Grangepans Meadow in bloom, Bo'ness, Firth of Forth (photo taken June 2017)

Bridging Scotland's B-Lines: The Effects of Wildflower Grassland Restoration on Pollinator Conservation in Bo'ness, Firth of Forth

"Our treasure lies in the beehive of our knowledge. We are perpetually on the way thither, being by nature winged insects and honey gatherers of the mind."- Friedrich Nietzsche, *On the Genealogy of Morality* (1887)

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Table of Contents

Abstract

The importance of managing natural habitat for pollinator insects has become a pressing issue in global conservation, due to the significant roles of pollinators in the ecosystem. Pollinator habitat across the UK have been drastically depleted due to factors like urbanisation and land use intensification. This study aimed to answer the question: has the establishment of two wildflower-rich habitats as part of the Bridgeness Biodiversity Project had a positive influence on pollinators in the Firth of Forth in comparison to conventional grassland management? Quantitative surveys sampled at seven time points between May and June 2017 were used to sample wildflower composition and pollinator visitation at four sites, two restored wildflower grassland sites and two amenity grassland sites. The majority of total pollinator abundance and species were found in Grangepans Meadow and Bridgeness Ship Breakers brownfield, which had greater wildflower frequency and species richness than the control sites. Although there were differences between sampling methods, management has positively influenced the local ecology as there was a statistically significant correlation between wildflower species richness and pollinator abundance and species richness ($p<0.5$). These findings support the importance of restoring wildflower grassland as an effective method of improving pollinator abundance and species richness in urban areas. Beyond the specific study sites, the findings suggest that mitigation of current pressures currently facing pollinators could be carried out through targeted habitat restoration efforts in local areas, which could be strengthened through

landscapewide approaches to pollinator conservation such as the B-Lines initiative.

1. Introduction

1.1 Overview

Insect pollinators represent an essential component of natural ecosystems, providing vital ecosystem services and trophic stability within both natural and human-managed habitats. 87.5% of pollination of flowering plants is carried out by insects (Ollerton *et al*., 2011), including an estimated 84% of EU crops valued £120 billion annually (Nogué *et al*. 2016). Of these flowering plants, 62% are limited by the transference of insect pollen. Wild pollinator species across the United Kingdom and worldwide currently face numerous threats to their populations, from intensive agriculture and increased use of pesticides to climate change. Recent reports on the state of wild pollinators in the UK have shown that there has been an overall decline of abundance of pollinator insects (Potts *et al.* 2010), leading to significant concerns regarding the effects of such declines on ecosystem stability. As such, there have been increased efforts towards changing land management practices to encourage pollinator species conservation across the UK. While much focus has been given to shifting agricultural methods toward pollinator-friendly practices, it is key to consider the potential impacts of pollinator conservation within non-agricultural landscapes, including developed land such as urban green spaces, council-owned amenity grassland and brownfields. While the role of specific pollinators such as honeybees have been studied extensively for their significance within agricultural habitats, less focus has been given to the role of non-agriculturally important pollinators, including many species of wild insect pollinators. However, given that urbanisation is a major driver of land use change and is often seen as contributing to current trends of pollinator decline, there has been an increased focus on management of urban and non-agricultural developed land for pollinator conservation.

1.2 The Bridgeness Biodiversity Project

One example of such urban pollinator conservation efforts in the UK can be seen in current landscape conservation efforts taking place within the Inner Forth Landscape Initiative (IFLI) in Scotland. In conjunction with IFLI, Buglife – an environmental charity focused on invertebrate conservation – has sought to combat local and national declines in insect pollinator biodiversity through the Bridgeness Biodiversity project in Bo’ness. Since its inception in 2015, the Bridgeness Biodiversity project has established and managed two local areas specifically for pollinator biodiversity– Bridgeness Ship Breakers brownfield and the newly-created Grangepans Meadow (Figure 1.1 and Figure 1.2). While some limited monitoring of wildflower restoration has been conducted since the establishment of the project, more data is required to understand if wildflower grassland management has had positive impacts on pollinators (Burgess 2016).

Figure 1.1 Grangepans Meadow (Taken June 2017)

Figure 1.2 Bridgeness Ship Breakers Brownfield (Taken June 2017)

The Bridgeness Biodiversity project is also part of Buglife's national B-Lines project which represent a series of "insect pollinator pathways" across UK countryside and towns where Buglife is working to restore and creating a series of wildflower-rich habitats for pollinators and other species (Buglife 2017). While an extensive network of B-Lines has been mapped in England, currently mapped BLines in Scotland only consist of the John Muir Way (Figure 1.3). Currently, additional efforts are ongoing to expand interconnection of pollinator habitat corridors within Scotland in order to connect them to those across the UK (Figure 1.4).

Figure 1.3. Scotland's first B-Line, along the John Muir Way (Burgess 2016b)

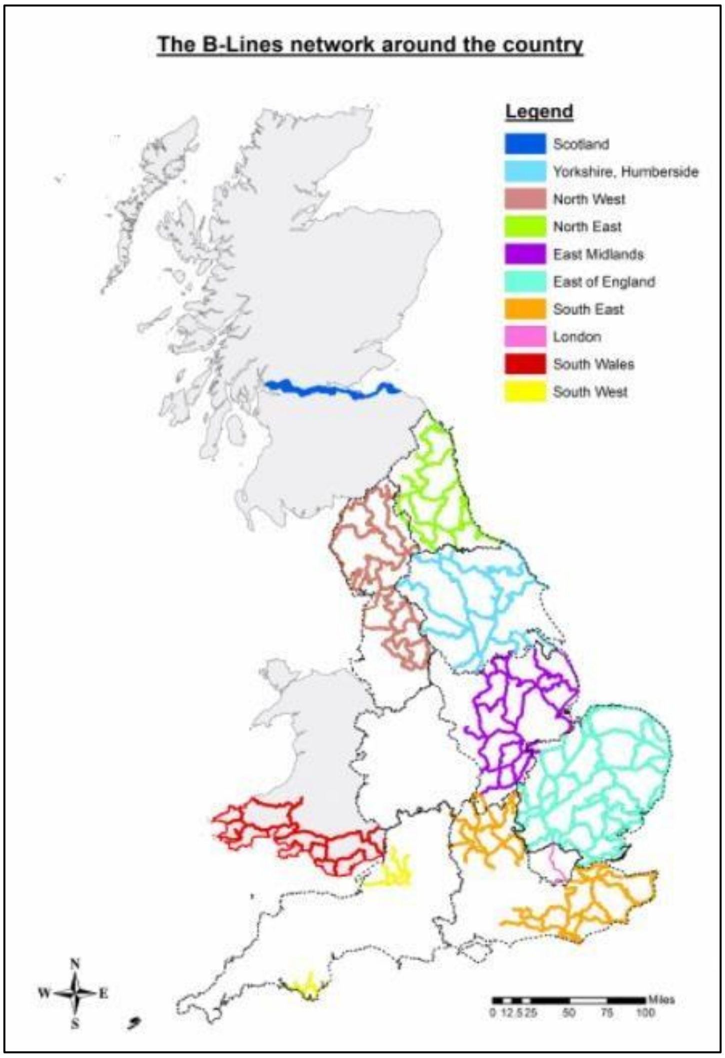

Figure 1.4. B-Lines across the UK (Buglife 2017)

1.3 Aims

In order to contribute to current understandings of the relationship between pollinators and wildflower restoration, as well as the greater body of knowledge on pollinator conservation across Scotland, this study will examine the relationships between management of wildflower grassland sites in the UK and the impacts on insect pollinator species, based on primary field research data as well as desk-based secondary research on the state of pollinators and pollinator habitats in the UK. More specifically, this study aims to answer the question: has the establishment of two wildflower-rich habitats as part of the Bridgeness Biodiversity Project had a positive influence on pollinators in the Firth of Forth in comparison to conventional grassland management? Using data on pollinators and wildflowers collected from the two managed sites in Bo'ness, this study will examine if and how current management practices of the Bridgeness Biodiversity project impact the abundance and species richness of local insect pollinators, as well as evaluate the wider conservation benefits of establishing wildflower-rich habitat in Bo'ness as part of the B-Lines project. The results of this study will contribute to current pollinator conservation efforts undertaken by Buglife and the Inner Forth Landscape Initiative through providing a better understanding of impacts of current management practices in Bo'ness, as well as provide lessons for pollinator conservation efforts in urban areas across Scotland and the UK.

2. Literature Review

2.1 Pollinator insects in the UK: an overview

The majority of pollination of flowering plants is carried out by insects including bees, butterflies, moths, wasps, flies, and beetles, some of which are displayed in figure 1.5. There are 24 types of bumblebees in the UK, and an additional 225 species of solitary bees (Bumblebee Conservation Trust 2017). Of the other important pollinators, there are 350 species of wasps, 280 species of hoverfly in the UK (Agriland 2017), 59 species of butterflies (UKBMS 2016) and 2500 species of moths (Butterfly Conservation 2017).

Figure 1.5. Examples of UK pollinators that are important for pollinating services (From top left to right: *Bombus terrestris* & *Bombus lapidarius*, *Andrena tarsata* & *Andrena fulva, Episyrphus balteatus* & *Helophilus pendulus*, *Anthocharis cardamines* & *Zygaena filipendulae*. Images sourced from Steven Falk, 2017)

Ollerton *et al*. (2011) surmised that 87.5% of pollination of flowering plants is carried out by insects. As such, many pollinator species are integral components of stable agricultural systems and natural ecosystem functioning. The process of pollination itself has been termed a "mobile agent-based ecosystem service," as pollinators deliver services locally but the community dynamics of the "mobile organisms" are influenced by resource management at larger scales (Kremen *et al*. 2007). Both domesticated and wild pollinators provide numerous ecosystem services and broader socio-economic benefits. From helping to support higher trophic levels in local ecosystems and providing reproductive capability to many plants, pollinators are key to the survival of flowering plants in both natural and human-managed ecosystems. Kleijn *et al.* (2015) argue that only a small percentage of wild pollinator species actually contribute specifically to crop productivity. While the survival of certain wild pollinator insect species likely has no direct implications for pollination of crops, but they are needed for other natural ecosystem functions such as providing floral resources and supporting higher trophic levels (Senapathi *et al.* 2015). Elmqvist *et al.* (2003) found that environmental change can reduce the functionality of ecosystems through lowering response diversity and altering reactions to environmental variables between functional groups, which can lead to extinction. For instance, while loss of specialist species of pollinators may not have a direct impact on agriculture, it can reduce ecosystem processes and in some cases functions carried out by specialists may not be carried out at all, leading to biodiversity loss and instability in the future. There is a significant knowledge gap in understanding the complex role of many wild insect pollinator insects in the UK, as well as basic pollinator ecology and the role of anthropogenic impacts on species and populations. The *Scottish Pollinator Strategy* (2016) admits that the "overall contribution [of wild pollinator insects] to pollination services in Scotland is not well known," while the *National pollinator strategy: for bees and other pollinators in England* (2014) lists the nation's population numbers of bumblebees and hoverflies as unknown, leading to difficulties in identifying changes in wild pollinator population and abundance over time. Going forward, conservationists should focus on two key research priorities for exploring the multitude of pressures on pollinators, as suggested in Vanbergen *et al*'s (2013) paper. Firstly, expanding basic pollinator ecology would improve the identification of pressures through finding significant pollinators for dominant and rare wild flowers (Klejin and Raemakers 2008) and secondly, further understand anthropocentric impacts on pollinators through landscapescale impacts of numerous interactions.

2.1.1 Threats to pollinators

A key finding within research on pollinators is that multiple factors are affecting health, abundance and diversity of pollinator numbers rather than a single threat, which poses more of a challenge for conservation efforts and complicates the process of monitoring and predicting trends (Potts *et al*. 2010). Factors that could impact pollinator populations include land use change, disease, non-native invasive species, climate change, and use of chemical pesticides, along with other unknown anthropogenic impacts.

Land use change

Land use change in the UK has been one of the most significant drivers of pollinator decline. 70% of the UK's land surface consists of developed agricultural land (DEFRA 2012), much of which has been converted from natural pollinator habitat such as unimproved grassland and wildflower meadow. As a result of agriculture, forestry, and urbanisation, pollinator habitats across the UK landscape are fragmented and cover small discontinuous surface areas, which prevent species from expanding their range for resources. However, there is debate within the scientific community on the effects of urbanisation on pollinator species richness — 35% of hoverfly species were recorded in one garden in the UK (Owen 2012). Overall however, land use change in the UK has led to a decrease in food and nesting resources for pollinators, which have had direct impacts on pollinator abundance – land cover changes over the past 80 years in England have been shown to have significant effects on richness and composition of bee and wasp species (Senapathi *et al.* 2015).

Climate change

Climate change is already having a significant effect on pollinators' distribution and range globally. Parmesan (2006) has noted that temperature increases have accelerated spring events worldwide by an average of 2.3 days per decade, with species range shift of 6.1 km per decade towards the poles. Extreme weather events also make it difficult for pollinator species such as bees to forage, while longer wet winters and late springs have been suggested as a major problem for honeybees (Parmesan 2006). Many recent studies has shown shifting temperatures impacting insect pollinators through trophic mismatch and a decrease in available habitat resources due to misalignment of flying period of pollinators and flowering periods (Fitter & Fitter 2002; Memmott *et al*. 2007; Miller-Rushing and Primack 2008; Willmer 2012.)

