence, but results vary as to how and where (Lososová et al. 2004). Sowing season affects diversity, whereas standing and preceding crop affect the species found (Bourgeois et al. 2020, Rotchés-Ribalta et al. 2015).

Studies have shown that field margins are key for maintaining diversity in a landscape, and the community composition in them has been shown to depend on crop type and management (Bourgeois et al. 2020, Fried et al. 2009). The size of the field has also been correlated with diversity and presence of certain plants, though in which direction vary with the study – from a positive correlation (Rotchés-Ribalta et al. 2015) to a negative where diversity decreases with increased field size (Gaba et al. 2010), and sometimes no significant correlation at all (Marshall 2009).
1.3 Plant surveys
The sheer number of variables that need to be accounted for when studying arable plant diversity means an immense amount of data needs to be collected. At the same time, many of the surveys conducted are small-scale, with varying methods and purposes. Many surveys are conducted by county boards and private companies, or volunteers reporting observations into databases such as ArtDatabanken (managed by the Swedish University of Agricultural Sciences, SLU). Because much of the data available on local biodiversity comes from smaller scale surveys, it’s important to know how useful such data can be. If data from small scale surveys and citizen science projects can be used to monitor biodiversity, it would save time, energy and money designing, collecting and conducting a study that may span several years.

No national inventories have been taken in Sweden, unlike Denmark and Finland (Sundberg & Andersson 2020). Though larger inventories have been taken, these have been regional (Sundberg et al. 2021). It is this lack of information that has led to the initiative “Åkerogräsinventeringen” (Inventory of Arable Plants), a citizen science inventory of arable plants. The collection takes place in 2021 through 2023, and will help increase understanding of arable plants and the effectiveness efforts made to preserve them (Sundberg & Andersson 2020).

Since the drivers of arable plant biodiversity are still largely unknown, and may indeed be different from place to place, it is of interest to study these on both a large and a small scale. In this study I use data from “Åkerogräsinventeringen” on a smaller, regional scale to try to identify the drivers of diversity. For this, I have chosen Gotland as my focus area. Gotland is a good choice because of the high proportion of organic farms (Svensson 2022), and the observed number of red listed species is relatively high, which indicate both richness of rare species and a high frequency of visits (Bernes 2011), and makes it of public and scientific interest.

1.4 The aims of this study
The question being investigated here is what influences arable plant diversity on Gotland by testing some of the variables that have previously been identified as influential (soil texture, management system, crop type and field size). Additionally, an overarching question for this study is to evaluate if, how and how well the first question can be answered using data from “Åkerogräsinventeringen”. More precisely, the research questions are as follows:

1. How does field size, management, soil texture and standing crop influence Simpson’s and Shannon’s diversity indices and species richness?
2. How does field size, management, soil texture and standing crop affect the presence of red listed species?
3. Are there hotspots with higher Shannon’s diversity and/or more red listed species on Gotland?
4. Is there a pattern to how the individual species respond to the management of the field?
5. Is it possible to use a smaller dataset to evaluate diversity, and compare different surveys to examine the temporal pattern?
2. Methods and materials

2.1 Data collection

I used data collected on Gotland for the project “Åkerogräsinventeringen” collected by volunteers in summer 2021 (2022 for one field). It consists of both fields marked as “priority fields” in the project, and fields chosen by the participants themselves. The method of collection was to walk a 100 m long, 1 m wide stretch in a field margin and take note of all plants growing there. Participants would then estimate the number of individual plants either by counting all plants found, or counting all within a smaller area and extrapolating it for the whole stretch. All species were noted to species level, subspecies if applicable, and hard-to-identify species were collected for further identification. In rare cases, if nothing else was possible, species could be noted down only on genus level. Plants were counted as individuals for herbal plants, and in grasses, horsetail and certain herbaceous plants with runners, number of stems/straws/shoots/heads were counted. Crop, soil texture, and management system (organic/conventional) were also noted or estimated where possible (Sundberg & Andersson 2022).

A survey conducted on Gotland on July 10th 2005 was initially included to examine how diversity has changed over time. The method was similar to “Åkerogräsinventeringen” in that a stretch of 100 m was followed and all species found in it were noted. Common species were only noted by their presence, but uncommon ones were divided into five classes according to their abundance. In the methodology it was described that the sites were chosen because they were expected to have high diversity, as that was the purpose of the survey (Svensson 2006). Additionally, the surveyor explained that some fields that had been surveyed were not the originally specified ones, not all species had been noted in those, and rare species were only noted by their presence in the field (R. Svensson. Pers. Comm.). This uncertainty in the data, as well as the sampling bias (fields with high arable plant diversity were specifically chosen), led to the exclusion of this dataset from further analysis.