Neonicotinoids

New studies regarding agricultural pesticide use – specifically neonicotinoid pesticides – have led to concern over their impact on pollinators. Neonicotinoids work to inhibit the nicotinic acetylcholine receptors of insects leading to paralysis and death (Palmer *et al.* 2013). Criticism of current neonicotinoids testing highlight that scientists only test lethal doses levels, instead of exploring potential long-term behavioural and physical effects of neonicotinoids on pollinator insects (van der Sluijs *et al.* 2013), and subsequent studies have suggested that typical agricultural dosages of neonicotinoid pesticides impact common pollinator species mating rates (Vogel 2017), queen productivity and colony growth rates (Whitehorn 2012), and inter-annual reproductive success (Woodcock *et al.* 2017). As such, it has been argued that more study of the impacts of chemicals on pollinators and the knock-on effect for wild flowers is necessary (Gill *et al*. 2012).

2.1.2 Trends in pollinator species populations

Given the understudied nature of wild pollinator insects that are not important for agricultural production, there is not a clear picture of the changing abundance and composition of wild pollinator taxon, or what effects such changes will have on various ecosystems. In the UK, only a small number of species have been monitored efficiently in order to identify long trends of decline, none of which are specific to Scotland. While local changes in pollinator ecology have been observed, the lack of a national pollinator-monitoring scheme means that studies are often limited in scope to individual species and areas (Biesmeijer *et al*. 2006). In a comparative study of wild pollinators in the UK and the Netherlands, Biesmeijer *et al*. (2006) provides the most systematic overview of pollinator status in the UK, noting a decrease of 52% in bee species diversity in Britain since the 1980s (Figure 2.1).

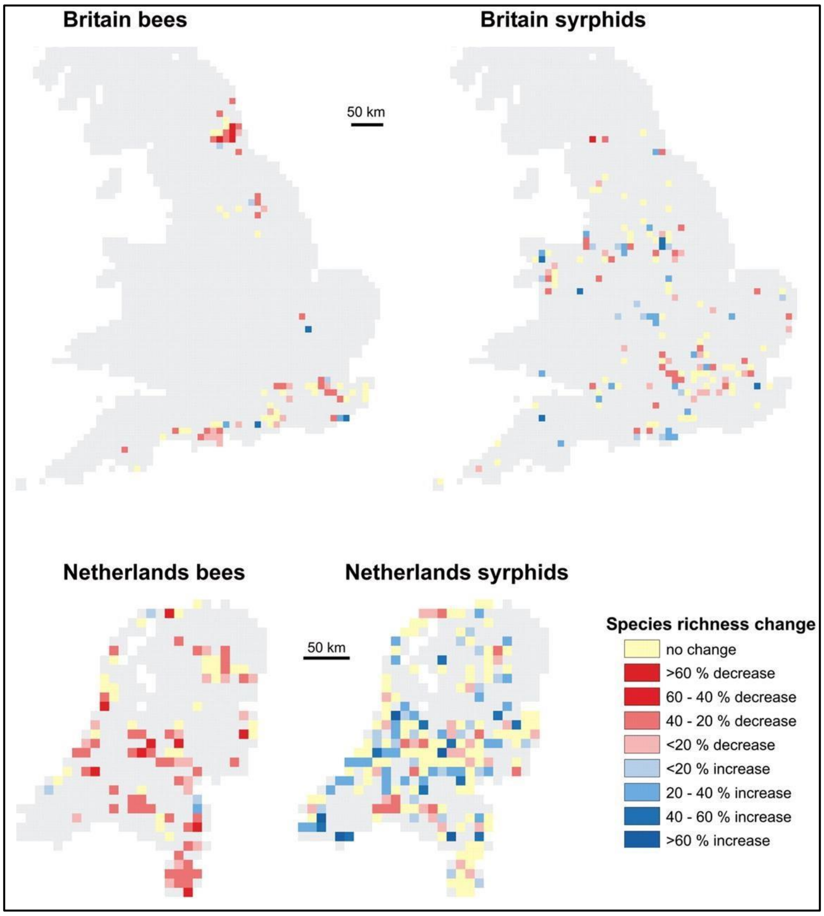

Figure 2.1. The trend of bee and syprhid (hoverfly) richness in the UK and Netherlands since the 1980s in 10X10 km cells (Biesmeijer *et al.* 2006)

Additionally, Biesmeijer *et al*. (2006) noted that UK plant species that rely on such pollinators have declined in relation to other plant species, highlighting the parallel impacts of pollinator decline on certain plant communities. Specific British insect pollinator species have also experienced recent declines. Two species of bumblebee – Cullem's bumblebee (*Bombus cullumanus*) and the shorthaired bumblebee (*Bombus subterraneus*) – have gone extinct, while six bumblebee species' ranges have been constricted (DEFRA 2016). Moths and butterflies, while less effective pollinators, have also been affected with declines in species abundance and range. 62 UK moth species have gone extinct since the 1960s (Fox *et al*. 2013).

2.2 Land Use Management for Pollinator Conservation

With regards to wild pollinator conservation, there is a clear need to focus on better landscape management in order to combat declines in pollinator populations and species diversity. Incorporating pollinator habitat needs into greater planning efforts is required in order to provide connectivity between habitats, such as strategically agri-environment projects alongside protected or semi-natural areas. Another important assessment that can be carried out would be for insect pollinators to be compared and modelled across different scenarios of habitat degradation to predict changes to their ecology under certain outcomes (Forister *et al*. 2010).

2.2.1 Wildflower meadows

Given that pollinators require an array of floral resources for phenological functions, wildflower meadows have high value as pollinator habitat. It has been shown that flower-rich patches of grassland provide more nectar and pollen resources for pollinators than actively managed amenity grassland, for example that which makes up many urban green spaces (Breeze *et al*. 2011). Perennial wildflower meadows can produce up to 20 times more nectar and 6 times more pollen than annual meadows and therefore even higher resources levels compared to amenity grassland (Hicks *et al* 2016). Following this, studies have shown that wildflower species which provide food resources to pollinators is directly correlated with pollinator species abundance (Roulston 2011). Blaauw and Isaacs (2014) show that planting a mix of 15 perennial wildflower species with seasonlong bloom increased annual wild bee and syphrid/hoverfly abundance in fields adjacent to the wildflowers over the subsequent 3 years. Blackmore *et al*. (2014) also found that wildflower plots had 13 times more hoverflies compared to grassland control sites, with the abundance of bumblebees being 50 times greater. However, the current state of wildflower meadow grassland across the UK is highly non-conducive to pollinator conservation efforts. Since the 1930s, 97% of wildflower meadows across the UK have disappeared, and while grassland accounts for approximately 25% of Scotland's landscape, only 1% is considered semi-natural (Hayhow *et al*. 2016). While restoration of wildflower meadow habitats is likely to have a positive impact on pollinator abundance and diversity, many unknowns remain with regards to best practices for such restoration efforts. For example, it is imperative that seed mixes designed to support pollinators must supply pollen and nectar throughout the season, without depressions in seasonal resource availability that could potentially limit pollinator populations (Roulston and Goodell 2011). However, Hicks *et al.* (2016) point to significant knowledge gaps with regards to seed mixes for restoring pollinator-friendly meadows, as it unknown what nectar and pollen resources are per flower or per unit area are provided by different wildflower seed mixes.

2.2.2 Brownfield sites

Brownfield sites are a surprising source of pollinator biodiversity and are an important part of urban management for pollinators. Because of their newly discovered importance, there is little literature coming from the scientific community but instead is coming from conservation organisations. As a result of

Scotland's industrial period, currently 12,435 hectares across Scotland are currently classified as being derelict or vacant (Scottish Government 2016). While seemingly underutilised, 12-15% of the UK's scarce insects have been found in brownfield areas (Buglife 2012), highlighting the importance of conserving urban pollinator habitats. Further, brownfields contribute to the connection of habitats through wildlife corridors, allowing organisms to traverse between urban environments and semi-natural environments. Kattwinkel *et al* (2011) suggests a life cycle of 15 years holds the highest conservation value for brownfields, as they take years to form. Areas which contain specialist or rare species should be discouraged from being repurposed. Additionally, it has been shown that brownfields that are between 15-20 years old will eventually revert back to woodland, which suggests that more significant management is required to maintain them as pollinator habitat (DEFRA 2012).

3. Methodology

3.1. The Study Area: Bo’ness, Firth of Forth

Data collection was conducted in Bo’ness, a coastal town situated on the south bank of the Firth of Forth, Scotland. Traditionally a place of heavy industry, the town is now used as a commuter town as it is situated near the cities of Glasgow, Edinburgh and Falkirk, as well as a stop along the historic John Muir Way. As part of the Inner Forth Landscape Initiative, special attention is now being paid to the ecological importance of Bo’ness within the Firth of Forth. Bo’ness has a warm and temperate climate, with an average of 804 mm of rainfall per annum (Climate data.org 2017). Under the Köppen and Geiger climate classification, Bo’ness is classified as a marine west coast (Cfb) climate which is characterised by short, dry summers and extensive precipitation during winter (Kottek *et al*. 2006). The average annual temperature is 8.6°C with the highest temperatures appearing in July, which has an average of 14.9°C. (Climate data.org 2017).

3.2 Research Design

Sampling was carried out in four sites□ Treatment with two locations and Control with two locations (Figure 3.1), which were selected with the support of IFLI and Buglife who initiated and provide ongoing management of both sites. Grangepans Meadow (Treatment Site 1) and the Bridgeness Ship Breakers brownfield site (Treatment Site 2) are currently managed by IFLI and Buglife to encourage pollinator abundance and species diversity.

Figure 3.1. Map displaying four sampling sites in Bo'ness, Scotland (Map created using Esri ArcGIS)

Three methods of sampling were used to collect data in each site. Wildflower frequency sampling was conducted using quadrats along a transect, while pollinator data was collected via observation (passive sampling) and sweep net sampling (active sampling) in order to gain a broad understanding of plantpollinator interactions within an area. Data was collected weekly from 8th May- 19th June 2017 for a total of seven weeks. Data collection was dependent on weather conditions – only on dry days with a maximum Beaufort wind force of 4 and no precipitation in order to follow best practice as suggested by the Bumblebee Conservation Trust (2010).

Site management

Burgess (2016a) outlines the management practices used to establish and maintain Grangepans Meadow and Bridgeness Shipbreakers brownfield sites as pollinator habitat. The process of establishing Grangepans Meadow began in 2015 when the site was identified, and sprayed with weed killer in early October to decrease competition for the subsequent plants. The site was ex-industrial thus had thin soil so a power harrow was then used to rotate the soil and then a roller was used to further break up the soil. Seed mixes for the new wildflower meadow were sourced from Scotia Seeds (Scotia Seeds, 2017) for the wildflower meadow, a seed supplier which uses Scotland specific seeds where appropriate. Native wildflower seed mixes along with grass mixed were selected and sown within site, with a high percentage of perennial wildflowers along with annual wildflowers in order to insure a successful first year bloom (see Appendix 1 for detailed list of seed species and mix percentages). To prevent grasses species from outcompeting newly sown wildflower species, the meadow was cut in October 2016 and the cuttings were removed. In October 2016, an additional area of meadow was also created alongside one of the sown areas to remove one of the regularly cut strips that ran alongside woodland. This additional area totalled 0.1 hectares in size and was planted with approximately 2,310 plug plants of 13 native wildflower species (see Appendix 1). In October 2016, a further 0.2 hectare of grassland meadow was also created using the same combination of seed mixes, but with different quantities (see Appendix 1). Bridgeness Ship Breakers brownfield was identified as an important site for biodiversity (Burgess 2016a). As a result, it began to be managed in October 2015 using different techniques than were used to create

Grangepans Meadow. Litter removal, scrub clearance, habitat pile creation, invasive alien species control were all carried out in the brownfield, and Yellow rattle seeds were sown in order to control grasses and encourage wildflower growth. The site continues to be actively managed through scrub and invasive species removal (Burgess 2016a). The control sites (Control 1 and 2) were both amenity grassland sites near the Treatment plots, which are traditionally managed (i.e. intensively cut) by the local council. Between the months of March and October, public spaces are mowed approximately every 3 weeks (Falkirk Council 2017). Control sites were located near residential areas and therefore have not been managed for wildlife. Since the study began, vegetation at the control sites was cut two times. Between those periods of cutting, the two Treatment sites experienced vegetation growth, including wildflowers blooming.

Wildflower transects

Five quadrats along a 100 metre transect were used to assess plant frequency within each of the study sites at approximately the same location. Recordings of frequency of vegetation species were taken every 20 metres. While each study site varied in size, the regularity along the transect remained the same for consistency. Each site took approximately 30 minutes to complete the quadrat sampling, thus each site was sampled for 3.5 hours overall.