The survey data was downloaded from ArtDatabanken, a database for reporting field observations driven by the Swedish University of Agricultural Sciences (SLU). Block data with information on management system and field size came from the Swedish Board of Agriculture (Jordbruksverket), and soil texture data came from the Swedish Geological Survey (Sveriges Geologiska Undersökning, or SGU). Though both management system and soil texture were noted in the survey (Åkerogräsinventeringen), these factors were double-checked with the above-mentioned data in QGIS (version 3.28).

2.2 Data management

Of the 19 fields surveyed in 2021 (and 2022), 17 were included in the analysis. The two excluded fields were excluded due to sampling inconsistencies; both had the same coordinates and had been surveyed on the same date and time. In the cases where a plant had been observed as only “noterad” (noted) they were considered to be one individual. The recorded crops were divided into groups of cereal, non-cereal and mixed (cereal together with non-cereal). Distinction was not made between summer- or winter-grown crops, as that was not included in the downloaded data. The soil types of the surveyed fields were divided into groups of “sandy” soils and “loamy” soils (figure 1) to limit the number or grouping variables.

Out of the 17 fields included in the analysis, five were organic and 12 were conventional. Further, 10 fields grew cereal, four grew non-cereals and three had a mixed (cereal + non-
cereal) crop. Soil texture was divided into two groups, where five fields had loamy soil and 12 had sandy. The smallest field was 1.19 hectares, and the largest was 20.43 hectares.

![Soil texture triangle](image)

Figure 1: Soil texture triangle showing the number of fields in each category. The surveyed fields all fell in mostly one corner of the triangle, in either the “sandy” (yellow) or “loamy” (purple) group.

I calculated Shannon’s and Simpson’s diversity indices using the “Vegan” package version 2.6-4 in R (version 2023.03.0+386). The main focus was Shannon’s diversity, due to its emphasis on species richness rather than evenness. I also counted the number of species found in each field (species richness), as well as the number of red listed species. The number of red listed species was defined as the number of species in any red list category ranging from near threatened (NT) to critically endangered (CR). These species can be viewed as “rare” species.

To visualise the findings, I made heatmaps for Shannon’s diversity and number of red listed species in QGIS, using maps from the GADM database (Database of Global Administrative Areas), version 2.8 (downloaded November 2015).

2.3 Statistical analyses
I evaluated the main drivers of Shannon’s diversity, Simpson’s diversity, species richness and number or red listed species by using backwards stepwise linear regressions in R. A stepwise linear regression uses a stepwise approach to go from a full model (with all independent variables included) to the model with the best fit (called the reduced model, where underperforming variables are excluded). It is done by removing independent variables from the model one by one and comparing different versions with Akaike Information Criterion (AIC). The model with the lowest AIC value is the best fit to the data, and the one I have used to interpret the effects of the predictors on the responses. No interaction terms or random mixed models could be included due to the size of the dataset. This means that the effect of one predictor to one response is analysed at a time. The results were visualised with the help of packages “ggplot2” (version 3.4.2) and “Hmisc” (version 5.0-1).

While not the focus of the study, I conducted a principal component analysis (PCA) in R after transforming the data using a Hellinger’s transformation. This was to examine the response of
individual species to the different environmental variables (field size, management, crop and soil type). Clear distinctions here could indicate the potential for functional diversity to better explain differences than species diversity.

2.4 Limitations of the study
Due to the limited number of observed fields as well as due to the spatial and temporal limitation of this study, it is not the aim to give a conclusive answer to drivers of diversity on Gotland. Rather, the aim is to identify trends and patterns and to examine the use of a smaller dataset and tries to find a suitable model to do so.

3. Results

3.1 Brief summary
Of the studied environmental variables, field size had the greatest effect on diversity, primarily Simpson’s diversity index. Management affected the number of species found as well as the presence of red listed species, with higher richness and more red listed plants in organic fields. This was also reflected in the PCA, where some species showed a preference for either organic or conventional management. Red listed species were also more likely to be found in sandy agricultural soil types.

3.2 Temporal comparisons
It was not possible to compare the survey from 2005 with the Gotland data from “Åkerogräsinventeringen” due to the differences between the two datasets. After contacting the coordinator of the 2005 survey it was explained that it had been done with the intent of finding fields that had a high number of rare species. As such, there was a heavy sampling bias and species abundance had been evaluated differently in between fields. Because of this, I decided to omit this dataset from analysis.

3.3 Diversity analysis
In order to identify the key drivers of biodiversity I performed backwards stepwise linear regression to find the model with the best fit. More complex models were not possible because of the low number of fields surveyed (n = 17), and the amount of independent grouping variables (crop type, soil texture, field size and management system). The full models were non-significant for all of the dependent variables (table 1). The reduced model (i.e the model that showed the best fit to the data) was significant only for Simpsons diversity at a significance level of 0.1, but species number and Shannon’s diversity were near significant and may still suggest trends (table 1).
Management system had no significant effect on any of the dependent variables (table 1). There is, however, a suggested trend of more red listed species in organic fields, though the model was statistically non-significant (p = 0.19) and the span of values was large (figure 2d). Both organic and conventional fields showed large variation within the depended variables (figure 2).

Figure 2: All dependent variables had large spans of values in organic and conventional fields, with no very clear difference. There were fewer organic (n = 5) than conventional (n = 12) fields.

At a significance level of 0.1, field size had a significant effect only on Simpson’s diversity index (p = 0.032, model p-value = 0.085), with a lower score the larger the field (figure 3b, c).
For Shannon’s diversity index, there is a suggested trend of a lower diversity in larger fields (figure 3a, blue line), though the model was non-significant (p = 0.165). Only two fields were larger than 15 hectares (16.85 and 20.43 hectares respectively), and as such, an alternative regression line was drawn excluding those fields (figure 3a and b, red dashed line). Without the largest fields, there is a suggestion at a positive trend. Field size had no apparent effect on species richness or number of red listed species (figure 3c and d).

Figure 3: Linear regressions of the effect of field size (sample size n = 17) on Shannon’s diversity (a), Simpson’s diversity (b), Species number (c) and number of red listed species (d). a) a suggested, though non-significant, negative trend of Shannon’s diversity with larger field size (blue line). If the two largest fields are treated as outliers and removed, the trend instead becomes positive (red, dashed line). b) At a significance level of 0.1, there is a negative effect of larger field size on Simpson’s diversity as well, which also turns positive if the largest fields are treated as outliers.

No effect of crop type could be observed for any of the tested dependent variables. There is a great variation in observed values (figure 4).
Figure 4: No significant effect of crop type on any of the dependent variables. More cereal fields than mixed or non-cereal fields were surveyed.

Soil texture had no detectable effect on diversity or number of species present in a field. There was a suggested positive relationship between the number of red listed species and sandy soil texture ($p = 0.095$), but the model was not statistically significant ($p = 0.19$). Again, high variability within the tested depended variables were observed (figure 5).

Figure 5: No significant effect of soil texture on any of the variables, though there’s a suggested positive relationship between number of red listed species and the “sandy” category. A greater number of fields in the “sandy” category had been surveyed.
3.4 Heat maps
Species diversity using Shannon’s diversity index remained relatively constant across Gotland, though more red listed species were found in the south of the island. However, more fields had been surveyed in the south, which may have had an influence on their discovery (figure 6).

![Heatmaps for Shannon’s diversity (left) and number of red listed species found (right) show that diversity is evenly spread out over Gotland, though more red listed species were found in the southern parts.](image)

3.4 Principal component analysis
To analyse whether effects of management system, crop type or soil texture influenced individual species rather than on overall diversity, a principal component analysis was done, weighting each species found according to their individual abundance in each field. No discernible pattern could be found for crop type or soil texture. In management system, there is a hinted pattern of some species showing higher abundance in conventional fields (e.g. *Thlaspi arvense*) and some in organic (e.g. *Capsella bursa-pastoris*). There is also a suggested trend of fewer and more dominant species in conventional fields, and a more diverse community with no highly dominant species in organic ones (figure 7).
Figure 7: PC1 explains around 15% and PC2 around 12% of the variability in the species found in each field. The management system has a suggested effect on the species composition, as some species pull to the left side (conventional, purple ellipse) others to the right side (organic, yellow ellipse) of the x-axis. Ellipses show where 68% of samples in a replicated study would fall.