Observation representative patch sampling

Flower visitation by pollinators in a representative 2 by 3 metre patch per site were observed to assess true number of pollination visits and visitors within each site over the pollinating season. Pollinator insects that visited all open flowers within the area were counted and identified. As sites were exposed to the coastal winds, areas with tree cover were chosen, in addition to patches that were in the middle of the site as to not be influenced by verging habitats. Three sets of 15minute-long observations were carried out, with hour breaks between each observation in order to avoid repeat visitations by individual pollinators. Overall, each site was observed for 5.3 hours. Similar studies which have used representative patches have employed shorter time frames. Blaauw *et al*. (2014) for example, had 1.5 hours per site over a six-week period.

Sweep net sampling

Sweep net sampling for additional pollinator recording was carried out in order to assess general pollinator abundance and diversity over a wider sampling range in comparison to flower visitation. Sampling was carried out over fixed routes with added altering random routes within so that the repeated sampling would be consistent and reduce bias. Each sweep net sampling took approximately 20 minutes, thus 2.3 hours of sweep netting at each site was completed.

3.3 Data Analysis

Total wildflower frequency and species richness was calculated for each site by totalling the sample counts. Then total pollinator species richness and abundance metrics were calculated for each site by totalling the different observation and sweep netting sample counts. The total abundance, frequency and species richness were then tested for a normal distribution using the probability distribution plot in Minitab. To assess the impact of the different management sites on pollinators, general linear models (GLM) were utilised. For statistical analysis, a model was created for each sampling method. All models were simplified through model reduction using stepwise process. Models were authenticated by plotting standardised residuals vs. fitted values and histograms of residuals. If p-values were significant, post-hoc Tukey all-pair comparisons were carried out using Minitab.

Wildflower dataset

The effects of fixed factors (site and sampling week) on wildflower frequency and species richness was tested using a general linear model in the statistical package, Minitab (Minitab 2017). It is expected that there will be statistical difference due to management of Treatment. Grass cutting and precipitation were included in the initial model as factors and temperature as a covariate with non-significant factors eliminated through a step-wise process.

Pollinator dataset

Three general linear models were run for pollinator data. The first model tested for the effects of fixed factors, site and sampling week, on pollinator abundance and pollinator species richness. The second model tested for the effects of covariates, wildflower frequency and species richness, on the responses, pollinator abundance and species richness, for each method. The third model was run to test wildflower frequency and richness, as co-variates, on species group richness— bees, hoverflies, butterflies—for each sampling method. Grass cutting, precipitation were included in the initial models as factors and temperature as a covariate with non-significant factors eliminated through a step-wise process.

Diversity indices

Shannon-wiener Diversity Index is a calculation of variability which takes into account both richness and evenness within samples. It has been a valuable instrument to understand the levels of biodiversity across study areas. Simpson's Diversity Index is a measure of diversity which takes incorporates the number of species present, as well as the relative abundance of each species. For both indices, as species richness and evenness increase, the diversity increases. The Shannon-Weiner Index and Simpson's Diversity Index were calculated for diversity in each sampling method— wildflower species richness, observation species richness and sweep net species richness – using the vegan package in R package 3.4.1 (The R Foundation for Statistical Computing 2017).

4. Results

4.1 Wildflower Surveys

4.1.1 Sites

Overall, both Treatment sites were shown to have greater wildflower diversity in comparison to Control sites, as calculated through Shannon-wiener diversity index and Simpson diversity values (Figure 4.1). Bridgeness Ship Breakers (Treatment Site 2) was found to have the highest values in both indices, while Control 2 was calculated to have the lowest value in both indices. Species richness was 2.9 times higher in the Treatment Sites compared to the Control Sites overall, with the Treatment sites having similar levels of richness (Figure 4.2). Total plant frequency varied significantly between sites and sampling week, in addition to precipitation and temperature (Table 4.1). May was a dry and warm month whereas June was an exceptionally wet and warm month (Metoffice 2017). Wildflower species richness varied significantly between sites and sampling week (Table 4.3). As sites were significant, a post hoc comparison using Tukey HSD test was carried out which indicated that Site 1 and Site 2 of the Treatment were statistically different to the two Control sites at $p<.05$ (Table 4.4).

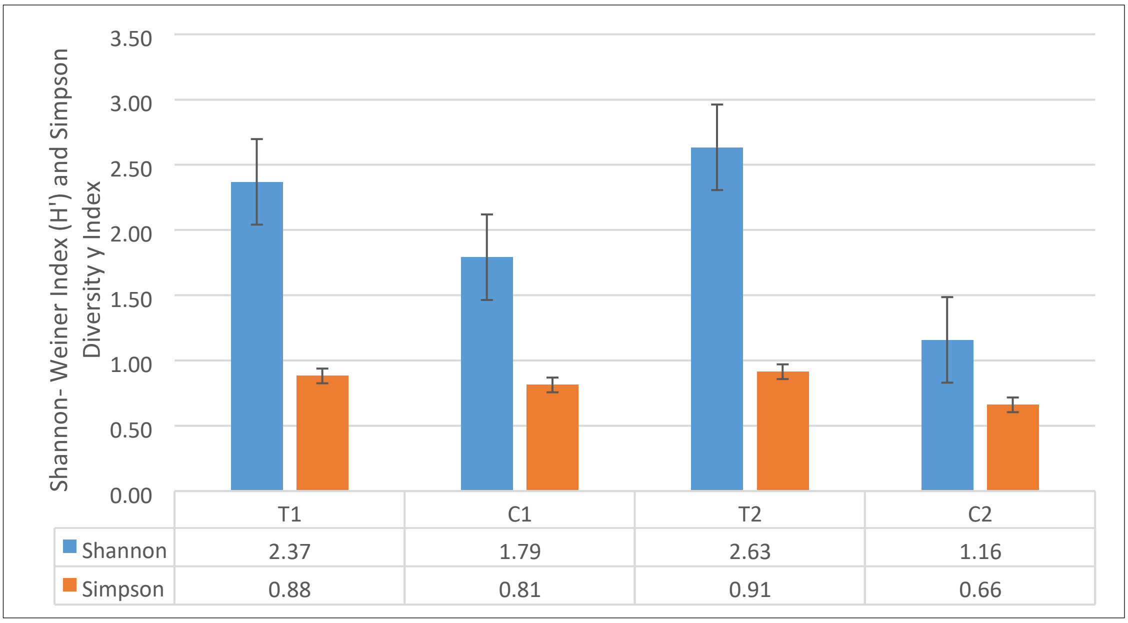

Figure 4.1. Shannon-wiener diversity and Simpson's diversity indices for wildflower species present in treatment and control sites.

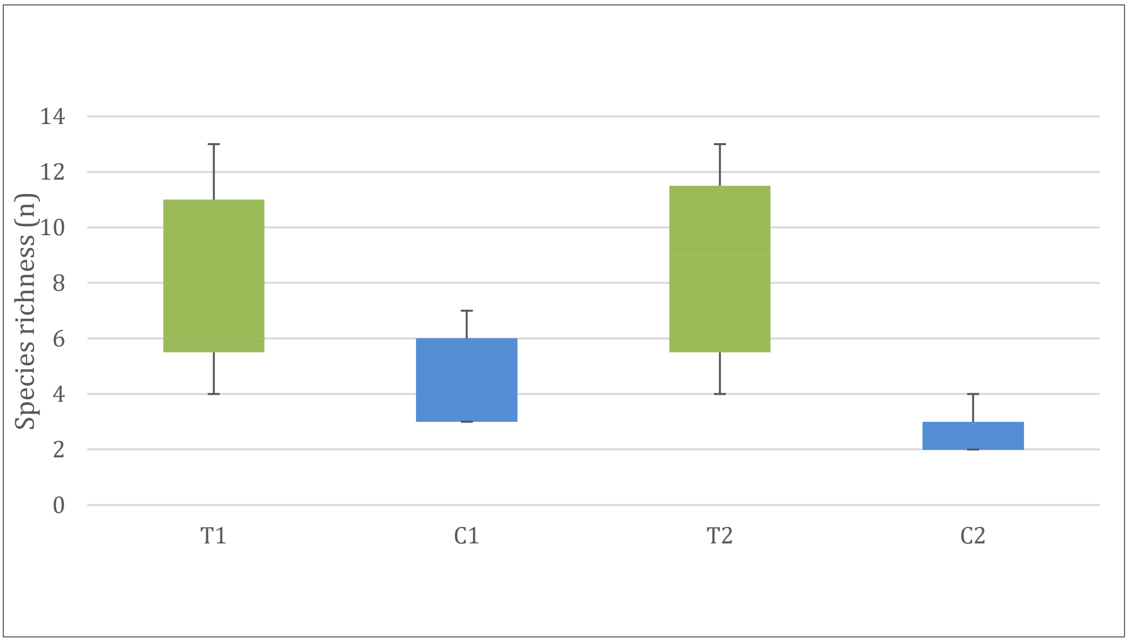

Figure 4.2. Boxplot distribution of wildflower species richness between treatment sites (green) and controls sites. (blue)

Table 4.1. A summary of test statistics derived from the models examining the effect of sites and

weeks on wildflower frequency. Significance for p<.05 is shown in bold.

Plant frequency	DF	F-Value	P-Value
Site	3	6.55	**0.003**
Week	6	2.56	0.057
Precipitation	1	4.4	**0.05**
Temperature	1	7.4	**0.02**
Grass cutting	1	0.30	0.6

Table 4.2. Tukey HSD comparison of sites for wildflower frequency. Significance for p<.05 is shown in bold.

Difference of Site Levels	T-Value	P-Value
C1-T1	-4	**0.004**
T2-C1	-2.18	0.166
C2-T1	-3.6	**0.01**
C1- T2	1.82	0.295
C2-C1	0.4	0.978
T2-C2	-1.42	0.502

Table 4.3. A summary of test statistics derived from the models examining the effect of sites and weeks on wildflower species richness. Significance for p<.05 is shown in bold

Plant species richness	**DF**	**F-value**	**P-value**
Sites	3	15.85	**0.0001**
Weeks	6	3.28	**0.03**
Temperature	1	6.3	**0.03**
Precipitation	1	5.4	0.08
Grass cutting	1	2.9	0.1

Table 4.4. Tukey HSD comparison on sites for wildflower species richness. Significance for p<.05 is shown in bold.

Difference of Site Levels	**T-Value**	**Adjusted P-Value**
C1– T1	-3.28	**0.025**
T2 – T1	1.86	0.288
C2 – T1	-4.68	**0.002**
T2 – C1	4.99	**0.001**
C2 – C1	-1.87	0.286

C2 – T2	-6.78	**0.00007**

4.1.2. Species

Wildflower species found throughout the sampling period varied across the two sites. Certain species were recorded at the beginning of the sampling period while others emerged later on in the season, such as tufted vetch (*Vicia cracca*), yellow loosestrife (*Lysimachia vulgaris*) and Hairy tare (*Vicia hirsute*), which did not emerge until the third week of observation. Two wildflower species, Birdsfoot trefoil (*Lotus corniculatus*) and Ribwort plantain (*Plantago lanceolata*) were recorded in Control 1 (Figure 4.3 and 4.4). Within Grangepans Meadow (Treatment Site 1), *Rhinanthus minor*, *Lotus corniculatus*, *Achillea millefolium*, and *Echium vulgare* were the most frequently observed wildflower species across the sampling period (Figure 4.5) Bridgeness Ship Breakers Brownfield (Treatment Site 2) displayed a different mix and frequency of wildflower species, with *Lotus corniculatus*, *Plantago lanceolata*, *Ranunculus repens*, and *Vicia cracca* as the most frequently observed wildflower species across the sampling period (Figure 4.6).

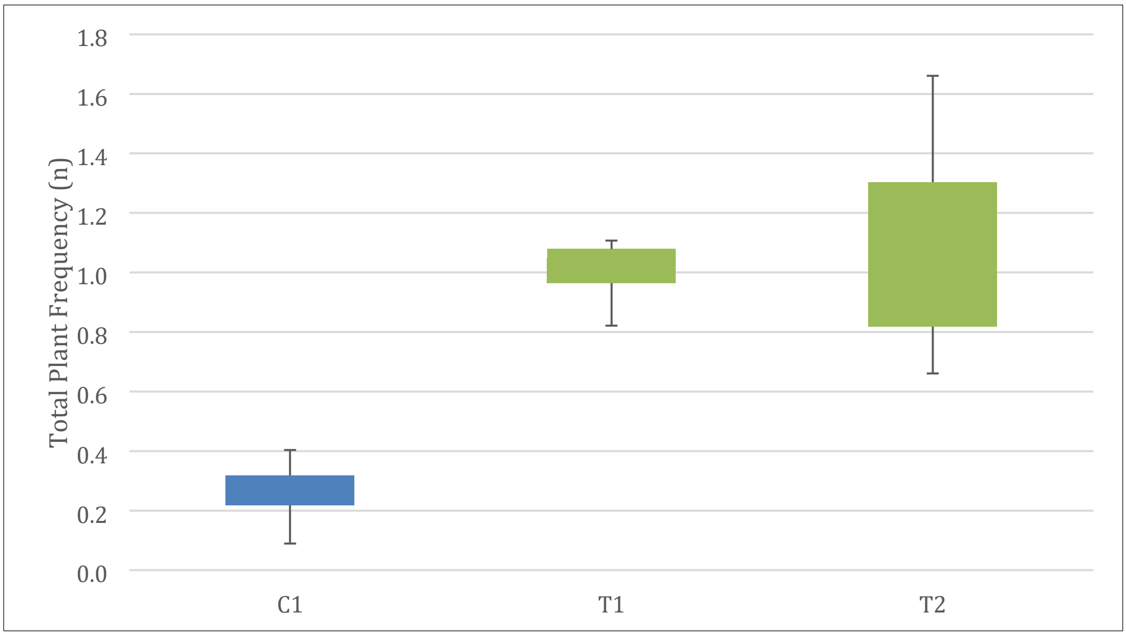

Figure 4.3. Boxplot distribution of total frequency values found for *Plantago lanceolata* between sites.

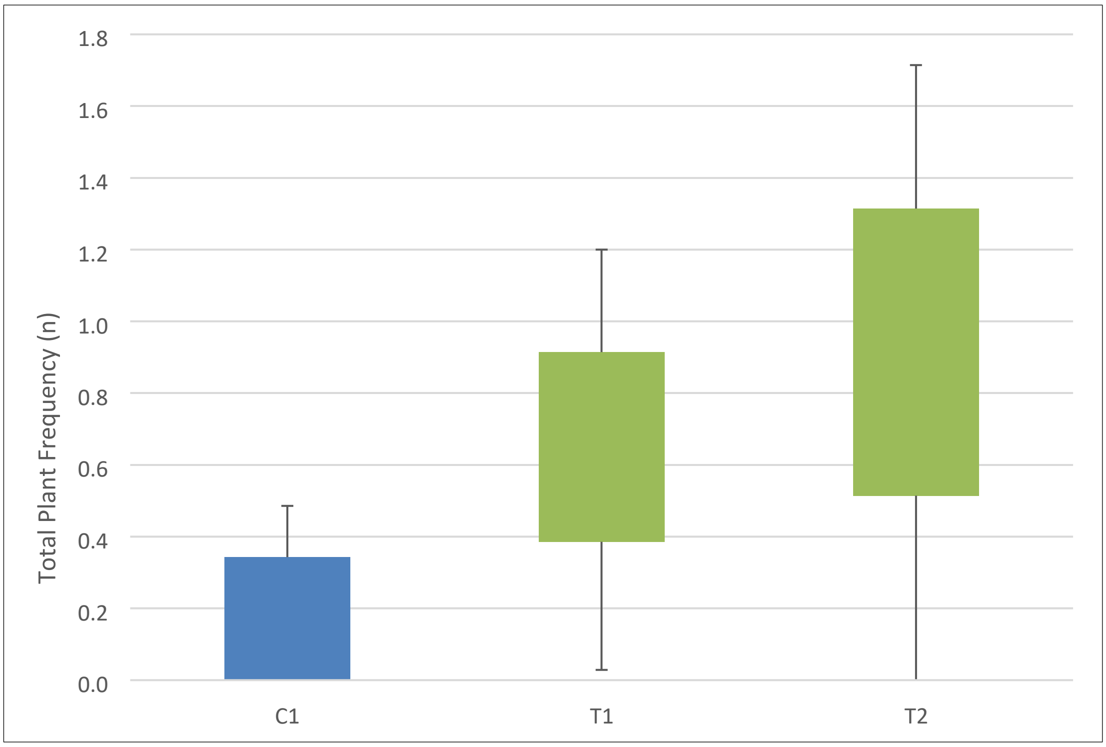

Figure 4.4. Boxplot distribution of total frequency values found for *Lotus corniculatus* between sites.

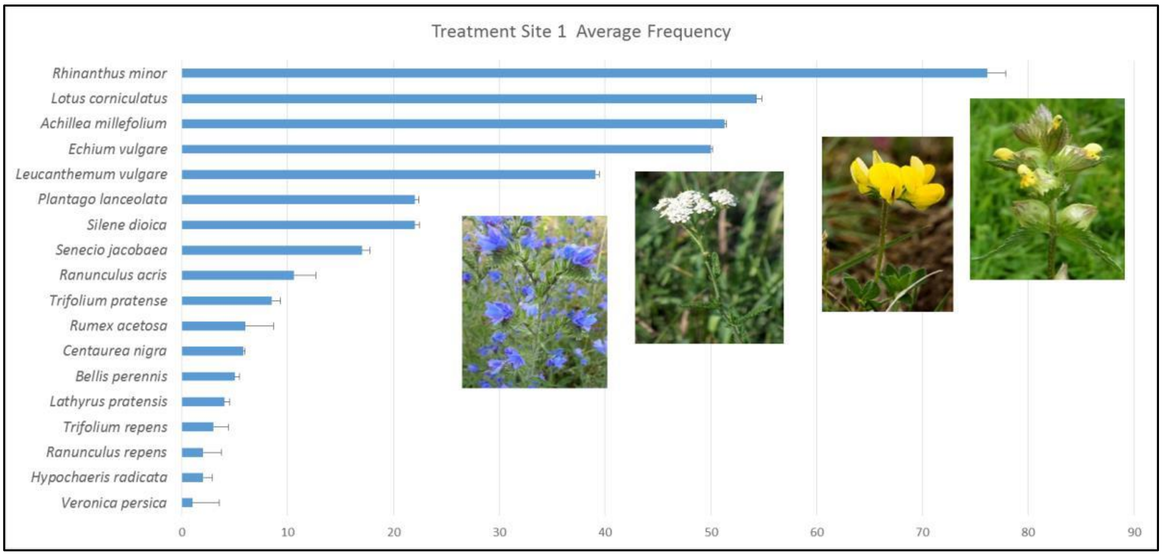

Figure 4.5. Total ranked average frequency of plants recorded in Treatment Site 1 (Grangepans Meadow). Images of the top ranked species are shown, with the highest-ranked at right (*Rhinanthus minor*, *Lotus corniculatus*, *Achillea millefolium*, *Echium vulgare*).

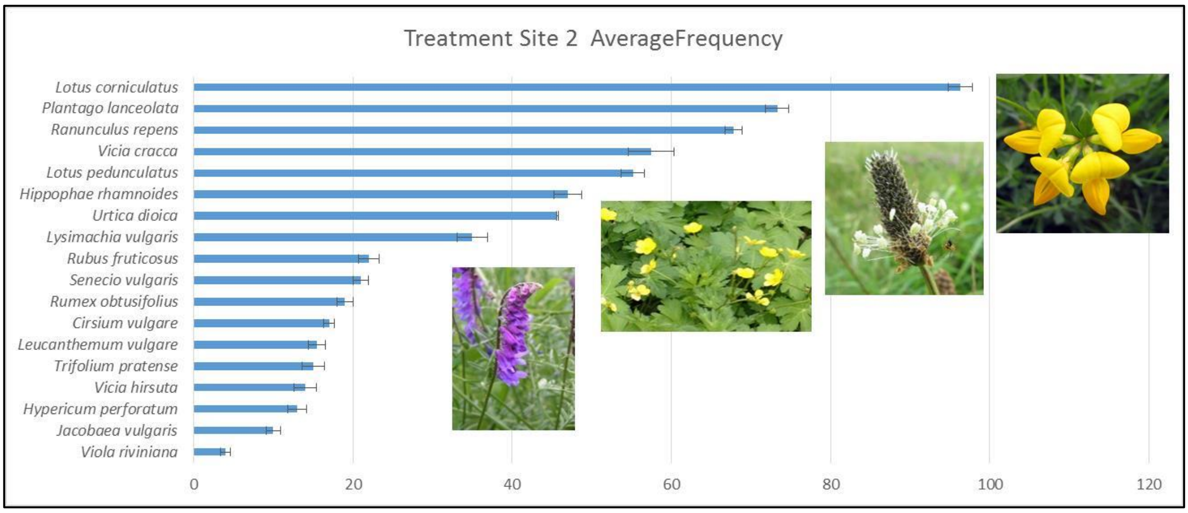

Figure 4.6. Total ranked average frequency of plants recorded in Treatment Site 2. Images of the top ranked species are shown, with the highest-ranked at right (*Lotus corniculatus*, *Plantago lanceolata*, *Ranunculus repens*, *Vicia cracca*)

4.2 Pollinator Abundance

4.2.1 Observation

Through the observation survey, 183 individuals were recorded over the sevenweek sampling period. The total of recorded individuals in May was 78, compared to June which was 105. The total number of insect pollinators in 29th May was six times higher compared to 8th May. Pollinator recordings were highest overall across Treatment sites, with 160 observed individuals, 87.2% of the recorded total. Grangepans Meadow (Treatment Site 1) had the highest percentage of observed individuals with 59% (108) of total individuals, while Treatment Site 2, which had 28.2% (52) of the total recordings (Figure 4.7). Treatment Site 1 had approximately 20 times as many insect pollinator recordings than the amenity grassland control site and Treatment Site 2 had approximately 3 times as many pollinator recordings than Control 2. Of the 183 recordings overall, 79.8% were bees followed by hoverflies (12.6%) and butterflies (6.6%). The most abundant species overall was the red-tailed bumblebee (*Bombus lapidaries*), which occupied
45.9% (84) of the total abundance. This was followed by the buff-tailed bumblebee (*Bombus terrestris*) with18.6% (34) of total abundance. Insect pollinators were more active in June as can be seen with observations noticeably increasing by the end of May (Figure 4.8). The abundance of pollinators varied significantly between sites and by weeks (Table 4.5). There was a significant effect of pollinator abundance on number of individuals collected at the $p<.05$ level for the sites. Post hoc comparisons using Tukey HSD test indicated that pollinator abundance in

Grangepans Meadow (Treatment Site 1) was statistically different to both Control sites and Bridgeness Ship Breakers (Treatment Site 2).

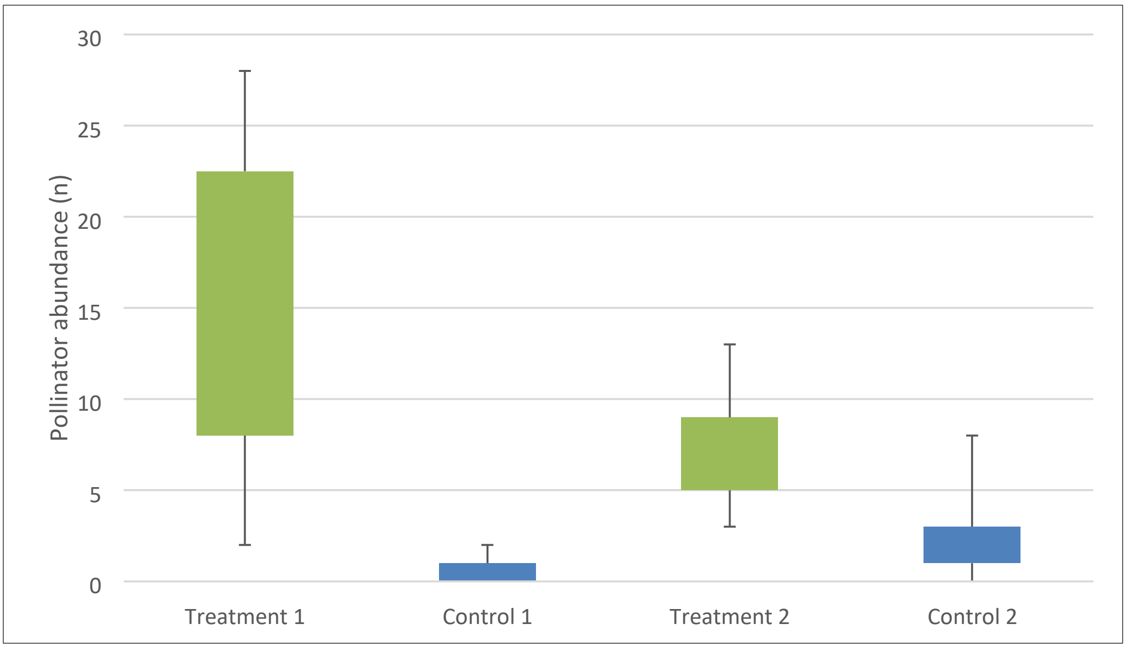

Figure 4.7. Boxplot distribution of frequency values for pollinator abundance between sites.

Table 4.5. A summary of test statistics derived from the models examining the effect of sites, weeks and sampling method on observed pollinator abundance. Significance for $p<.05$ is shown in bold.

Pollinator Observation	DF	F-Value	P-Value
Site	3	15.15	**0.00004**
Weeks	6	2.64	**0.05**

Table 4.6. Tukey HSD comparison of sites for pollinator abundance using observation method.

Significance for p<.05 is shown in bold

Difference of Site Levels	T-Value	P-Value
C1-T1	-6.17	**0.0001**
T2-T1	-3.35	**0.02**
C2-T1	-5.39	**0.0002**
T2-C1	2.81	0.1
C2-C1	0.78	0.9
C2-T2	-2.04	0.2

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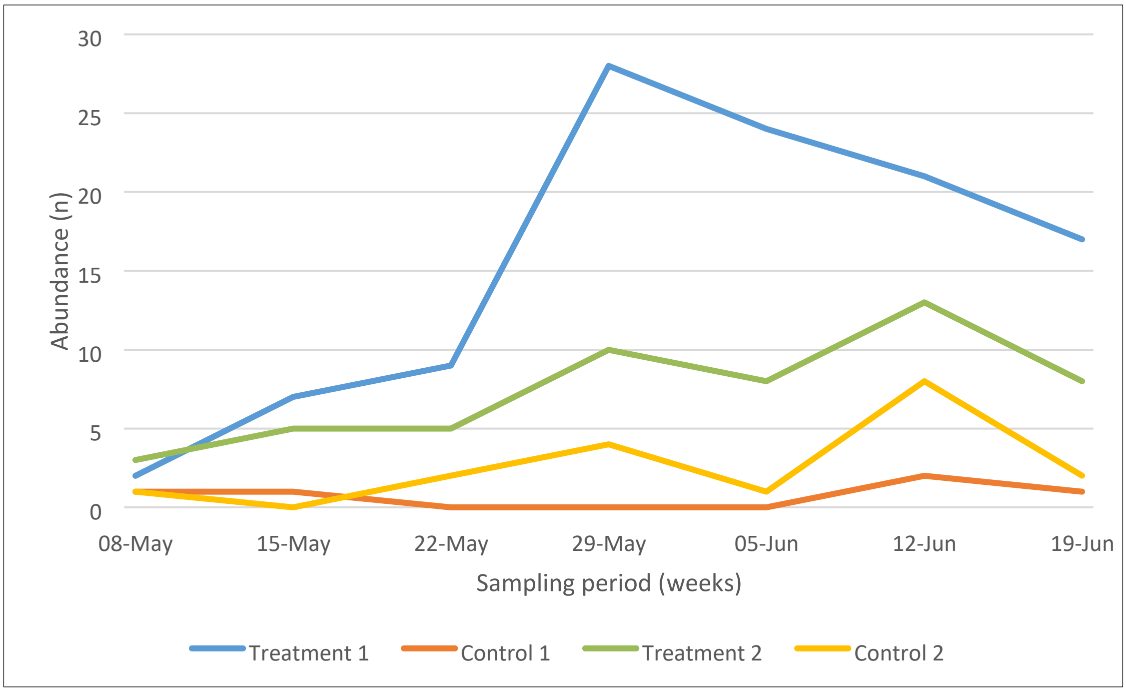

Figure 4.8. Abundance of insect pollinators observed in all four sites over the seven-week survey period.

4.2.2 Sweep Net Sampling

Through sweep net sampling, 208 individuals were recorded over the seven-week sampling period. As seen in observation sampling, June was a more active month for recording individuals, and spiked in Week 4, the end of May. The total recordings for May were 82, compared with June, which had 124. Treatment had 87.5% of the total sampling individuals (Treatment Site 1= 50.5%, Treatment Site 2= 37%). The Treatment had six times the abundance of insect pollinators than Control. Of the total abundance, 73.1% were bees, then hoverflies (17.8%) and butterflies (5.8%). Sweep netting recorded additional species which the representative patch did not: wasps (1.9%) and sawflies (1.4%), although small percentages of overall abundance. Similarly to observation sampling, *Bombus lapidarius* (38%) and *Bombus terrestris* (25.5%) were the most abundant species and were recorded in all sites. The abundance of pollinators varied significantly between sites and by weeks (Table 4.7; Table 4.8).

There was a significant effect of pollinator abundance on number of individuals collected at the $p<.05$ level for the sites. Post hoc comparisons using Tukey HSD test indicated that Site 1 and Site 2 of the Treatment was statistically significant to Site 1 and Site 2 of the Control.

Table 4.7. A summary of test statistics derived from the models examining the effect of sites and weeks on pollinator abundance from sweep net sampling. Significance for p<.05 is shown in bold.

Pollinator Sweep Net Sampling	DF	F-Value	P-Value
Site	3	13.92	**0.0001**
Weeks	6	2.92	**0.0359**

Table 4.8. Tukey HSD comparison of sites for pollinator abundance using sweep net method.

Significance for p<.05 is shown in bold

Difference of Site Levels	T-Value	P-Value
C1-T1	-5.22	**0.0003**
T2-T1	-1.59	0.4
C2-T1	-5.22	**0.0003**
T2-C1	3.63	**0.0094**
C2-C1	0	1
C2-T2	-3.63	**0.0094**

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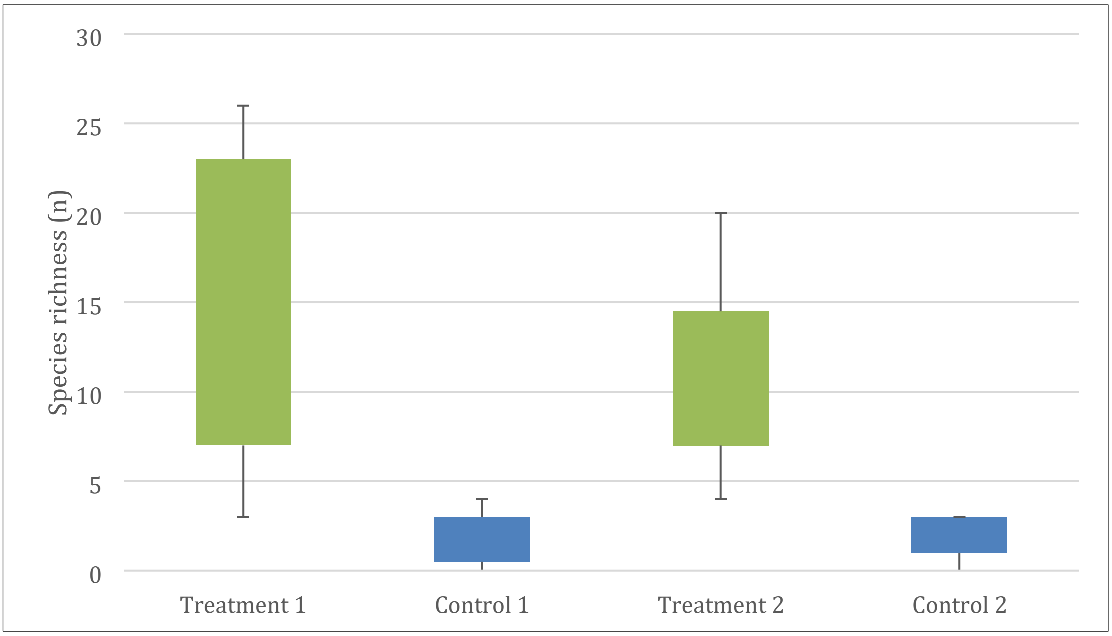

Figure 4.9. Boxplot distribution of pollinator species abundance from sweep net sampling of each survey site.

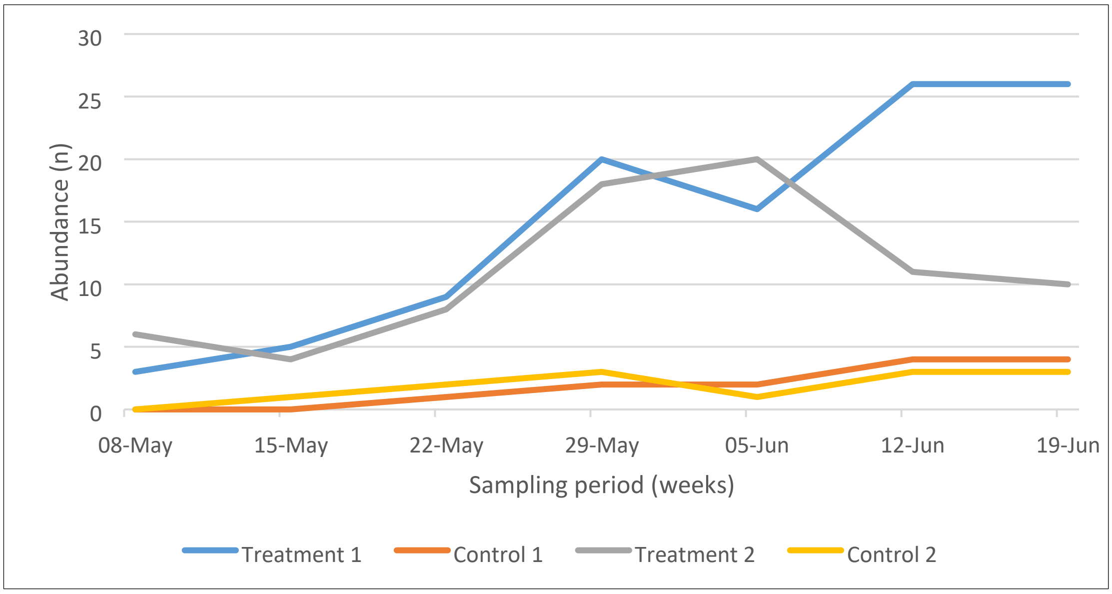

Figure 4.10. Abundance of pollinators across sites found through sweep net sampling over sampling period.

4.3 Pollinator Diversity

4.3.1 Observation

Bridgeness Ship Breakers Brownfield (Treatment Site 2) had the greatest diversity values by both indices, and Control 1 has the lowest through the observation survey (Figure 4.11). Pollinator species richness was relatively even between the two Treatment sites, as well as compared between the two Control sites (Figure 4.12). Treatment sites recorded 29 combined species, 3.6 times greater than compared combined species richness of the control sites with 8 species. The species richness of pollinators varied significantly between sites; however, they did not vary significantly by week, with two predictors explained 77.3% of the variance. There was a significant effect of pollinator species richness on number of individuals collected at the $p<.05$ level for the sites (Table 4.9). Post hoc comparisons using Tukey HSD test indicated that Treatment's Site 1 and Site 2 was statistically different to both sites of Control and statistically insignificant to Site 2 of Treatment.

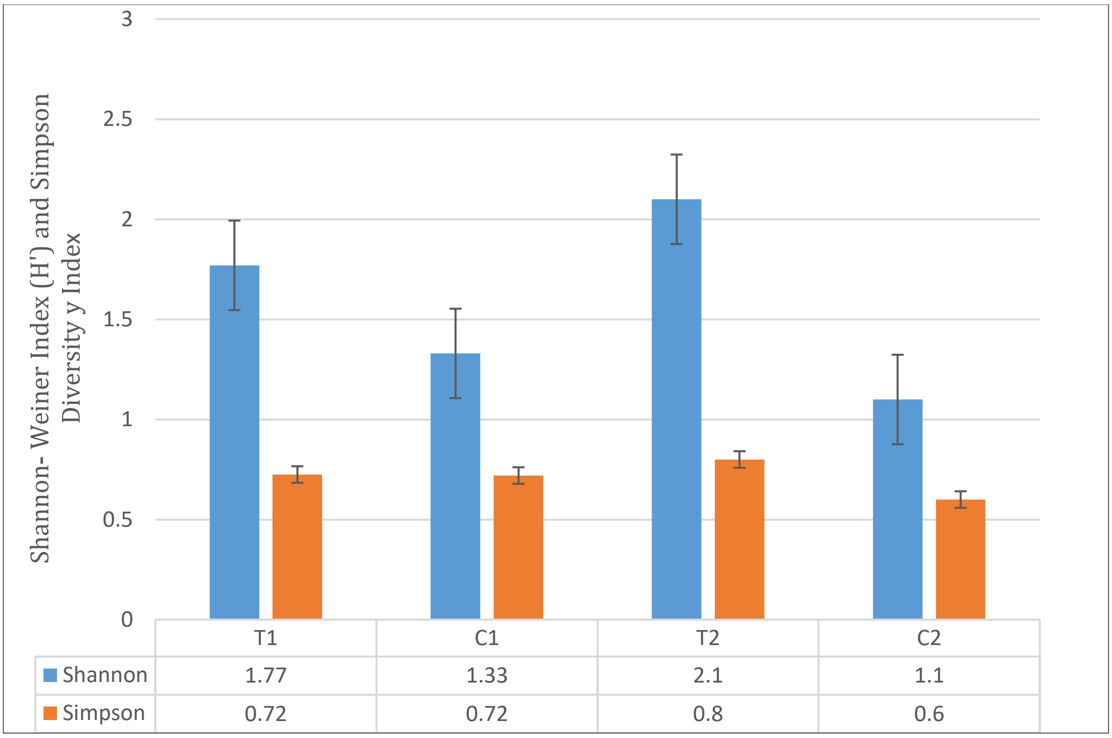

Figure 4.11. Shannon-wiener diversity and Simpson's diversity indices calculated for pollinator species observed in Grangepans Meadow (T1) and Bridgeness Ship Breakers Brownfield (T2) and control sites (C1, C2).

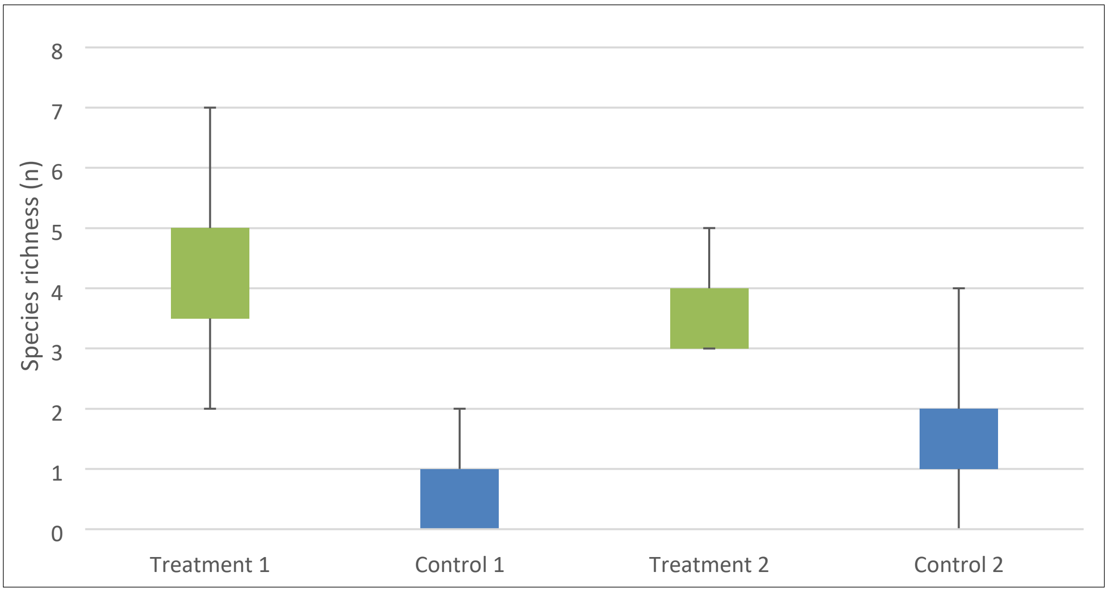

Figure 4.12. Boxplot distribution of species richness of pollinator species observed in each survey site.

Table 4.9. A summary of test statistics derived from the models examining the effect of sites and weeks on species richness. Significance for $p<.05$ is shown in bold. Predictors accounted for 77.2% of variance.

	DF	**F-Value**	**P-Value**
Site	3	17.27	**0.00002**
Weeks	6	1.54	0.222

4.3.2. Sweep Net Sampling

Both Treatment sites had higher Shannon-wiener and Simpson diversity values than control sites, with treatment's Site 2 having the highest value and Control Site 1 having the lowest (Figure 4.13). The Treatment had collectively 27 species between them compared to the Control which had 9 species recorded collectively. Species richness in Treatment's two sites was 3.9 times higher than in Control's two sites. The species richness of pollinators varied significantly between sites but did not statistically vary between weeks (Table 4.10). There was a significant effect of species richness on number of individuals collected at the $p<.05$ level for the sites. Post hoc comparisons using Tukey HSD test indicated that Site 1 and 2 of the Treatment were statistically different to Site 1 and 2 of Control.

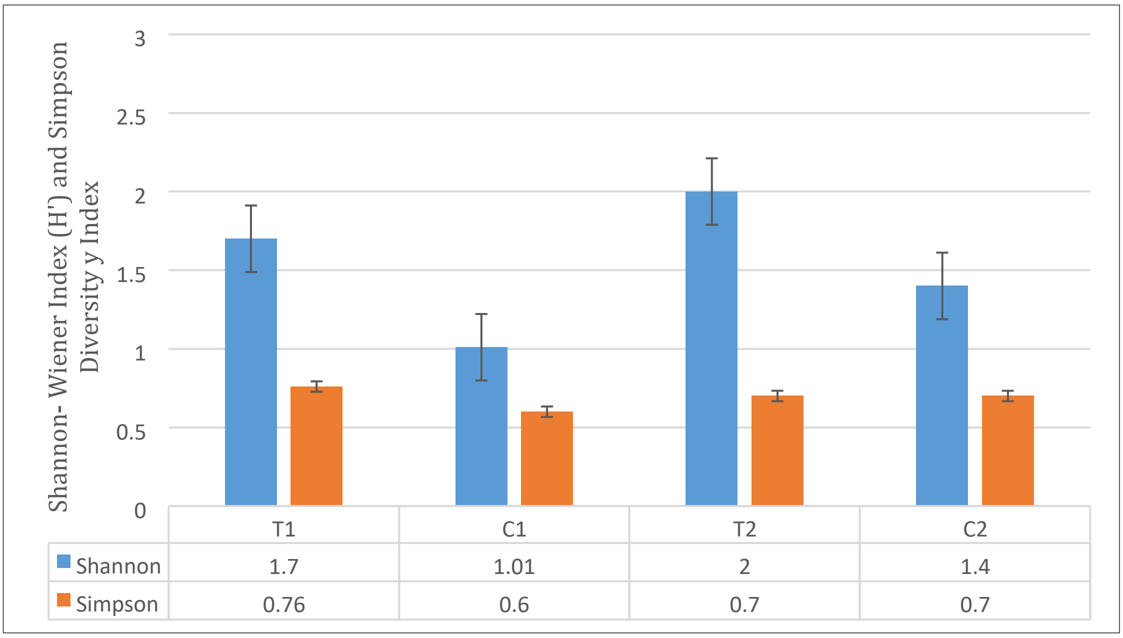

Figure 4.13. Shannon-wiener diversity and Simpson's diversity indices calculated for pollinator species found in Grangepans Meadow (T1) and Bridgeness Ship Breakers Brownfield (T2) and control sites.

Table 4.10. A summary of test statistics derived from the models examining the effect of sites and weeks on pollinator functional groups from sweep net sampling. Significance for p<.05 is shown in bold. Predictors accounted for 76.4% of variance.

Pollinator Sweep Net Sampling	DF	F-Value	P-Value
Site	3	15.85	**0.000027**
Weeks	6	1.8	0.155751

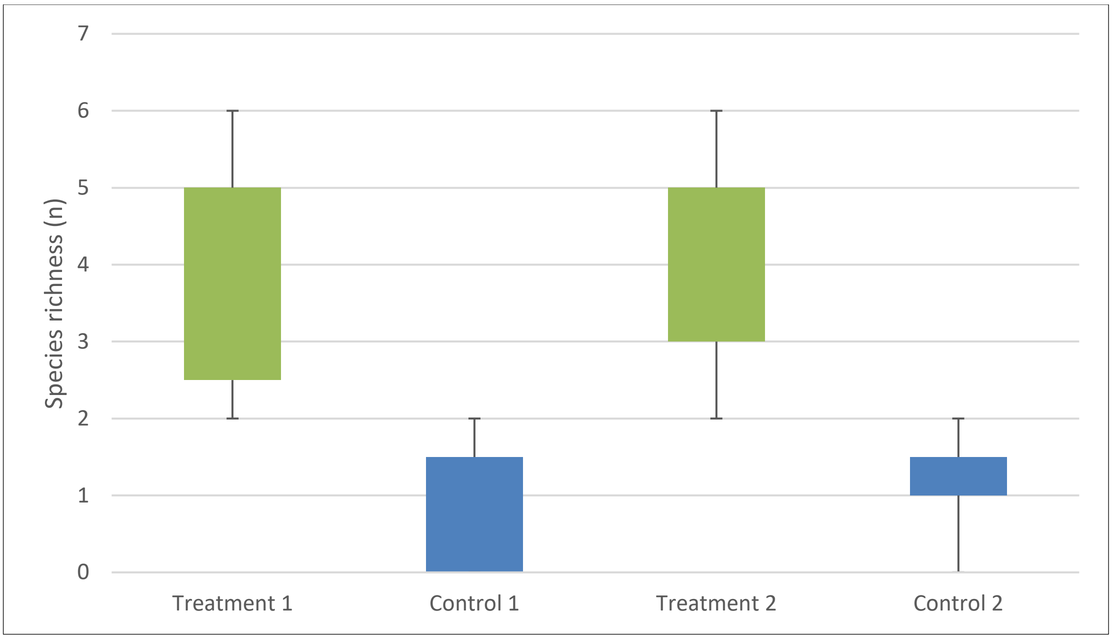

Figure 5.6. Boxplot distribution of pollinator species richness from sweep net sampling of each survey site.

4.4. Wildflower-pollinator interactions

Total plant frequency varied significantly between pollinator abundance, for both methods, while species richness varied significantly only with sweep net sampling (Table 4.11). The total abundance and species richness of the sweep net method were statistically different from wildflower richness (Table 4.10). However, observation abundance and richness were not statistically significant. Wildflower frequency was found to be a significant predictor for bee richness (Table 4.13) with the observation method. Wildflower frequency was a significant predictor for bees and hoverflies, but not butterflies (4.14). For the observation method, wildflower richness was found to be statistically insignificant for observation method (Table 4.10) for all groups. For sweep net sampling, wildflower richness was statistically different to bee richness (Table 4.14).

Table 4.11. A summary of test statistics derived from the models examining the effect of wildflower frequency on pollinator abundance and species richness. Significance for p<.05 is shown in bold

Wildflower frequency	**DF**	**F-Value**	**P-Value**
Observation abundance	1	4.87	**0.041**
Sweep net abundance	1	12.93	**0.002**
Observation richness	1	0.23	0.641
Sweep net richness	1	4.46	**0.05**

Table 4.12. A summary of test statistics derived from the models examining the effect of sites, weeks and sampling method, and other external variables on wildflower richness. Significance for p<.05 is shown in bold. The predictors accounted for 96% of the variance.

Wildflower richness	**DF**	**F-Value**	**P-Value**
Observation abundance	1	2.41	0.14
Sweep net abundance	1	40.07	**0.00002**
Observation richness	1	0.12	0.73
Sweep net richness	1	22.72	**0.0003**

Table 4.13. A summary of test statistics derived from the models examining the effect of wildflower frequency on observed species groups. Significance for p<.05 is shown in bold.

Pollinator Observation	**DF**	**F-Value**	**P-Value**
Bees	1	8.09	**0.011**
Hoverflies	1	1.3	0.271
Butterflies	1	1.89	0.187

Table 4.14. A summary of test statistics derived from the models examining the effect of wildflower richness on observed species groups. Significance for p<.05 is shown in bold.

Pollinator Observation	**DF**	**F-Value**	**P-Value**
Bees	1	0.02	0.9
Hoverflies	1	1.2	0.3
Butterflies	1	0.2	0.6

Table 4.14. A summary of test statistics derived from the models examining the effect of wildflower frequency on pollinator functional groups from sweep net sampling. Significance for p<.05 is shown in bold.

Pollinator Sweep Net Sampling	DF	F-Value	P-Value

Bees	1	8.9	**0.008**
Hoverflies	1	4.37	**0.052**
Butterflies	1	0.38	0.547

Table 4.14. A summary of test statistics derived from the models examining the effect of wildflower richness on pollinator functional groups from sweep net sampling. Significance for $p<.05$ is shown in bold.

Pollinator Sweep Net Sampling	DF	F-Value	P-Value
Bees	1	11.2	**0.004**
Hoverflies	1	0.33	0.5
Butterflies	1	0.5	0.4

5. Discussion

The study aimed to answer whether or not the creation of two wildflower-rich habitats in Bo'ness had benefited the local insect pollinators between these sites. The findings have shown that Grangepans Meadow and Bridgeness Ship Breakers brownfield had higher wildflower diversity than the amenity grassland control sites (Figure 4.1.1; Figure 4.1.3). Expectedly, as a result, the wildflower sites also had a high abundance and diversity of pollinators which were statistically significant in comparison to the control sites. While representative patch sampling and sweep net sampling generated different results for pollinator diversity, each method indicated the same general trend of increased pollinator diversity in comparison to control sites. Observation abundance and species richness were not statistically significant related to wildflower species richness. These results could indicate there were fewer flower visitations but higher numbers of species within the vicinity, or be explained by low levels of precipitation during the first weeks of the study, which likely led to the stark increase in overall pollinator counts for each sampling method in June. Overall, the results of the study indicate that current management strategies as part of the Bridgness Biodiversity project have been successful in the creation of suitable pollinator habitat and resources.

The results of this study are broadly consistent with previous studies and other urban pollinator projects which indicate that wildflower sites are more valuable to pollinators within urban environment compared to its amenity grassland (Haaland *et al*. 2011; Goddard 2016), as wildflower grassland vegetation is more diverse and offers greater floral resources than management of amenity grassland allows.