4. Discussion and conclusion

4.1 The dataset
While there are suggested trends emerging in the analyses, there is a lack of clarity in the results. The only significant correlation found was the influence of field size on Simpson diversity, which will be discussed further below. The main reason for the lack of significant results is likely the lack of data. Others have encountered this problem before, and several suggest large datasets from multiple surveys to be the best approach to accurately identify explanatory variables in weed community ecology and avoid overemphasis on a single parameter (Hanzlik & Gerowitt 2016, Lososová et al. 2004). This is complicated further because of the variability in method, purpose and approach in the different surveys which makes it difficult, if not impossible, to harmonise the different datasets to allow for comparisons. It was for these reasons that I had to exclude the survey from 2005, which not only removed half of the data in the dataset, but also removed the possibility of examining temporal trends in the diversity on Gotland. This plurality of method, the difficulty of analysis, and the need for large datasets are addressed by Hanzlik & Gerowitt (2016) who propose public supported, national surveys and databases to provide the consistency in method and size of data required for efficient analysis. The difficulty of analysis in this study further proves this point and shows how important projects such as “Åkerogräsinventeringen” are for the study of arable plants. While there is too little data to successfully analyse diversity on a local scale, this would likely be solved should the project continue. Additionally, this study covers only a fraction of the data available through “Åkerogräsinventeringen” (mimicking what a small, local survey would look like), and has not examined larger-scale diversity. An important point to consider is that there is evidence that the drivers of regional and national diversity may not be the same as the drivers of local diversity (Hawes et al.)
Thus, there is still a need for enough data on a smaller, local scale to properly identify explanatory variables there.

4.2 Effect of field size
Field size only significantly affected Simpson’s diversity (at a significance level of 0.1). A similar trend could be seen on Shannon’s diversity, which is notable despite the lack of significance. The regression model indicated that diversity decreased as field size increased for both Simpson’s diversity (and suggested such for Shannon’s), when all fields were considered. This is supported by earlier findings (Gaba et al. 2010, Gabriel et al. 2005). An explanation for this trend could be that a high edge-area proportion increases edge effects due to increased contact with comparatively diverse surrounding environments, and correlates with a greater landscape complexity (Gaba et al. 2010, Gabriel et al. 2005). It is interesting to note that without the two largest fields, the relationship was opposite; increased field size led to increased diversity. This, too, is supported in earlier findings, and could be attributed to larger fields either containing more niches, or historically having been created by the merging of several small fields with different management histories (Rotchés-Ribalta et al. 2015). Because of the limited amount of data (only two fields over 15 hectares), it is impossible to conclude whether they should be considered outliers, or representative of larger agricultural fields on Gotland. Neither can I draw conclusions about interactions with the other variables, as there was not sufficient data in each grouping variable. The positive effect of field size on diversity has previously been shown to be especially true for rare species in organic fields (Rotchés-Ribalta et al. 2015), which could not be investigated in this study, due to the limited number of fields fitting this description.

Field size was excluded as an explanatory variable for species richness and number of red listed species in the reduced model, although a larger field may be expected to contain a wider range of ecological niches. This could be due to interactions between the independent variables that could not be evaluated in this study, but effect of field size may depend on management practices (Rotchés-Ribalta et al. 2015). The unevenness of the dataset (few larger fields and many small) may be an alternative cause.

4.3 Effect of soil texture
Soil texture had no detectable effect on diversity. This may be because soil texture is primarily influential to community differentiation and what species are found, rather than how many (Andreasen et al. 1991, Fried et al. 2008). This is an important argument for looking at how these parameters affect functional diversity in addition to species diversity. Functional traits of the plants present may better describe their presence than their phytosociological identity. Furthermore, Gotland has an overall very homogenous soil-profile, and all the fields in this study clustered closer to one corner of the soil-texture triangle and largely functionally similar (figure 1). There may not be enough soil types included here to detect a difference in species richness. Interestingly, after dividing soils into sandy or loamy texture, a slight positive effect of sandy soils on the number of red listed species was hinted, though the model was non-significant (p = 0.19). If this suggested trend is true, it could be explained by the lower competition in sandy soils, their poorer nutrient content and lower moisture content would favour rare, stress-tolerant species that are at a disadvantage among more competitive species in richer soils (Albrecht & Mattheis 1998, Kleijn & Van Der Voort 1997).
4.4 Effect of crop type
Crop type had no effect on any of the diversity measures studied (Simpson’s diversity, Shannon’s diversity, species richness and number of red listed species). This can largely be explained by the diversity of crops in the surveyed fields, which necessitated a division into groups of cereals, non-cereals and mixed crops. Neither the sowing season nor cropping history had been consistently recorded, and could not be included as factors, again indicating the importance of sufficiently comprehensive datasets for this type of analysis. The lack of effect could also be due to crop type mainly acting as a filter for the species present, and a driver of community differentiation rather than diversity and abundance (Fried et al. 2008). This is particularly true for conventional fields, where effective control is more challenging for species with physiological similarities to the standing crop, given the risks of damage. It would be worth investigating the effect crop has on functional diversity rather than species diversity.