The study findings are also in line with previous data collected by Buglife regarding wildflower development during the first years of the Bridgeness Biodiversity project (Burgess 2016), demonstrating the continued successful development of wildflower grassland throughout the study area. Overall, wildflower species that were more abundant within Grangepans Meadow had a higher percentage by weight in the seed mix sown during the meadow's creation (Figure 4.5 and Appendix 1). The exception was common birdsfoot trefoil (*Lotus corniculatus*), which was abundant in both Grangepans Meadow and Bridgeness Shipbreakers but was sparsely included in the Mavisbank seed mix, indicating precolonisation of the species within the test area. Of the two managed sites, this study found the Bridgeness Ship Breakers brownfield (Treatment Site 2) to provide better pollinator habitat in the local area, as seen for both wildflowers and pollinators (Figure 4.1.1; Figure 4.1.3). Bridgeness Ship Breakers also had exclusive uncommon species, such as parasitic wasps (*Ichneumon stramentor*) and the vestal cuckoo bumblebee (*Bombus vestalis*) (see Appendix 2), which could be explained by the age of the site and the diversity of habitats within it. While Bridgeness Ship Breakers did not have a wildflower seed mix sown at the site apart from yellow rattle, the site still had a larger diversity value than Grangepans Meadow and the control sites. Brownfields are only recently becoming known for their importance to pollinators, and through this study's findings demonstrates that they should be more focus placed on them Although understudied, brownfields can contain 12-15% of the UK's scarce insects (Buglife 2012), emphasising the potential for Bridgeness Ship Breakers to support uncommon and rare pollinator species in the local area. This could be a result of the longevity of the site; however, as there is little literature for comparison this study cannot this factor warrants further exploration. However, Bridgeness Ship Breakers had species that could outcompete native flowering plants (Figure 4.6), such as sea buckthorn (*Hippophae rhamnoide*) and brambles (*Rubus fruticosus*). This finding is likely a result of the site's age, as vegetation within brownfields has been found to back to woodland and shrubs after 15 years (DEFRA 2012). Overall, common pollinator species have benefited greatly from the management of pollinator focused habitats in Bo'ness. Buff-tailed bumblebees (*Bombus.terrestris*), the most common bumblebee in the UK, were the most frequently sampled pollinator species within the study sites. Hoverflies and bumblebees were less predominant, which is consistent with other studies which have found wild bees to be surveyed in greater numbers (Blackmore *et al*., 2014). The large proportion of bees found compared to other pollinator functional groups is a fairly common observation, as shown in previous studies examining declining distribution of pollinators (Biesmeijer *et al.* 2006; Feltham *et al*. 2015), especially when surveying pollinator species within wildflower plots (Blackmore *et al*. 2014).

As there is little overlap in floral resources utilized by bees and hoverflies (Blackmore *et al*. 2014) the sites likely contained specific floral resources which lead to bees – specifically bumblebees – to benefit most from the management of the sites. In comparison to bumblebees, only a small number of solitary bees were recorded and no honeybees were observed. Additionally, bumblebees are generalists and are active for a longer period of time therefore have a higher probability of being included in the study. As habitat loss affects solitary bees greater than social bees, it is easier for bumblebees to respond to newly created wildflower-rich habitats (Steffan-Dewenter *et al*. 2002). However, there is less literature written about the comparison of pollinator interactions in response to newly created habitat sites over time and how these relationships are altered by increasing pressures. It is evident that the perennial-heavy seed mix used for the Grangepans Meadow (Treatment Site 1) site was a significant factor due to the array of diverse floral resources for pollinators which attracted insect pollinators (Figure 4.5). Perennials produce greater nectar and pollen resources, 20 times more nectar and 6 times more pollen than annuals (Hicks *et al*. 2016). This relates to the nectar and pollen quantities per species which should be focused on for promoting pollinator diversity (Haaland *et al*., 2011). Such findings are consistent with other studies which found that different insect groups prefer different seed mixes (Pywell *et al*. 2007) – therefore, an evolving plant community may attract greater number of pollinators to the site. As there are few studies exploring seed mix with floral resources and pollinator visitation, it is unclear what an "optimal" seed mix for promoting pollinator diversity. However, from the findings it can be concluded that the high pollinator abundance and diversity figures within Grangepans Meadow are a direct result of wildflower reintroduction.

As Control 1 was adjacent to Grangepans Meadow (Treatment Site 1) (Figure 3.1), it is likely that the amenity grassland's proximity to a wildflower meadow led to increased pollinator activity within the control site. In contrast, low pollinator species richness in Control 2 could be explained by its isolation in relation to wildflower grassland. The potential impact of site isolation in playing a key role in community assemblages highlights the importance of connectivity between habitats. Conventional grassland is located near residences and are typically isolated from other semi-natural habitats, preventing species moving between available greenspace. As habitation fragmentation is a leading cause of biodiversity loss for pollinators (Steffan-Dewenter & Tscharntke, 1999) and abundance and species richness of wild pollinators relates to the semi-natural habitats nearby (Steffan-Dewenter *et al*. 2002), the creation of interconnected wildflower habitats adjacent to woodlands has been a successful pollinator conservation strategy. While the study was unable to show statistical significance for grass cutting on wildflower diversity within the control sites (Figure 4.1), there were statistical significances between the Treatment and Control's wildflower richness and pollinator abundance and diversity. As such, it is likely that the intense cutting regime discourages pollinators from control sites but further study of these relationships is required. As the managed sites are relatively new, it is unclear whether these populations are permanent. This was the second year after the Treatment sites were established, but it can be surmised that the evolving plant community will continue to have positive impacts on pollinators over a longer period in comparison to amenity grassland. Studies have shown an increase in insect pollinator abundance as new wildflower habitat ages, especially one year after establishment (Barone & Frank 2003; Frank *et al*. 2007). As such, the two managed sites will likely improve as pollinator habitat over time. However, for both sites to have importance to pollinators, they must actively continue to be managed (Feltham *et al*. 2015).

Limitations

The results of this study have a number of potential limitations. The sampling period of this study does not encompass the entirety of the pollinating season, and thus did not survey the full spectrum of species that the sample sites could contain. This is important from a floral resource perspective as peak nectar sugar availability in studies have occurred in early August for both perennial and annual meadows (Hicks *et al*., 2016). Quantifiable nectar and pollen resources per site would further enhance understanding of when the peak nectar and pollen resources occur in Bo'ness. Additionally, due to the young age of the established sites, it is unclear if the findings are representative of wildflower and pollinator trends over time.

6. Conclusions and Recommendations

This study has explored the potential value of restoring wildflower rich habitats as part of a wider conservation effort to conserve wild pollinator species. The two wildflower-rich habitats as part of the Bridgeness Biodiversity Project had a positive influence on pollinators in the Firth of Forth in comparison to conventional grassland management. Wildflower frequency and diversity impacted pollinator abundance and frequency. Within the context of this study, it can be argued that wildflower grassland restoration as part of the Bridgeness Biodiversity project has had a positive impact on pollinator abundance and diversity within Bo'ness. Additionally, it highlights the benefits of managing underutilized grassland and ex-industrial sites for wildlife conservation, demonstrating a significant difference between the value of managed conservation areas and amenity grassland to wild pollinators. While the Bridgeness Biodiversity project would benefit from additional, long-term study, such as pollen and nectar resource quantification, in order to draw more specific conclusions about the impacts of specific management techniques, the results of this study point to important issues with regards to management of urban and developed areas for wildlife conservation. Many previous pollinator studies have focused on the impact of pollinator populations within agricultural and natural landscapes, but this study supports the growing recognition of the importance of reconnecting fragmented pollinator habitat through urban areas. Overall, the findings of this study are of direct practical relevance to current pollinator conservation initiatives across the UK, including the B-Lines initiative, demonstrating that habitat creation through wildflower grassland restoration can be an effective method of improving wild pollinator abundance and diversity in local areas. Although this study was conducted in one local area, the continued creation and management of interconnected wildflower rich-habitats across Scotland and the rest of the UK is likely to have a significant, positive impact on pollinator ecology. As such, some general management conclusions can be drawn from the results of this study with regards to further steps to improve pollinator conservation efforts. Firstly, greater focus should be placed on encouraging local authorities to cut public grassland less frequently in order for native flora to establish and be utilised by pollinators. Alternatively, local authorities can be encouraged to leave wildflower strips within public greenspaces in order to provide some resources while actively managing areas for the public. Secondly, an interactive pollinator monitoring scheme contained within the John Muir B-Line, like the B-Lines map, would give greater landscape-scale insight into the behaviour and distribution of pollinators in similar projects within the B-Line. As wild pollinators react differently to independent environmental factors, a monitoring scheme would provide accurate information on an annual basis, which is currently lacking as no national pollinator scheme is in operation. Through such a scheme the findings from this study could be replicated, gathering more information regarding best practices for pollinator habitat restoration in order to more effectively implement new projects in locations which sufficient wildflower rich corridors. As the amount of habitat required to maintain stable pollinator populations is still largely unknown, such monitoring would help would cover knowledge gaps which exist in the field in a landscape scale. While further studies would be required in order to design appropriate restoration and management plans across regions, as well as to anticipate and mitigation other potential impacts on pollinator populations, it is clear that bridging Scotland's B-lines through wildflower grassland restoration is an important step forward in protecting wild pollinators across the country.

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Bibliography

Agriland (2017). British Pollinators, http://www.agriland.leeds.ac.uk/resources/British_Pollinators.php. University of Leeds, Leeds.

Barone, M. & Frank, T. (2003). Habitat age increases reproduction and nutritional condition in a generalist arthropod predator. *Oecologia,* **135**, 78-83.

Biesmeijer, J., Roberts, S., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T. *et al.* (2006). Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science,* **313**, 351-354.

Blaauw, B.R. & Isaacs, R. (2014). *Larger patches of diverse floral resources increase insect pollinator density, diversity, and their pollination of native wildflowers*.

Blackmore, L.M. & Goulson, D. (2014). Evaluating the effectiveness of wildflower seed mixes for boosting floral diversity and bumblebee and hoverfly abundance in urban areas. *Insect Conservation and Diversity,* **7**, 480-484.

Breeze, T.D., Bailey, A.P., Balcombe, K.G. & Potts, S.G. (2011). Pollination services in the UK: How important are honeybees? *Agriculture, Ecosystems & Environment,* **142**, 137143.

Buglife (2011). *Scottish Invertebrate Habitat Management: Grasslands*. Buglife – The Invertebrate Conservation Trust.

Buglife (2012). *Scottish Invertebrate Habitat Management: Brownfields.* Buglife – The Invertebrate Conservation Trust.

Buglife (2016). *The B-Lines Initiative*. Buglife – The Invertebrate Conservation Trust, Peterborough.

Buglife (2017). B-Lines Hub, https://www.buglife.org.uk/b-lines-hub. Buglife - The Invertebrate Conservation Trust, Peterborough.

Bumblebee Conservation Trust (2010). *Bee Walks- Monitoring Handbook for Volunteers*. Bumblebee Conservation Trust.

Burgess, S. (2016a). *Bridgeness Biodiversity.* Buglife – The Invertebrate Conservation Trust, Peterborough.

Burgess, S. (2016b). *John Muir Pollination Way Report*. Buglife - The Invertebrate Conservation Trust, Peterborough.

Butterfly Conservation (2017). Butterflies and moths, http://butterflyhttp://butterfly-conservation.org/44/butterflies-and-moths.htmlconservation.org/44/butterflies-and-moths.html. Butterfly Conservation, Dorset, UK.

Conte, Y. & Navajas, M. (2008). *Revue scientifique et technique (International Office of Epizootics),* **27**, 499-510.

Climate-Data.org (2017). Climate: Bo'ness, https://en.climate-data.org/location/9123/.

DEFRA (2012). *Agriculture in the United Kingdom.* GOV.UK.

DEFRA (2015). National Pollinator Strategy 2014 to 2024: implementation plan. UK Government, Westminster.

DEFRA (2016). Bees' Needs: Food and a home, https://www.gov.uk/government/news/bees-needs-food-and-a-home. GOV.UK.

Elmqvist, T., Folke, C., Nyström, M., Peterson, G., Bengtsson, J., Walker, B. *et al.* (2003). Response diversity, ecosystem change, and resilience. *Front Ecol Environ,* **1**, 488494.

Falkirk Council. (2017). Parks & Grounds Maintenance, http://www.falkirk.gov.uk/services/sport-leisure-culture/parkshttp://www.falkirk.gov.uk/services/sport-leisure-culture/parks-outdoors/grounds-maintenance.aspx - faq3491outdoors/grounds-maintenance.aspx#faq3491. Falkirk Council.

Feltham, H., Park, K., Minderman, J. & Goulson, D. (2015). Experimental evidence that wildflower strips increase pollinator visits to crops. *Ecology and Evolution,* **5**, 3523-3530.

Fitter, A., & Fitter, R. (2002). Rapid Changes in Flowering Time in British Plants. *Science*, 1689-1691.

Forister, M.L., McCall, A.C., Sanders, N.J., Fordyce, J.A., Thorne, J.H., O'Brien, J. *et al.* (2010). Compounded Effects of Climate Change and Habitat Alteration Shift Patterns of Butterfly Diversity. *Proceedings of the National Academy of Sciences of the United States of America,* **107**, 2088-2092.

Frank, T., Kehrli, P. & Germann, C. (2007). Density and nutritional condition of carabid beetles in wildflower areas of different age. *Agriculture, Ecosystems & Environment,* **120**, 377-383.

Gill, R., Ramos-Rodriguez, O. & Raine, E. (2012). Combined pesticide exposure severely affects individual- and colony-level traits in bees. *Nature*, **491**, 105-108.

Goodard, M. (2016). *Urban meadows for pollinating insects.* Urban Pollinators Project.

HAALAND, C., NAISBIT, R.E. & BERSIER, L. (2011). Sown wildflower strips for insect conservation: a review. *Insect Conservation and Diversity,* **4**, 60-80.

Hajjar, R., Jarvis, D.I. & Gemmill-Herren, B. (2008). The utility of crop genetic diversity in maintaining ecosystem services.

Hayhow, DB., Burns, F., Eaton, MA., Al Fulaij, N., August, TA., Babey L., Bacon L., Bingham, C., Boswell, J., Boughey, KL., Brereton, T., Brookman, E., Brooks, DR., Bullock, DJ., Burke, O., Collis, M., Corbet, L., Cornish, N., De Massimi, S., Densham, J., Dunn, E., Elliott, S., Gent, T., Godber, J., Hamilton, S., Havery, S., Hawkins, S., Henney, J., Holmes, K., Hutchinson, N., Isaac, NJB., Johns, D., Macadam, CR., Mathews, F., Nicolet, P., Noble, DG., Outhwaite, CL., Powney, GD., Richardson, P., Roy, DB., Sims, D., Smart, S., Stevenson, K., Stroud, RA., Walker, KJ., Webb, JR., Webb, TJ., Wynde, R. & Gregory, RD. (2016) State of Nature 2016. The State of Nature partnership.

Hicks, D., Ouvrard, P., Baldock, K., Baude, M., Goddard, M. & Kunin, W. (2016). Food for Pollinators: Quantifying the Nectar and Pollen Resources of Urban Flower Meadows. *PLOS ONE,* **11**.

Kattwinkel, M., Biedermann, R. & Kleyer, M. (2011). Temporary conservation for urban biodiversity. *Biological Conservation,* **144**, 2335-2343.

Kleijn, D. & Raemakers, I. (2008). A RETROSPECTIVE ANALYSIS OF POLLEN HOST PLANT USE BY STABLE AND DECLINING BUMBLE BEE SPECIES. Ecology, 89, 1811-1823.

Kleijn, D., Winfree, R. & Potts, S. (2015). Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. *Nature Communications,* **6**.

Kremen, C., Williams, N.M., Aizen, M.A., Gemmill-Herren, B., LeBuhn, G., Minckley, R. *et al.* (2007). Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. *Ecology Letters,* **10**, 299-314.

Memmott, J., Craze, P.G., Waser, N.M. & Price, M.V. (2007). Global warming and the disruption of plant–pollinator interactions. *Ecology Letters,* **10**, 710-717.

Miller-Rushing, A.J. & Primack, R.B. (2008) Global warming and flowering times in Thoreau's Concord: a community perspective. *Ecology*, **89**, 332–341.

Nogué, S., Long, P.R., Eycott, A.E., de Nascimento, L., Fernández-Palacios, J.M., Petrokofsky, G. *et al.* (2016). *Pollination service delivery for European crops: Challenges and opportunities*.

Nietzsche, F. (1887). *On the Genealogy of Morality*, Germany.

Ollerton, J., Winfree, R. & Tarrant, S. (2011). How many flowering plants are pollinated by animals? *Oikos,* **120**, 321-326.

Owen, J. (2010). *RHS Wildlife of a Garden: A Thirty-Year Study.* Royal Horticultural Society.

Palmer, M., Moffat, C., Saranzewa, N., Harvey, J., Wright, G. & Connolly, C. (2013). Cholinergic pesticides cause mushroom body neuronal inactivation in honeybees. *Nature Communications,* **4**.

Parmesan, C. (2006). Ecological and Evolutionary Responses to Recent Climate Change. *Annual Review of Ecology, Evolution, and Systematics.,* **37**, 637-669.

Potts, S.G., Biesmeijer, J.C., Kremen, C., Neumann, P., Schweiger, O. & Kunin, W.E. (2010). Global pollinator declines: trends, impacts and drivers. *Trends in Ecology & Evolution,* **25**, 345-353.

Pywell, R.F., Bullock, J.M., Tallowin, J.B., Walker, K.J., Warman, E.A. & Masters, G. (2007). Enhancing diversity of species-poor grasslands: an experimental assessment of multiple constraints*. Journal of Applied Ecology*, **44**, 81-94.

Roulston, T. & Goodell, K. (2011). The Role of Resources and Risks in Regulating Wild Bee Populations. *Annual Review of Entomology,* **56**, 293-312.

Saure, C. (1996). Urban habitats for bees: The example of the city of berlin. *The Conservation of Bees* (eds A. Matheson, S. Buchmann & C. O'Toole), pp. 47-53. Academic Press, London.

Scottish Government (2016). *Scottish Vacant and Derelict Land Survey 2016*. Scottish Government, Edinburgh.

Senapathi, D., Biesmeijer, J.C., Breeze, T.D., Kleijn, D., Potts, S.G. & Carvalheiro, L.G. (2015). *Pollinator conservation—the difference between managing for pollination services and preserving pollinator diversity*.

Scottish National Heritage (2015). *A Pollinator Strategy for Scotland 2016 – 2026: Consultation document*. SNH.

Steffan-Dewenter, I. & Tscharntke, T. (1999). Effects of habitat isolation on pollinator communities and seed set. *Oecologia,* **121**, 432-440.

Steffan-Dewenter, I., Münzenberg, U., Bürger, C., Thies, C. & Tscharntke, T. (2002). SCALE-DEPENDENT EFFECTS OF LANDSCAPE CONTEXT ON THREE POLLINATOR GUILDS. *Ecology,* **83**, 1421-1432.

Tschumi, M., Albrecht, M., Bärtschi, C., Collatz, J., Entling, M.H. & Jacot, K. (2016). *Perennial, species-rich wildflower strips enhance pest control and crop yield*.

UKBMS (2016). Species List, http://www.ukbms.org/Specieslist.aspx. Butterfly Conservation.

Vanbergen, A.J. & Initiative, t.I.P. (2013). Threats to an ecosystem service: pressures on pollinators. Frontiers in Ecology and the Environment, 11, 251-259.

Van der Sluijs, J.P., Simon-Delso, N., Goulson, D., Maxim, L., Bonmatin, J. & Belzunces, L.P. (2013). *Neonicotinoids, bee disorders and the sustainability of pollinator services*.

Vogel, G. (2017). Where have all the insects gone? *Science,* **356**, 576-579.

Whitehorn, R., O'Connor, S., Wackers, F. & Goulson, D. (2012). Neonicotinoid Pesticide Reduces Bumble Bee Colony Growth and Queen Production. *Science,* **336**, 351-352.

Willmer, P. (2012). *Ecology: Pollinator–Plant Synchrony Tested by Climate Change*. *Cell Biology*, **22**.

Woodcock, B.A., Bullock, J.M., Shore, R.F., Heard, M.S., Pereira, M.G., Redhead, J. *et al.* (2017). Country-specific effects of neonicotinoid pesticides on honey bees and wild bees. *Science,* **356**, 1393-1395.

Appendix 1

Four seed mixes were in October 2015, with different quantities. Seed mixes were chosen to include a diverse range of native wildflowers and grasses and sourced by Scotia Seeds. In October 2016, approximately 2,310 plug plants were sown in a 0.1 hectare extension. A further 0.2 hectare of grassland meadow was also created using the same original four seed mixes, but with different quantities.

Overview of 4 seed mixes used for Grangepans Meadow in October 2015.

10kg	Mavisbank Meadow seed mix
4kg	Cornfield annual seed mix
8kg	Get Nectar Rich Quick seed mix
3kg	Yellow rattle seed

Comprehensive list of seeds within each seed mix and percentage of overall weight by species.

Mavisbank Seed Mix

Species	**Common name**	**% by weight**
Wildflowers (20%)		

Achillea millefolium	Yarrow	1
Centaurea nigra	Common Knapweed	2
Cerastium fontanum	Common Mouse-ear	0.5
Galium verum	Lady’s Bedstraw	2.5
Lathyrus pratensis	Meadow Vetchling*	0.5
Leucanthemum vulgare	Ox-eye Daisy	2
Lotus corniculatus	Birdsfoot Trefoil	0.1
Plantago lanceolata	Ribwort Plantain	2.1
Primula veris	Cowslip	0.1
Prunella vulgaris	Selfheal	2.5
Ranunculus acris	Meadow Buttercup	2.5
Rhinanthus minor	Yellow Rattle	1
Rumex acetosa	Common Sorrel	2
Scorzoneroides autumnalis	Autumn Hawkbit	0.5
Succisa pratensis	Devils-bit Scabious	0.5
Vicia cracca	Tufted Vetch	0.2

Grasses (80%)		
Agrostis capillaris	Common Bent	8
Alopecurus pratensis	Meadow Foxtail	3
Anthoxanthum odoratum	Sweet Vernal Grass	2
Cynosurus cristatus	Crested Dog's Tail	12
Festuca rubra ssp. commutata	Chewings Fescue	35
Poa pratensis	Smooth-stalked Meadow Grass	20

Cornfield Annual Mix

Species	**Common Name**	**% by weight**
Centaurea cyanus	Cornflower	42
Glebionis segetum	Corn Marigold	16
Papaver dubium	Long-headed Poppy	4
Papaver rhoeas	Corn Poppy	28
Triploeurospermum inodorum	Mayweed	10

Get Nectar Quick Mix

Species	**Common name**	**% by weight**
Annuals		
Centaurea cyanus	Cornflower	12.6
Glebionis segetum	Corn Marigold	3
Papaver dubium	Long-headed Poppy	0.6
Papaver rhoeas	Corn Poppy	10.8
Tripleurospermum inodorum	Mayweed	3
Biennials		
Dipsacus fullonum	Teasel	1
Echium vulgare	Viper's Bugloss	8
Perennials		
Achillea millefolium	Yarrow	2
Centaurea nigra	Common Knapweed	10
Galium verum	Ladys Bedstraw	6
Geranium pratense	Meadow Cranesbill	2

Knautia arvensis	Field Scabious	2
Lathyrus pratensis	Meadow Vetchling	2.5
Leucanthemum vulgare	Ox-eye Daisy	5
Origanum vulgare	Wild Marjoram	0.5
Plantago lanceolata	Ribwort Plantain	4
Prunella vulgaris	Selfheal	6
Silene dioica	Red Campion	7
Silene flos-cuculi	Ragged Robin	2
Silene latifolia	White Campion	7
Stachys sylvatica	Hedge Woundwort	1
Vicia cracca	Tufted Vetch	1
Vicia sepium	Bush Vetch	1

Yellow Rattle Seed

Rhinanthus minor	Yellow Rattle	3 kg

List of plug plants that were sown in October 2016.

Scientific Name	Common Name	Spring 2016

Centaurea nigra	Common knapweed	300
Leucanthemum vulgare	Oxeye daisy	400
Knautia arvensis	Field scabious	200
Silene dioica	Red campion	50
Anthriscus sylvestris	Cow parsley	100
Digitalis purpurea	Foxglove	150
Lathyrus pratensis	Meadow vetchling	300
Lotus corniculatus	Common bird's foot trefoil	150
Lamium album	White dead nettle	66
Trifolium pratense	Red clover	200
Cardamine pratensis	Cuckoo flower	50
Daucus carota	Wild carrot	200
Galium verum	Ladies bedstraw	150

Selection of seed mixes and weight for October 2016 additional planting.

Yellow rattle	1.2kg
Mavisbank Meadow seed mix	5kg
Cornfield annual seed mix	1kg
Get Nectar Rich Quick seed mix	1kg

Appendix 2

Table displaying the different types of species found in each site over the sampling period, arranged in Order.

Common name	*Scientific name*	Grangepans meadow	Control 1	Ship Breakers	Control 2
Anthophila					
Early mining bee	*Andrena haemorrhoa*		•		
Tawny	*Andrena fulva*	•		•	
Gypsy cuckoo	*Bombus bohemicus*	•			
Field cuckoo	*Bombus campestris*	•			
Red tailed	*Bombus lapidarius*	•	•	•	•
White tailed	*Bombus lucorum*	•	•	•	
Common carder bee	*Bombus pascuorum*	•		•	•
Buff tailed	*Bombus terrestris*	•	•	•	•
Southern cuckoo bee	*Bombus vestalis*			•	
Red mason bee	*Osmia bicornis*	•			
Syrphidae					
Cheilosia bergenstammi	*Cheilosia bergenstammi*			•	
Marmalade fly	*Episyrphus balteatus*	•		•	•
Eristalis pertinax	*Eristalis pertinax*			•	
Eupeodes corollae	*Eupeodes corollae*	•			
Eupeodes luniger	*Eupeodes luniger*	•			
Helophilus pendulus	*Helophilus pendulus*	•			
Melanostoma scalare	*Melanostoma scalare*			•	
Meliscaeva auricollis	*Meliscaeva auricollis*	•			
Sericomijia silentis	*Sericomijia silentis*	•			

Syrphus ribersii	*Syrphus ribersii*			•	•
Volucella bombylans	*Volucella bombylans*				
Xylota segnis	*Xylota segnis*			•	
Lepidoptera					
Small tortoise shell	*Aglais urticae*	•			
Orange tip	*Anthocharis cardamines*	•		•	
Ringlet	*Aphantopus hyperantus*			•	
Large White	*Pieris brassicae*			•	
Green- veined white	*Pieris napi*			•	
Small White	*Pieris rapae*	•	•	•	
Common blue	*Polyommatus icarus*			•	
Apocrita					
Ichneumon stramentor	*Ichneumon stramentor*			•	
Common wasp	*Vespula vulgaris*			•	
Symphyta					
Tenthredo arcuata	*Tenthredo arcuata*	•		•	