4.5 Effect of management system
No significant effects of management system (organic or conventional) could be detected, but a suggested trend can be seen in number of red listed plants. One potential explanation is that Gotland has a complex agricultural landscape, with diversity in crops, field shapes and sizes as well as the surrounding landscape. Landscape complexity is known to be an important factor in diversity, even if the extent of that importance is debated (Gabriel et al. 2005, Marshall 2009). Landscape complexity has a greater effect in conventional farms than organic, so much that conventional and organic farms have similar diversities in complex landscapes in spite of their management differences (Roschewitz et al. 2005). The suggested positive effect organic farming had on number of red listed species found could be due to these species being more sensitive to herbicides and fertilisation, both of which are likely to be detrimental to rarer species (Rotchés-Ribalta et al. 2015).

When examining the responses of individual species, a different pattern emerges. PC1 shows a trend for certain species to prefer conventional farms to organic, and vice versa. This is in line with the suggestions of some previous studies (Fanfarillo et al. 2020, Bourgeois et al. 2020), but others claim the presence of certain species is only partially explained by management, and is better explained by random chance (Roschewitz et al. 2005, Rotchés-Ribalta et al. 2015). Nevertheless, the results of the PCA show a tendency for certain species to prefer one system to another, and suggests a pattern of fewer, more dominant species in conventional fields and a more complex community in organic. This is a pattern that has been observed by others, with fewer, sometimes herbicide resistant, plants becoming dominant in conventional fields (Owen et al. 2014, Neve et al. 2014). This can be attributed to the selective pressure land-use intensification and herbicide application puts on arable plants which risks creating multi-resistant “super-weeds” (Storkey & Neve 2018).

4.6 A note on functional diversity and statistics
This study has further shown the difficulties involved when trying to identify drivers of diversity. As in previous studies, the results are inconclusive, hard to interpret and contradictory. A small-scale survey cannot cover all the possible variables that explain diversity, and including data from several surveys is not always possible due to inconsistent methodologies. With a small dataset, such as the one used in this study, one must use sub-optimal methods (such as a linear regression with no interaction terms instead of a mixed model that can evaluate random effects). While this is enough to identify patterns, it is not enough to draw definite conclusions. This could, in part, explain why none of the explanatory
variables that have previously been shown to influence diversity had any significant effect in this study. It also highlights a problem with looking at species diversity rather than functional diversity: The number of species found is, by itself, not a sufficient measure of diversity, as it says very little about their niche and why they are found there in the first place. As can be seen in the PCA, certain species seem to respond differently to different treatments, even if Shannon’s diversity index did not show this. Certain species therefore have certain traits that are better suited for the given conditions. While this pattern can be seen even at a species level, it cannot be understood until the specific traits have been mapped and studied. It is therefore important to not only examine species diversity, but functional diversity as well. This is something that has been argued for a long time (Bengtsson 1998), and is increasingly implemented in ecological studies. As I, and many before me, have proven, identifying the drivers of diversity can be notoriously difficult. The solution, I believe, lies in part in standardising the approach, organising large-scale, long-term projects to obtain the necessary data. Yet, studies much larger than this one have tried and failed to discern what causes diversity. It may be that the answer lies in shifting focus to the diversity of traits, rather than diversity of species.

Acknowledgements
I would like to thank my supervisors Alexander Menegat and Darwin Hickman for all the help and encouragement during this project, and the patience, enthusiasm, and humour with which they gave it. I would also like to thank Chloe Maclaren for helping me with the coding and understanding of the statistical models (particularly the PCA). Further, I want to thank Roger Svensson for his assistance with understanding the data, even if it was not used in the end. Lastly, I want to say thank you to the people involved with “Åkerogräsinventeringen” and at SLU Ecology Centre for this opportunity.

References:


