Pollinator Activity and Floral Variation of Sable Island, Nova Scotia

By

Evan R. McNamara

A Thesis Submitted to
Saint Mary's University, Halifax, Nova Scotia
in Partial Fulfillment of the Requirements for
the Degree of B.Sc. Honours Environmental Science

March 2019, Halifax, Nova Scotia

Copyright Evan R. McNamara, 2019

Approved: Dr. Jeremy Lundholm
Supervisor
Department of Biology

Approved: Dr. Erin Cameron
Examiner
Department of Environmental Science

Approved: Dr. David Richardson
Examiner
Department of Environmental Science

Date: April 4th, 2019

Pollinator Activity and Floral Variation of Sable Island, Nova Scotia

By

Evan R. McNamara

A Thesis Submitted to
Saint Mary's University, Halifax, Nova Scotia
in Partial Fulfillment of the Requirements for
the Degree of B.Sc. Honours Environmental Science

April 2019, Halifax, Nova Scotia

Approved: Dr. Jeremy Lundholm
Supervisor
Department of Biology

Approved: Dr. Erin Cameron
Examiner
Department of Environmental Science

Approved: Dr. David Richardson
Examiner
Department of Environmental Science

Date: April 4th, 2019

Pollinator Activity and Floral Variation of Sable Island, Nova Scotia

By

Evan R. McNamara

ABSTRACT

Pollinators provide an important service to ecosystems worldwide. This includes Sable Island, located in the North Atlantic Ocean ~160 km offshore Nova Scotia. Two plant communities on Sable Island, heath and marram grassland, were compared to determine pollinator foraging activity within each community. For sampling, large 100×200 m sites were set up with several smaller 5×5 m sampling plots within. Pollinator visits to flowers in a 30-minute time period were recorded, along with floral resources, so a comparison between communities could be made in both July and August. In marram, 39 and 19 unique pollinator taxa visited flowers in July and August, respectively, and in heath, 22 and 29 unique pollinator taxa visited flowers in July and August, respectively, with seven pollinator taxa found in both plant communities. Statistical analysis showed no significant differences in average number of pollinator visits and pollinator diversity between the two communities in July, though in August heath had significantly more pollinator visits and diversity. Many pollinators found during the study included non-bee pollinators, making up 46% of visits in the heath and 79% of visits in the marram. Based on these results, I concluded that the non-bee pollinators are more important to Sable Island than once thought, and both plant communities contain diverse assemblages of pollinators.

March 20th, 2019

ACKNOWLEDGMENTS

There is a lot of work that goes into a thesis, and with that work, there are a lot of people to be thankful for. First, I would like to thank my supervisor, Dr. Jeremy Lundholm, and his Ecology in Plants and Communities (EPIC) lab. I am forever grateful for your trust and belief in my potential in taking me on as an Honours student. Your guidance and patience helped me to overcome the at-times seemingly insurmountable task of completing this thesis. You, and the fellow members of the lab, were always willing to enthusiastically help, and I thank you for it.

Next, I would like to thank the Sable Island Parks Canada team. With their help, I had the opportunity of a lifetime to perform fieldwork on Sable Island, made better by the individuals I shared the experience with. Special thanks to Dan Kehler and Sara Solaimani-Baghainia for assisting in setting up the sampling plots, and Sarah Medill for her support and ensuring my well-being every morning before fieldwork.

While on the island, Zoe Lucas and Dr. Andy Horn of the Sable Island Institute graciously helped to search for and establish sampling sites, with Zoe also providing some of her vast knowledge of Sable Island. As well, I would like to thank the research group from the University of Saskatchewan, who provided a great deal of moral support, with Ruth Greuel assisting me in cleaning up my sites once sampling was finished.

Finally, I would like to thank my friends, family, and fellow Honours students for their support and interest in my project over the last year. Special thanks to my partner, Mallory, who motivated me and pushed me to do my best, even when I thought I could not.

To everyone who has helped me get this far: thank you.

1. INTRODUCTION

1.1 Importance of Insect Pollinators

Pollination of plants by animals is an ecosystem service crucial to both natural ecosystems and human crop production worldwide (Ollerton et al., 2011; Potts et al., 2010; Klein et al., 2007). It is estimated that approximately 85% of flowering plants globally are animal-pollinated, with almost 35% of the crops accounting for the global food supply relying on animal pollination (Ollerton et al., 2011; Klein et al., 2007). Insects form the largest group of pollinators and are the primary pollinators for the majority of animal-pollinated plants (Potts et al., 2010). The economic valuation of pollination services provided by insects to agriculture globally was estimated to be €153 billion per year in 2005, or about 9.5% of human food production value (Gallai et al., 2009). Conservation of pollination services is thus crucial to the persistence of angiosperm communities and humans globally (Kearns et al., 1998).

Despite their importance to both humans and natural ecosystems, pollinator populations are on the decline globally (Potts et al., 2010). Several factors are believed to contribute to this decline including habitat loss and fragmentation, introductions of non-native organisms, climate change, intensification of agriculture, pesticide use, and disease (Vanbergen et al., 2013; Potts et al. 2010). Pollinator extinctions could lead to extinctions of plant species dependant on this service critical to their survival. In the context of the ongoing biodiversity crisis, this could lead to the coextinction of pollinator and plant species in ecosystems worldwide (Koh et al., 2004). Plant species will need a rapid evolutionary response of new reproductive strategies less reliant on pollination services in order to cope with declines of pollinator diversity (Thomann et al., 2013).

The diversity of insect pollinators is large, spanning across several taxonomic groups. Bees, belonging to the superfamily Apoidea within the order Hymenoptera, are the insects most important and specialized for pollination, being most responsible for the pollination of globally important crops (Klein et al., 2007; Kevan and Baker, 1983). Orders Coleoptera, Diptera, Lepidoptera, and non-bee Hymenoptera also contain large numbers of pollinators, with other insect orders containing minor amounts (Kevan and Baker, 1983). Non-bee pollinators are not as efficient as flower pollinators compared to their bee counterparts, depositing less pollen on flowers per visit, however this is compensated by their high visitation frequency (Rader et al., 2015). With only 38% of flower visits found by Rader et al. (2015) to come from non-bee pollinators, bees are crucial in maintaining interactions between plants and pollinators. Fragility of interactions between flowers and bees make their conservation important to the maintenance of ecosystems worldwide (Carman and Jenkins, 2016; Klein et al., 2007).

1.2 Pollinator-Plant Interactions

There is known to be a significant positive correlation between pollinator diversity and plant diversity (Fründ et al., 2010). Reproductive success of plants is often increased in the presence of diversity amongst pollinators (Albrecht et al., 2012). In 2005, a link was discovered by Fontaine et al. between losses in pollinator diversity and plant community persistence, with such pollinator declines possibly leading to plant losses or even extinctions. This illustrated that interactions between plants and pollinators are critical for many ecosystems, with pollinator diversity maintenance critical to ecosystem function (Fontaine et al., 2005). Pollination plays a role in shaping the structure of plant communities

by both filtering or facilitating the inclusion of new plant species and acting as a driver of competition between plants for their services. (Sargent and Ackerly, 2008).

Plant diversity, alongside pollinators, can strongly influence interaction networks, as is seen in the Arctic (Robinson et al., 2018). Plant specialization for individual pollinator species may occur, typically in the presence of diverse groups of pollinators. This is due to the need of co-flowering species to adapt new strategies to optimize pollination success in these diverse communities to reduce the negative effects of competition for pollinators (Fantinato et al., 2017). This specialization can often provide an explanation for flowering plant diversity within ecosystems (Fenster et al., 2004). Complementary specialization of both plant and pollinator species is common at the community level (Blüthgen and Klein, 2011).

Many different pollinators have been found pollinating different plant species (Blüthgen and Klein, 2011). Landscape diversity allows for the partitioning of both generalist and specialist pollinator niches (Mallinger et al., 2016). Specialization has been noted amongst both pollinator and plant species in many ecosystems worldwide (Mallinger et al., 2016; Blüthgen and Klein, 2011; Fründ et al., 2010; Fontaine et al., 2005). Specialization of pollinators for particular plant species, called oligolecty (Armbruster, 2017), is often the driver of increased diversity of pollinators found in highly diverse landscapes and communities (Fründ et al., 2010). This foraging strategy is often practiced by solitary bees (Armbruster, 2017).

1.3 The Sable Island Ecosystem

Sable Island is a small, smile-shaped island located in the North Atlantic Ocean over 160 km offshore the nearest point of land on the North American landmass, Canso Head in Nova Scotia. It is long and narrow, though the length is ever-changing in this dynamic system (Parks Canada Agency, 2016; Stalter and Lamont, 2006); it is currently approximately 40 km long from west to east, with its maximum width being 1.4 km from North to South beach (Stalter and Lamont, 2006). Sable Island is composed entirely of unconsolidated sand (Stalter and Lamont, 2006) and is among the largest dune systems found in eastern North America (Parks Canada Agency, 2016). The interior of the island contains rolling dunes and several freshwater ponds, which are critical in sustaining terrestrial life (Parks Canada Agency, 2016; Stalter and Lamont, 2006). Over 230 species of vascular plants, 330 species of birds (though most are migrants or vagrants), and 573 terrestrial invertebrates have been recorded on Sable Island (Freedman et al., 2014a). The island is also home to the world's largest breeding colony of grey seals, and a herd of wild horses (Parks Canada Agency, 2016). Approximately one-third of the island is vegetated (Parks Canada Agency, 2016), with a 1996 survey estimating vegetative cover on the island to be 1548 hectares. Of this area, 1208 ha was grassland, 316 ha was heath, and 1 ha was sandwort vegetation according to Freedman (2001).

Studies and identification of the vegetation found on Sable Island date back to the early 20th century (Stalter and Lamont, 2006). Accounts and catalogues of previous plant species records were compiled by St. John (1921), including 11 plant taxa that had not previously been found on the island. Several distinct varieties of plant species were also identified by St. John (1921). Erskine (1953) disputed some of the distinct varieties

described by St. John, instead choosing to revert them to their previously designated species. Records from the most recent studies consist of 183 plant species (Freedman et al., 2014a). Despite numerous species introductions, the number of vascular plant species has remained relatively stable, including the number of native species (Stalter and Lamont, 2006). Of the 230 total species that have records from Sable Island, 34% are non-native (Freedman et al., 2014a). Knowledge of the plants found on Sable Island allows for their grouping into communities and probable successional pathways to be identified.

Catling et al. (1984) identified seven terrestrial vegetation communities on Sable Island. These communities were sandwort, marram-forb, marram, marram-fescue, shrub heath, cranberry heath, and pond-edge herbaceous. Tissier et al. (2013) would use these communities to identify successional pathways and divide the vegetation into three much broader groups. Group 1 by Tissier et al. (2013) had no indicator species and is believed to represent an early successional community, such as marram grassland or sandwort communities. Groups 2 and 3 contained 3 and 10 indicator species, respectively, which were all herbaceous in Group 2, with Group 3 including heath species and woody shrubs (Tissier et al., 2013). The indicator species for Group 2 include many species commonly found together in the marram-forb grasslands identified by Catling et al. (1984). Group 3 is thought to be a late successional community based on its location in more stable, sheltered parts of the island, with Group 2 being a transitional stage, as it contains many species from both Groups 1 and 3 (Tissier et al., 2013). Due to the dynamic nature of the Sable Island ecosystem, community composition is ever-changing, and succession is frequently reverted to early stages (Catling et al., 1984). The constant erosion and

deposition of sand results in much shorter-lived plant communities than typically found on the mainland due to these disturbances (Freedman et al., 2014b)

Another notable disturbance comes from the island's resident horses, the activity of which can alter plant community composition (Welsh, 1975). Horse-related disturbance has likely contributed to past extirpations of plant species on the island and could lead to many more in the future (Mazerolle, 2015). Though pond edges are notably impacted via the creation of 'horse lawns' due to trampling and overgrazing, horse disturbance has the greatest impact on marram grasslands (Freedman et al., 2012). This is due to the prevalence of marram grass, also known as American beach grass (*Ammophila breviligulata*), the primary forage species of the Sable Island horse (Welsh, 1975). Dominant heath species were found to be unaffected by the impacts associated with horses (Freedman et al., 2012). However, despite the damage that the horses may cause, grazing may stimulate growth and increase annual production, overall providing a benefit for the island's vegetation (Welsh, 1975). The positive benefits of pollinator activity may provide a counterbalance to any negative impacts of herbivory on plants as well (Sauve et al., 2016).

1.4 Pollinators of Sable Island

The pollinator community of Sable Island is small--there are five bee species presently known to occur (Lucas, 2017), with little research on the other pollinator taxa of the island. Non-bee pollinators are known to still be important for plant communities (Rader et al., 2015), and given the diversity of insects that have been caught in Malaise traps on the island by the Biodiversity Institute of Ontario (2015), non-bee pollinators may

be important to the Sable Island ecosystem. But due to the important roles bees have as pollinators, the pollinations services provided by the five bee species are likely crucial in maintaining the restricted plant communities of Sable Island (Gibbs, 2014).

The five bee species of Sable Island are *Colletes simulans armatus*, *Lasioglossum novascotiae*, *Lasioglossum sablense*, *Megachile melanophaea*, and *Osmia simillima* (Lucas, 2017). All five species are known or presumed to be solitary bees (Sheffield et al., 2003). Despite solitary bees commonly exhibiting oligolectic foraging behavior (Armbruster, 2017), it appears that none of the bees with floral records from Sable Island practice this behavior based on the diverse floral visitation records among these species (Lucas, 2018; Lucas, 2017; Gibbs, 2014).

C. simulans armatus forages late in the flowering season on Sable, during September and October, with floral visitation observations primarily from seaside goldenrod (*Solidago sempervirens*) and New York aster (*Symphyotrichum novi-belgii*). It has been observed on five species aside from these two. *M. melanophaea* is the island's most widely distributed bee, with foraging records from 21 plant species. *L. novascotiae* is the most common sweat bee on Sable Island, occurring in a 3:1 ratio versus the less common *L. sablense* (Lucas, 2017). Floral visitation records for *L. novascotiae* on Sable Island come from 20 species (Lucas, 2018). *L. sablense*, also known as the Sable Island sweat bee, is a recently-discovered species endemic to Sable Island (Gibbs, 2014). Foraging has been observed on 15 flowering species (Lucas, 2018). Only *O. simillima* lacks floral visitation records from Sable Island.

With flower-bee interactions known to be sensitive to disturbance (Carman and Jenkins, 2016), understanding the threats faced by pollinators on Sable Island is important

to allow for their conservation (Lucas, 2017). This is especially important for *L. sablense*, which is listed as 'Threatened' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Gibbs, 2014). *L. sablense* is believed to be in decline due to a loss of vegetated areas of the island (Gibbs, 2014), this loss of vegetated area could also put the other bee species at risk. Horse-related activity could be putting pressures on the pollination network of the island, as there has been a negative link found between herbivory and pollinator behaviour (Barbosa, 2016; Gibbs, 2014). A lack of optimal foraging conditions is also a concern, as Sable Island often does not present the optimal windspeeds (<16 km/h) for foraging bees (Environment Canada, 2010; Teull and Isaacs, 2010; Stalter and Lamont, 2006). However, based on the definition of adverse conditions identified in the methods of Walker and Lundholm (2017) for bee foraging (minimum daily temperature below 15 ˚C, winds exceeding 30 km/h, and precipitation exceeding 1.0 mm) on coastal barrens, which Sable Island can be considered (J. Lundholm, pers. comm.), finds more conditions on the island adequate for bee foraging (Environment Canada, 2010; Stalter and Lamont, 2006). A better understanding of the life history and behaviors of the bees is also needed to address the impacts and interactions between these threats and the Sable Island pollinator community (Lucas, 2017).

1.5 Objectives

Identification of foraging habitat for the bees and other pollinator species of Sable Island is important for conservation efforts. It is known that smaller bee species, such as the two *Lasioglossum* species found on Sable Island, do not often stray far from their nesting habitat to forage (Greenleaf et al., 2007). A better understanding of pollinator foraging behavior

can thus give us a greater understanding of their life history beyond foraging behavior, allowing for accurate conservation efforts for species such as the at-risk *L. sablense* (Lucas, 2018; Gibbs, 2014). As the island is now under the jurisdiction of Parks Canada as Sable Island National Park Reserve, Parks Canada's mandate to protect natural areas now applies to Sable Island (Canada National Parks Act, 2017). This knowledge will better empower them to act to protect the Sable Island pollinator community.

The primary objective of this study is to determine the floral resource use by the pollinator community on Sable Island. Comparisons were drawn between two plant communities on the island, marram grassland and heath, to determine flowering species usage by pollinators in the two communities. Based on the abundance of flowering species in heath (Tissier et al., 2013; Catling et al., 1984), I believed that it would prove better foraging habitat for pollinator species than the marram grasslands, seen as greater diversity and total numbers of pollinators.

2. METHODS

2.1 Sampling Location

Sable Island lies at the junction of the southward-flowing, cold-water Labrador current and the northeastward-flowing, warm-water Gulf Stream. This interaction between ocean currents contributes to the island's temperate oceanic climate (Stalter and Lamont, 2006). Temperatures on the island are mild compared to mainland Nova Scotia. Winter temperatures typically fall between -5˚C and 5˚C, and summer temperatures reach their peak in August, at a daily average of 17.8˚C (Environment Canada, 2010; Stalter and

Lamont, 2006). Precipitation is spread relatively evenly throughout the year, with July being the driest month, and December and January the wettest months, on average. Only a small portion of precipitation (~9%) is snow. Sable Island has the least sunshine and most fog of anywhere in Nova Scotia, averaging 127 fog days per year. July is the foggiest month, with 22 fog days on average (Environment Canada, 2010). Winds are typically southwesterly and an average of 20 knots in the winter and 10 knots in the summer (Environment Canada, 2010; Stalter et al., 2006).

Sampling sites were selected prior to going into the field by locating suitable sites based on the 2014 Sable Island topography and land cover atlas (Applied Geomatics Research Group, 2015). Optimal sites contained a rectangular area of 100 m × 200 m of homogenous vegetation, with the 200 m side running East-West to minimize the environmental gradients due to distance from the North and South beaches (Tissier et al., 2013). Field surveys of preliminary sites were done, and from this, three sites were established in each of the marram grassland and heath. The selected locations can be seen in Figure 1. Sides of the plot were determined in the field using compass bearings to create the rectangle, with markers being put at each corner and at the halfway point of the 200 m side to divide the site into two 100 m × 100 m halves. GPS waypoints were taken at the site of each marker.

Following site setup, a pattern of subplots was created within each half of the larger plots that would be kept uniform across all plots, ensuring no bias in sampling locations within a plot (Figure 2). Using R statistical software, this pattern was turned into GPS coordinates, with lines of code dedicated to making the proper axis rotation away from north for each individual plot. Once the GPS coordinates of the subplots were determined,

field setup consisted of establishing 5 × 5 m subplots, using the GPS waypoint for each subplot as the southwest corner for each, with the exception to this being site M4, which used the GPS waypoint as the northwest corner due to an error during set-up. Measurement was done by three people using a 30 m measuring tape arranged into a right triangle, with the hypotenuse determined based off the two 5 m side adjacent to the right angle. After initial measurement and marking of plot corners, 'bop it' was declared, indicating that the triangle was to be flipped, with the hypotenuse staying in position, to mark the final corner. This was repeated to make 5 pollinator sampling subplots and 10 vegetation sampling subplots for each half of the larger plots, for a sampling total of 60 pollinator sampling subplots and 120 vegetation sampling subplots.

Figure 1. Locations of sampling sites on Sable Island. Imagery from Google Earth.

Figure 2. Arrangement of sampling plots within each site. Plots sampled for pollinators are represented with a 'P,' those sampled for vegetation with a 'V.' Image of site 'No2West.' Imagery from Google Earth.

2.2 Data Collection - Pollinator Sampling

Pollinator sampling took place across 6 days in each of July and August, with each site being sampled once each month. Upon arrival at the site in the morning, sampling took place starting at the 'P1' subplot in one of the halves of the site. Before sampling each subplot, notes were made of the temperature, windspeed, weather conditions, subplot half and number, and time sampling began. This was done to determine if conditions were appropriate for pollinator visitation, so data on these variables would not be analyzed as part of this project. A floral resource inventory was also conducted within the plot and in a

small, approximately 2.5 m buffer around the plot, counting total number of flowering stems of all species observed. Flowers that are not insect pollinated, such as wind-pollinated grasses, were excluded from these counts.

Sampling took 30 minutes for each subplot. This amount of time was chosen as all plots at a site needed to be done in a single day due to personnel and time constraints. Thus, a 30 minute sampling period provided a compromise between the time needed to get a more accurate sample and the number of samples. In these 30 minutes, all insects which were observed on a flower were noted, with further identification done using targeted sweep-netting to capture the insect, followed by observation within a vial to identify the pollinator. Notes about each pollinator were made, especially in the case of unsuccessful captures or releases. Pollinators which visited a plot more than once during sampling were noted. Movement within a plot was minimized to avoid trampling vegetation and flowers.

Different identification techniques were used for bees than with other pollinators, due to the need to prevent harm to *L. sablense* as well as the relative ease of identifying bee species in the field on Sable Island due to only five being present on the island (Lucas, 2017). Bees were observed in a non-lethal identification chamber, which consisted of a glass or transparent plastic vial and foam, the foam being used to impede movement while observing the bee. Following species identification, the bee would be released. For other pollinators, such as flies or moths, capture simply took place within a transparent vial. For pollinators that had yet to be observed during sampling, they were kept in these vials and given a unique number for further identification in a lab. Once back from sampling, all non-bee pollinators which had been captured were humanely euthanized via freezing. Insects

were then pinned upon arrival back to the mainland and further identified using an identification key while observing specimens under a dissecting microscope.

These insects were identified to Family, if possible, using a variety of keys. Hoverflies (Family Syrphidae) were identified to genus using a separate key. Once family was assigned, a Sable Island species list was used to attempt to classify the insects further, if any resembled only a single species closely. Morphospecies were assigned to morphologically similar individuals in which an identification to species could not be made, as well as to individuals that had been observed in the field but had not been captured.

2.3 Statistical Analysis

Statistical analysis was performed using R statistical software within the RStudio Integrated Development Environment (R Core Team, 2018; RStudio, 2018). P-values less than 0.05 were considered statistically significant results. The statistical analysis consisted of two parts: regression to look for correlations between variables, and an analysis of variance between community types. The analysis of variance for each variable measured was done for both July and August, as well as a repeated measures analysis that was done without the date as part of the sample identifier. Variables analyzed were pollinator visits, pollinator diversity, number of flowering stems, and floral diversity.

For regression, correlations were analyzed between pollinator visits and number of flowering stems, pollinator visits and floral diversity, pollinator diversity and floral diversity, and pollinator diversity and number of flowering stems in both July and August. Linear models (lm) were applied to the data. The variables were transformed as needed

using a logarithm in order to obtain more normal distributions of residuals. When a logarithm was applied to a variable, +1 also needed to be added onto the variable within the function to avoid errors if a 0 in the data was encountered. A summary of the model was then used to determine the direction of the correlation (positive/negative), significance by looking at the P-value, and the fit of the data to the regression line (R^2) given from the adjusted R-squared value.

Analysis of variance was done for each individual variable to compare their differences across plant community, and in the case of the repeated measures analysis, between sampling times. This was done by running a glmer followed by a lrtest similar to the regression, but with only the one variable instead of two. Site and half were used as random effects, though sometimes a new variable needed to be used which combined the two into a single variable. Different methods were used following the determination of the best model for the data for the single and repeated measures analysis. For the single measure analysis, least-squares means with Tukey Honest Significant Difference (HSD) pairwise post-hoc tests were conducted. For the repeated measures analysis, the best-fit model was compared with a null model, one only looking at differences in community, one looking only at differences based on date, and then an additive model of community and date. These models were all glmer with the same family of distributions as the best-fit model. The best-fit model was determined using a lrtest in the same way as before, and in all cases, it was the original best-fit, multiplicative, model. Following this, least-squares means were calculated and pairwise post-hoc comparisons carried out. Boxplots were then made for both single and repeated measures analyses based on the best-fit models.

3. RESULTS

3.1 Count Data

Total counts of pollinators during the sampling period revealed that more visits were observed in the marram grassland community for the month of July, while more visits were observed in the heath community in August (Figure 3). Table 1 breaks down these counts by the three sites for each community. For July, M3, a marram grassland site, showed the lowest number of pollinator visits to flowers observed, however the other two marram sites were higher than two of the three heath sites. The highest counts were recorded in marram site M4, and were higher than the highest heath site, which was No2West. In August, all the heath sites recorded higher numbers of pollinator visits than even the highest of the marram sites (Table 1). Heath had the highest number of pollinators over the entire summer (Figure 3: Figure 7).
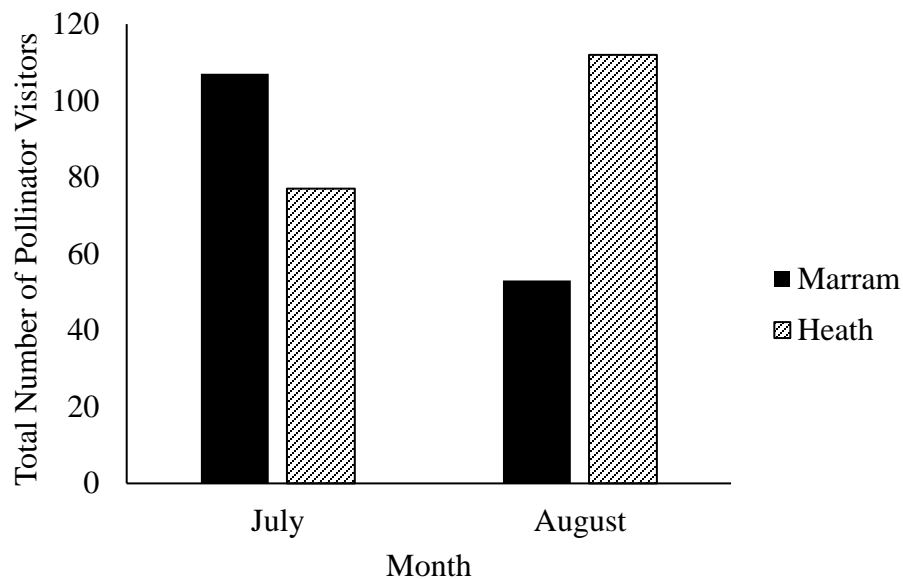
Figure 3. Pollinator visits observed within two plant communities on Sable Island for the months of July and August. Bars represent a total count of all visits recorded within all the sites for the given community.

Table 1. Pollinator visits observed within each site in the two plant communities studied on Sable Island.

| | Total Number of Pollinator Visits | | | | | |
| | Marram | | | Heath | | |
	M2	M3	M4	H2	Hfield	No2West
July	32	11	64	23	18	36
August	20	11	22	26	40	46

Total counts of flowering stems in sampled areas of each habitat can be seen in Table 2 and Figure 4. Heath had nearly double the number of flowers compared to marram in July, whereas marram grasslands had more flowers in August, though the difference between the two communities was smaller. Both communities experienced a decline in flowers from July to August. The diversity of flowering species increased between the two

months despite this decline in total number of flowers (Figure 4; Figure 6). Marram site No2West showed the highest numbers of flowering stems in July, and marram site M4 showed the highest numbers of flowering stems in August (Table 2).
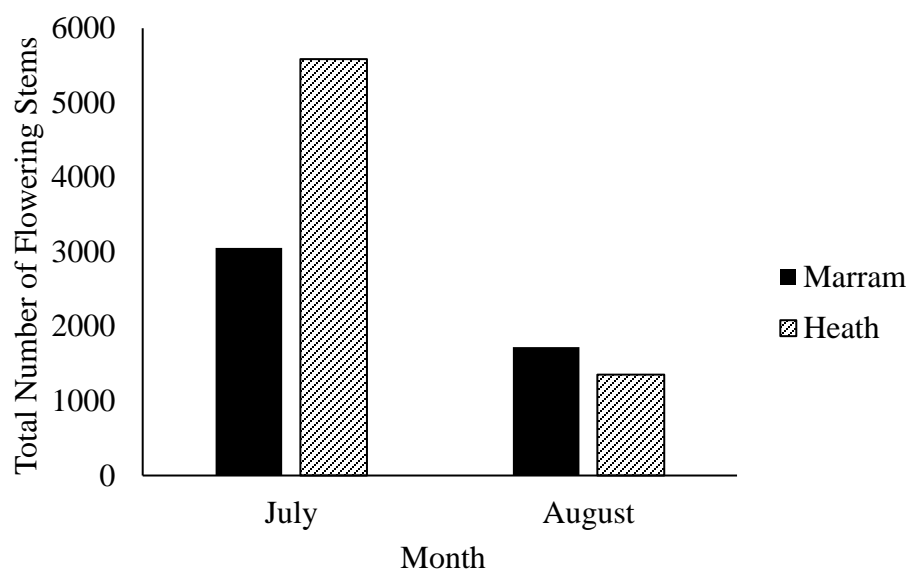

Figure 4. Total numbers of flowering stems observed during floral resource surveys in sample plots for marram and heath plant communities for the months of July and August.

Table 2. Total numbers of flowering stems observed during floral resource surveys conducted in sample plots for each site in July and August.

	Total Number of Flowering Stems					
	Marram			Heath		
	M2	M3	M4	H2	Hfield	No2West
July	878	745	1428	1940	1057	2588
August	126	495	1101	213	406	733

Total diversity counts reveal more visiting pollinator species in the marram grassland in July, and more visiting species in the heath in August (Figure 5). The site with

the most diversity was the marram site M2 in July, and the site with the least diversity was the same site but in August (Table 3). All marram sites showed a trend of decreasing pollinator diversity and abundance throughout the sampling period, whereas all heath sites increased in both pollinator diversity and abundance throughout the sampling period (Table 1; Table 3).
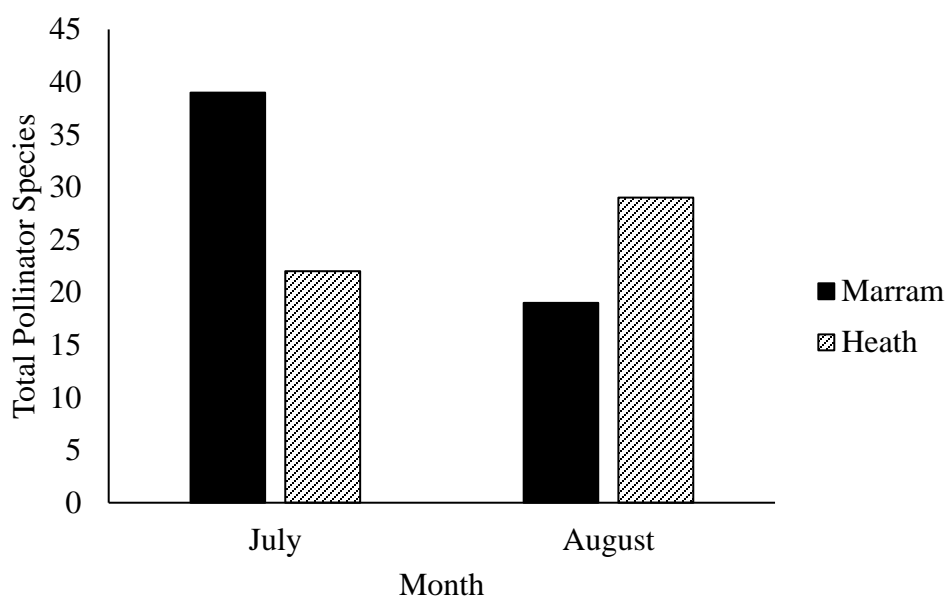

Figure 5. Total pollinator taxa found in the two plant communities sampled on Sable Island for the months of July and August. Bars represent the total diversity found within all the sites in a community. Identical species found in more than one site in a community were counted as one towards the community total.

Table 3. Total number of unique pollinator taxa found for each sampled site on Sable Island in July and August.

| | Pollinator Diversity | | | | | |
| | Marram | | | Heath | | |
	M2	M3	M4	H2	Hfield	No2West
July	17	9	16	10	6	13
August	5	6	12	13	9	12

Plant species diversity among communities increased in both communities as summer went on (Figure 6). Heath had more diverse floral records than marram in both months. Despite plant diversity increasing in August in the marram grassland community, the number of species found in each of the marram sites remained stable throughout the summer (Table 4). All of the heath sites experienced an increase in flowering species from July to August (Table 4).
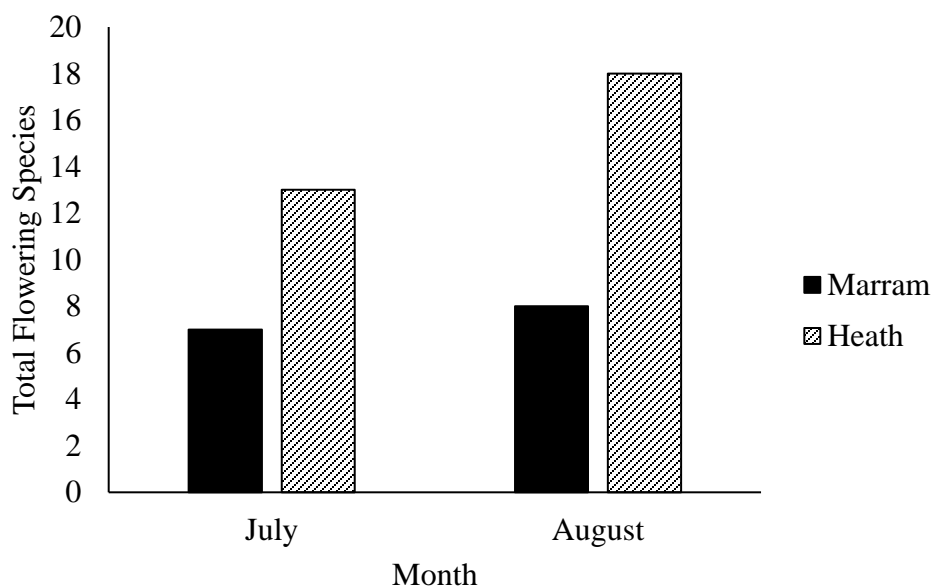

Figure 6. Total species diversity of plant species flowering during July and August on Sable Island. Bars represent the total species diversity within each community. Species which were found in multiple sites within a community are counted as one.

Table 4. Total numbers of plant species found at each site on Sable Island for the months of July and August.

	Flowering Plant Diversity					
	Marram			Heath		
	M2	M3	M4	H2	Hfield	No2West
July	3	3	6	6	8	11
August	3	3	6	7	10	13

A breakdown of the flowering stem abundances among plant species found in each community can be found in Tables 5 and 6. In the marram grassland (Table 5), we can see that beach pea (*Lathyrus japonicus* var. *maritimus*) is the most abundant flowering species in July, whereas in August its flower numbers decline and are overtaken in abundance by common yarrow (*Achillea millefolium* var. *occidentalis*). In the heath (Table 6), we can see large numbers of grove sandwort (*Moehringia lateriflora*), little yellow rattle (*Rhinanthis minor*), and white clover (*Trifolium repens*) flowers in July. In August, while the flowers of these species are still abundant, the distribution of flowers amongst species is more even, with no species having more than 282 flowers. August also shows more variety in flowering species in the heath (Table 6).

Table 5. Abundance of the flowering species found in the marram grassland community on Sable Island in July and August.

Flowering Stems in Marram Grassland			
Scientific name	Common name	July	August
Achillea millefolium var. *occidentalis*	Common Yarrow	212	1421
Brassica kaber	Wild mustard	26	35
Cakila edentula	American Sea Rocket	89	11
Calystegia sepium	Hedge bindweed	1	13
Lathyrus japonicus var. *maritimus*	Beach pea	2711	202
Ligusticum scoticum	Scots lovage	6	0
Moehringia lateriflora	Grove Sandwort	6	2
Rumex crispus	Curled dock	0	37
Solidago sempervirens	Seaside Goldenrod	0	1

Table 6. Abundance of the flowering species found in the heath community on Sable Island in July and August.

Flowering Stems in Heath			
Scientific name	Common name	July	August
Achillea millefolium var. *occidentalis*	Common Yarrow	19	98
Anaphalis margaritacea	Pearly Everlasting	0	1
Centaurium erythraea	Common centaury	195	92
Cerastium fontanum ssp. *vulgare*	Common mouse-eared chickweed	617	145
Fragaria virginiana ssp. *glauca*	Wild Strawberry	1	0
Leontodon autumnalis	Fall Dandelion	140	182
Moehringia lateriflora	Grove Sandwort	1617	209
Oenothera parviflora	Small-flowered Evening Primrose	0	6
Photinia floribunda	Purple Chokeberry	0	2
Rhinanthis minor	Little Yellow Rattle	1340	48
Rosa virginiana	Wild Rose	228	282
Rubus arcuans	Wand Dewberry	109	22
Sisyrinchium angustifolium	Blue-eyed grass	341	14
Spiranthes romanzoffiana	Hooded Ladies'-tresses	0	8
Stellaria graminea	Grass-leaved Starwort	0	4
Symphyotrichum novi-belgii	New York Aster	0	1
Thalictrum pubescens	Tall Meadow Rue	9	6
Trientalis borealis	Northern Starflower	87	0
Trifolium repens	White Clover	882	187
Vaccinium angustifolium	Large Cranberry	0	45

3.2 Pollinator Taxa

A breakdown of the pollinator taxa found across all sites, as well as for each individual community, can be found in Figure 7 below. It should be noted that only seven pollinator species were found in both heath and marram. From this data, flies (Order Diptera) are the most numerous pollinators on Sable Island, accounting for 61% of total visits by pollinators to flowers in sample plots. Flies accounted for most visits in the marram community, with 79% of visits attributed to the order. However, in the heath, they only accounted for 46% of visits. While this is still almost half of the pollinator visits for the community, the

majority (53%) of pollinator visits in heath were by Hymenopterans, which includes the ants, bees, and wasps. Hymenopterans accounted for 19% of pollinator visits in marram, and 37% of total visits, making them the second largest group of pollinators on Sable Island.
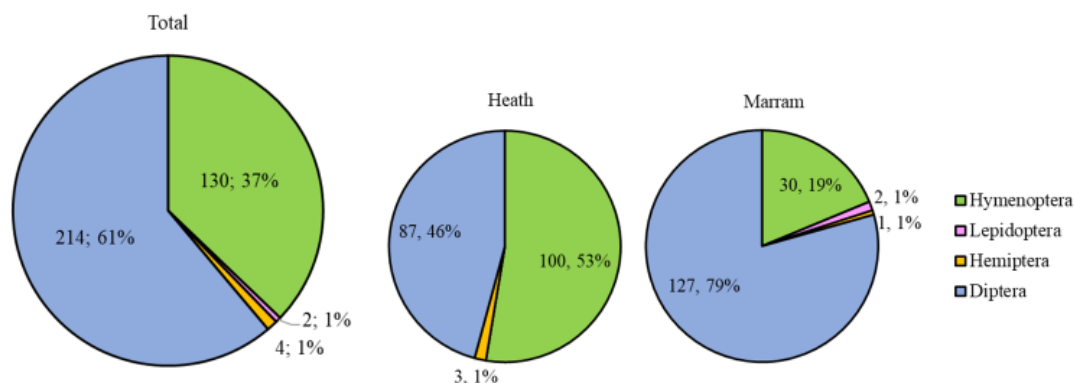

Figure 7. Proportions of pollinator visitors from each of the orders that are listed on the right. The orders listed were the only pollinator orders observed during pollinator sampling on Sable Island. Left: Total proportions for both communities combined. Center: Proportions found in heath sites. Right: Proportions found in marram sites.

Table 7 provides a deeper look into the important Hymenopteran pollinators present on Sable Island. This allows us to analyze the visits by the island's native bee species, alongside the other members of the Order. Only three of the five bee species present on the island were found during sampling--*Lasioglossum novascotiae*, *Lasioglossum sablense*, and *Megachile melanophaea*. None of the *Lasioglossum* bees observed were found in marram sites--all were found in the heath. *M. melanophaea* was the most frequently observed bee species in this study and was distributed in relatively even numbers between the marram grassland and heath communities.

Ants (Family Formicidae) accounted for the most Hymenopteran observations during the sampling period (Table 7). They were more abundant than even all the bee

species combined. All observations of ants visiting flowers came from heath. Wasps were also identified; however, it should be noted that all 12 observations for Ichenumonidae Morphospecies A came from one marram sampling plot (4MP). It did not reappear anywhere else or at any other time during sampling. Apart from this, wasps only accounted for two other observations during the sampling period, with both being in heath.

Table 7. Observations of insects within Order Hymenoptera from sampling on Sable Island.

Family	Abundance		
	Heath	Marram	Total
Halictidae	**13**	**0**	**13**
Lasioglossum novascotiae	7	0	7
Lasioglossum sablense	4	0	4
Unidentified *Lasioglossum* spp.	2	0	2
Megachilidae	**22**	**18**	**40**
Megachile melanophaea	22	18	40
Formicidae	**63**	**0**	**63**
Ichneumonidae	**1**	**12**	**13**
Morphospecies A	0	12	12
Morphospecies B	1	0	1
Unidentified Wasp Family	**1**	**0**	**1**

3.3 Statistical Results

No statistically significant differences in average pollinator visits between the two plant communities were noted for the month of July. In August, a significant difference was noted (P=0.0149), with heath having significantly more pollinator visits on average than marram (Figure 8). Conducting an analysis with all times taken into consideration revealed near-significant differences (P=0.0522) between marram and heath in August (Figure 9). This result cannot be considered statistically significant, but it should still be noted due to the small margin its P-value bears between significant and non-significant.
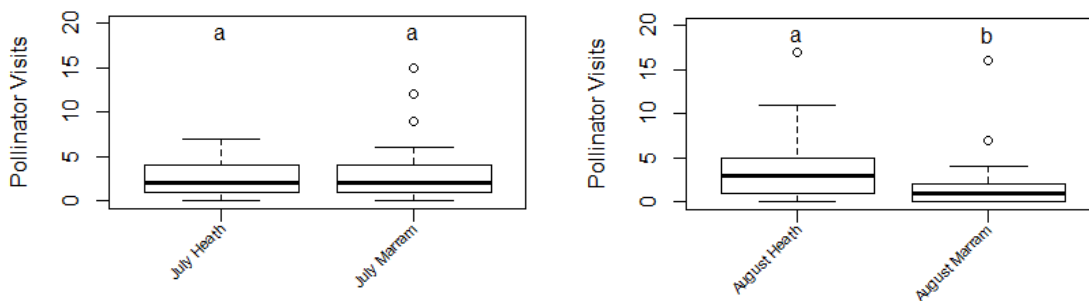
Figure 8. Boxplots showing average number of pollinator visits to each sampling plot within each community. Left: Pollinator visits in July. Right: Pollinator visits in August. Groups that share letters are not significantly different at α=0.05.
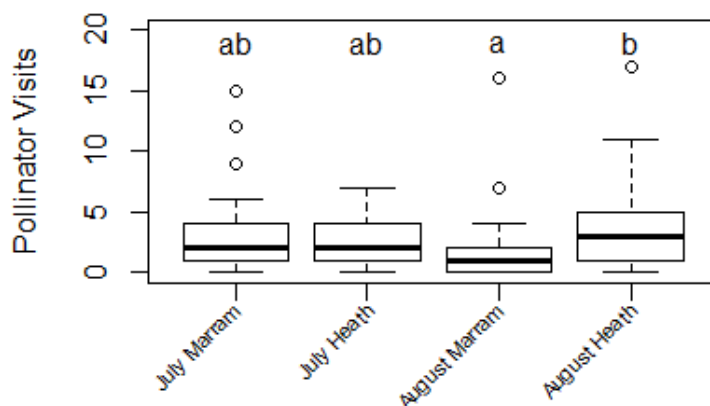

Figure 9. Boxplot comparing average numbers of pollinator visits to each sampling plot within each community. Comparisons are made within as well as between the months sampled. Groups that share letters are not significantly different at α=0.05.

No significant differences in pollinator diversity between communities were noted in July. In August, there was a statistically significant difference (P=0.0088) between marram and heath in pollinator diversity. Heath plots contained more diversity amongst

pollinator species on average than marram plots in August (Figure 10). When comparing between communities across all times sampled (Figure 11), significant differences were obtained between heath and marram in August once more (P=0.0145), as well as within the marram community from July to August (P=0.0296). As can be seen in Figure 11, in August, the marram community had fewer pollinator species on average than the same community in July.
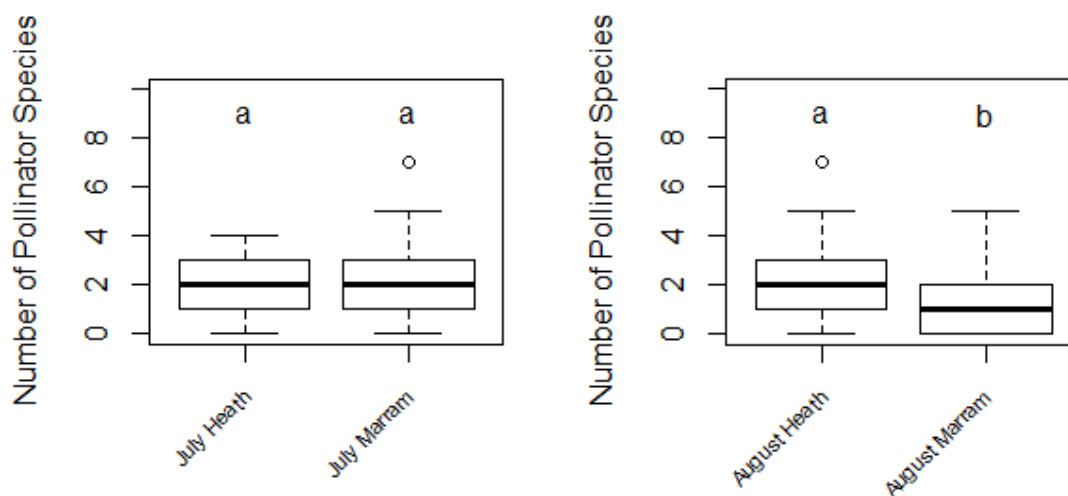

Figure 10. Boxplots comparing average pollinator diversity between two vegetation communities on Sable Island. Left: Pollinator diversity in July. Right: Pollinator diversity in August. Groups that share letters are not significantly different at α=0.05.
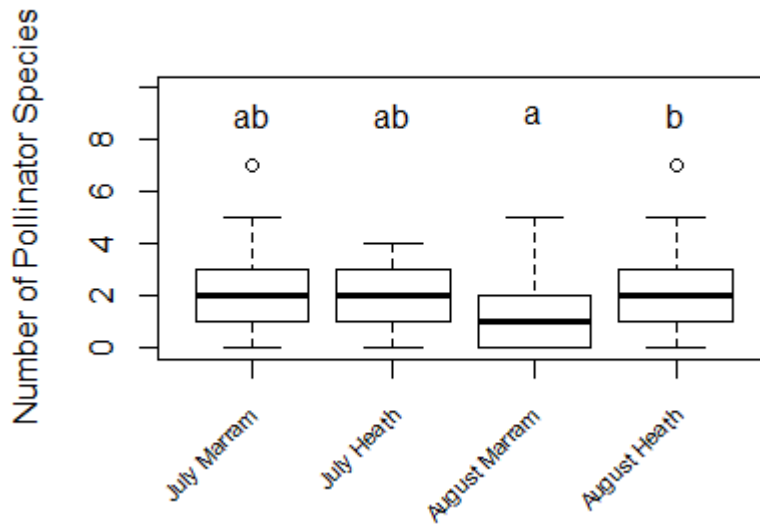
Figure 11. Boxplot comparing average number of pollinator species in each sample plot within each community. Comparisons are made within and between each month sampled. Groups that share letters are not significantly different at α=0.05.

There were no statistically significant differences in average numbers of flowering stems in sample plots for both July and August. It should be noted that based on Figure 12, it appears for July that there are more flowering stems on average in the heath. However, while this may be true, this difference is not significant, and thus no conclusions can be drawn from it. Some significant results were found when comparing both sampling times (Figure 13). Statistically significant differences were found in both heath and marram between July and August (P<0.0001 and P=0.006, respectively). A significant difference between the number of flowering stems in the July heath and August marram grassland (0.0116) was also found.
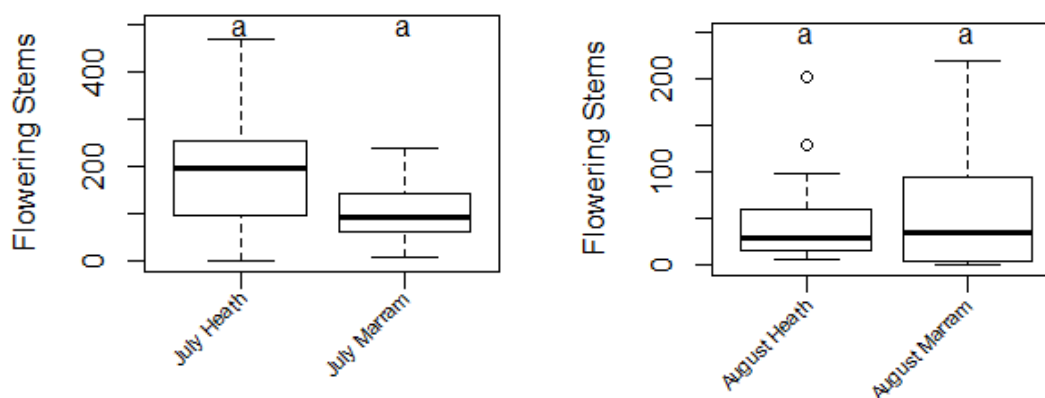
Figure 12. Boxplots comparing average numbers of flowering stems recorded at sampling plots during floral resource surveys. Left: Flowering stems in July. Right: Flowering stems in August. Groups that share letters are not significantly different at α=0.05.
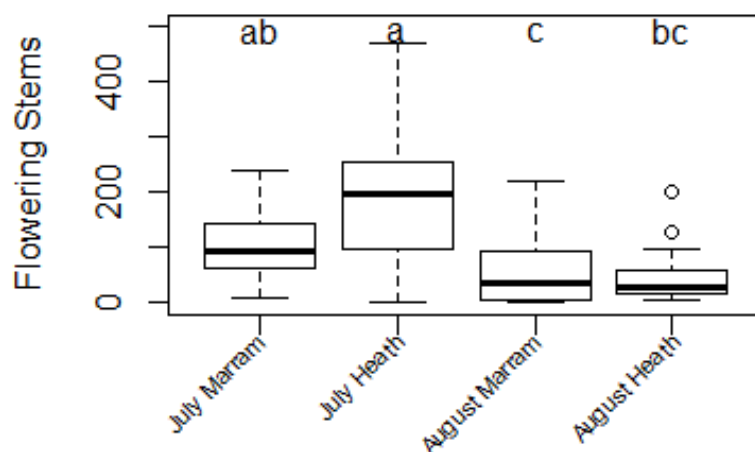

Figure 13. Boxplot comparing average number of flowering stems counted during floral resource surveys at each sample plot. Comparisons are made within and between each month sampled. Groups that share letters are not significantly different at α=0.05.

Analysis of floral species diversity in both July and August show no significant differences between communities, although in August the P-value is near-significant (P=0.0529) (Figure 14). Comparing the data without time as an identifier does show significance between communities at each month. Significant differences were also found between July and August in each community. Little variance is seen in the July marram community, as nearly all plots sampled contained ~2 flowering species, with a few plots containing one more or one less species (Figure 14; Figure 15). In this analysis (Figure 15), there are significant differences between marram and heath in both July (P<0.0001) and August (P<0.0001). Significant differences were also noted between July marram and August heath (P<0.0001) and between July heath and August marram (P<0.0001).
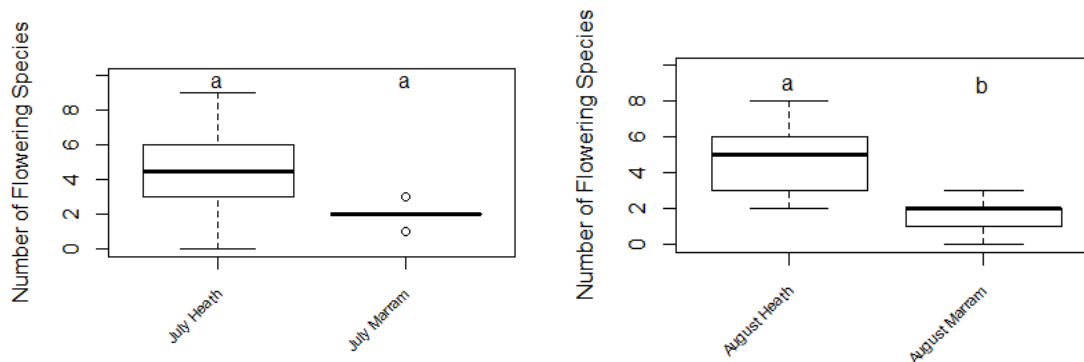

Figure 14. Boxplots comparing average number of flowering plant species noted during floral resource surveys in sample plots within each community. Left: Floral diversity in July. Right: Floral diversity in August. Groups that share letters are not significantly different at α=0.05.
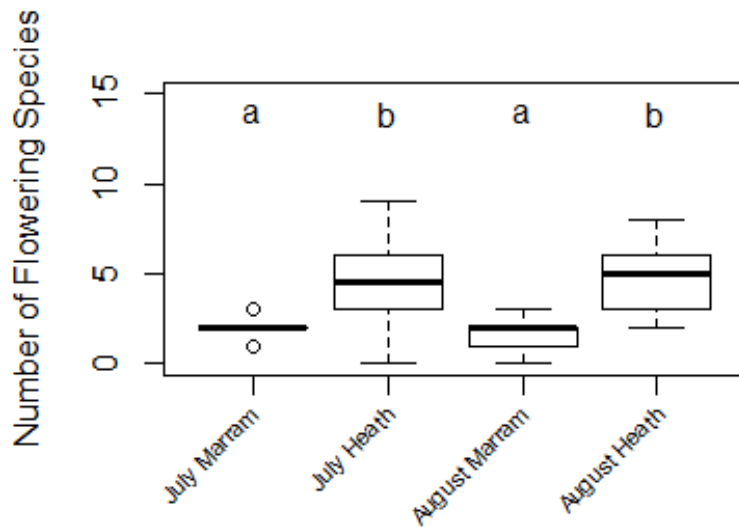
Figure 15. Boxplot comparing average numbers of flowering plant species during floral resource surveys of sample plots. Comparisons are within and between months. Groups that share letters are not significantly different at α=0.05.

Correlative relationships were identified between all variables sampled. In July, significant positive correlations were found between number of pollinator visits and number of flowering stems (P=0.00282, R^2=0.1289), pollinator diversity and flowering species diversity (P=0.00714, R^2=0.1031), pollinator diversity and number of flowering stems (P=0.000209, R^2=0.199), and number of pollinator visits and floral species diversity (P=0.0207, R^2=0.07322). In August, all variables compared showed statistically significant relationships. Positive correlations were found between number of flowering stems and pollinator visits (P=3.45×10^{-6}, R^2=0.3006), pollinator diversity and flowering species diversity (P=3.84×10^{-5}, R^2=0.2424), pollinator diversity and number of flowering stems

(P=1.18×10^{-6}, R^2=0.3252), and pollinator visits and flowering species diversity (P=0.000114, R^2=0.2147).

4. DISCUSSION

4.1 Plant Community Comparison

My expectations of trends in pollinator diversity and visits were only partially met. Only in August were more visits recorded on average and in total for heath. The same trend was found for the number of pollinator species (pollinator diversity), with more species found in heath only in August. It seems my expectations undervalued the importance of the marram grassland and its pollinator community. More total pollinator visits and higher total number of pollinator taxa were noted in the marram in the month of July. Statistical analysis also notes no significant differences in the average number of pollinator visitors and pollinator species between marram plots and heath plots for July. Marram also had a higher total number of flowering stems in August, though interestingly, in both months more pollinators in total were found in the community with fewer total flowering stems.

In the marram community, most flowering stems were beach pea (*Lathyrus japonicus* var. *maritimus*) in July, and common yarrow in August. In the months in which each was the most abundant species, they made up most of the flowers found in the marram grassland. Based on the decline of marram pollinator visits and diversity in August, it seems that beach pea may provide an important resource for pollinators within this habitat, with many pollinator visits in July being to beach pea flowers. Common yarrow (*Achillea millefolium* var. *occidentalis*) did experience high numbers of visits in August, but not as

high as found on the July beach pea flowers, possibly due to lower total numbers of flowers as compared to the beach pea or being less preferred by pollinators.

Grove sandwort (*Moehringia lateriflora*), little yellow rattle (*Rhinanthis minor*), and white clover (*Trifolium repens*) were the most abundant heath flowers in July. The finding of white clover as one of the most abundant heath flowers is notable, as it was only found in the 'No2West' site, and it is not native to Sable Island (Catling et al., 2014). In August, the most abundant flowering species was wild rose (*Rosa virginiana*), though it was not as abundant as any of the most abundant species in July, and numbers of wild rose flowers increased little from July. Number of flowering stems declined in the heath from August to July, and unlike in the marram no single species seemed to become overtly abundant enough to replace them. However, a higher floral diversity which was more evenly-distributed in numbers, as found in August, may have provided some relief from the decline in flowering stems in heath. Some of the species which were more common in August may have been preferred by pollinators, as little yellow rattle and grove sandwort were both uncommonly used by pollinators, explaining the increase in pollinator visits in August in heath despite fewer flowering stems. Species that flowered more commonly before sampling began (such as lowbush blueberry, *Vaccinium angustifolium*, or wild strawberry, *Fragaria virginiana*) or after sampling ended (such as New York aster, *Symphyotrichum novi-belgii*, or seaside goldenrod, *Solidago sempervirens*) could also provide important resources for pollinators in times not encompassed by this study (DeLong, 2017; Lucas, 2017).

Heath did show more flowering species in both months compared to the marram community, as expected. Heath also showed more total flowering stems for July, though

the numbers diminished as summer went on to be fewer than in the marram by August. Significant differences in numbers of flowering stems were recorded between July and August for each community, indicating a large change in the amount of resources available to pollinators for both communities. Among floral species, this is seen as the high abundances in July of beach pea in marram, and grove sandwort, little yellow rattle, and white clover in heath, which were subsequently lost in August. This loss of floral resources as time went on through the summer could put strain on pollinators emerging later in the season, such as *Colletes simulans armatus* (Lucas, 2017). A trend of pollinator visits and species richness decline could be noted in much of the analysis, though heath did have more visits in total in August than in July.

4.2 Pollinator Activity

Megachile melanophaea was the most common bee species found on Sable Island during sampling; this was also found during recent bee surveys conducted by Lucas (2017). No *Osmia simillima* or *Colletes simulans armatus* were found during sampling. As *O. simillima* is a known oak wood-nester (Cane et al., 2007), and Sable Island lacks abundant natural oak wood sources, it is often associated with man-made structures for nesting (Z. Lucas, pers. comm.). This lack of captures was thus likely due to distance of sample plots from man-made structures for the former, and the time period of sampling occurring prior to emergence for the latter (Lucas, 2017). Though the sample size is quite small, *Lasioglossum novascotiae* was found in a nearly 2:1 ratio to the less common *Lasioglossum sablense*. This ratio of *L. novascotiae* to *L. sablense* has been found in previous bee surveys (Gibbs, 2014). Only one species of bee, *M. melanophaea* was found foraging in marram,

whereas all three species found during sampling were found in heath vegetation. This suggests that the heath habitat provides better foraging habitat to a greater diversity of bees, including the at-risk *L. sablense*, thus supporting our hypothesis.

New floral visitation records for Sable Island bees were found for *L. sablense* and *M. melanophaea* during this study, not noted in previous bee studies conducted on the island (Lucas, 2018; Lucas, 2017). Both species were recorded visiting grove sandwort, representing the first records of bees visiting this plant species on Sable Island. As well, a *M. melanophaea* was recorded visiting a little yellow rattle, representing the first recorded bee for the plant species on Sable Island.

An important finding seems to be the importance of non-bee pollinators for the Sable Island ecosystem, akin to the findings of Rader et al. (2015). Even within Order Hymenoptera, bees were not the most common pollinators, with ants establishing themselves as the largest Hymenopteran pollinator group on the island. A study by Cembrowski et al. (2014) found that visiting ants on flowers can reduce pollination by bees. This could provide some explanation as to why ants were so prevalent on flowers over bees in the heath. However, more studies need to be done to understand the role of the ants themselves as pollinators of plants (Rostás and Tautz, 2010; Kevan and Baker, 1983). It is believed that ants can be beneficial to plant species if functioning as pollinators (Rostás and Tautz, 2010).

Order Diptera (true flies) was the most numerous pollinator Order found during the study period, accounting for approximately 61% of total visits. Other sources have found Dipterans to be the second most important group of pollinators, only behind the Hymenopterans (Ssymank et al., 2008), but based on their abundance presented here, they

may be the most important group to the Sable Island ecosystem. Hoverflies (Family Syrphidae) accounted for a notable portion of these visits to flowers by flies. Past studies have reported hoverflies to be important pollinators for ecosystems, with most species being specialized for pollination (Ssymank et al., 2008; Kevan and Baker, 1983), and it seems that no exception is being made for the Sable Island ecosystem. Several other Dipteran families observed visiting flowers during this study are known to contain pollinators as well, including the Anthomyiidae, Calliphoridae, Lauxaniidae, Muscidae, and Tachinidae (Ssymank et al., 2008; Kevan and Baker, 1983). However, much like ants, there is a gap in knowledge on Dipteran pollination that needs to be filled (Ssymank et al., 2008).

The pollinator communities in both the heath and marram allow for the maintaining of Sable Island's vegetated areas in the unique conditions present on the island (Gibbs, 2014; Catling et al., 1984). With a positive correlation between diversity in pollinators found on Sable Island, much like in previous studies done in other locations (Fründ et al., 2010), the discovery of diverse pollinator assemblages in both the heath and marram communities is promising. This is especially important in the marram grassland, where pollinators may be needed more to offset grazing by horses within the community, as the positive benefits of pollination can provide a counterbalance to the negative effects of herbivory on plant species, contributing to a more stable community (Sauve et al., 2016; Freedman et al., 2012). Pollinators can link organisms within an ecosystem to each other, with strong pollination networks increasing ecosystem resilience to change (Lundberg and Moberg, 2003).

4.3 Limitations and Future Research

Given my results, further research should focus on establishing more knowledge on the role of non-bee pollinators on Sable Island. This should especially be done for ants and flies, which were found in high numbers, but this was the first known research done accounting for their share of pollination services on the island. Due to the observations of *L. sablense* foraging, it may be presumed that their nesting habitat is not far (Greenleaf et al., 2007), and so efforts to locate nests can be based upon the locations the species was found foraging at during this study. For the sole purposes of protection of the at-risk *L. sablense*, marram need not be considered for proposed plans, as neither of the *Lasioglossum* species were found in the community. Previous studies have also noted a preference among Sable Island's two *Lasioglossum* species for the heath community (Lucas, 2018). Marram is now known to house an abundant and diverse pollinator community, including the bee *M. melanophaea*, and future pollinator studies done on the island could look to further establish their knowledge of this community, as past surveys have been more heath-focused. Further research will also allow for more seasoned pollinator researchers to identify true pollinator visits to flowers, and which visits were just coincidental records of species landing on flowers, but not to forage. Expansion of sampling times should also be done to gain an understanding of the pollinator communities both earlier and later in the foraging season, at times not included in our study.

4.4 Summary

Change is ever-present in the dynamic environment of Sable Island. But anthropogenically-caused changes can bring new factors into play in this system, some of which could put the ecosystem at risk (Freedman et al., 2014c). Higher biodiversity can reduce the impacts of a loss of a species (Borrvall et al., 2000), which shows the importance of our findings of pollinator diversity amongst both plant communities sampled. Sable Island is not a diverse landscape in comparison to other ecosystems (Stalter and Lamont, 2006), so despite these findings of apparent diversity in pollinator taxa, the Sable Island ecosystem is still a fragile one.

Plant and pollinator diversity are intertwined and important to many ecosystems, as found by the results from this study as well as many previous (Fründ et al., 2010; Fontaine et al., 2005). With diversity providing resilience in ecosystems (Lundberg and Moberg, 2003), ecosystems with more biodiversity may be less impacted by the ongoing loss of pollinators worldwide (Potts et al., 2010). Pollinators are valuable to ecosystems worldwide, and in less diverse ecosystems such as the ones found on Sable Island, pollinators such as bees provide a crucial function to the ongoing prosperity of the ecosystem (Gibbs, 2014). But non-bee pollinators have been known to be important within pollinator communities (Rader et al., 2015), and with the abundance of them on Sable Island now known, a better understanding of the Sable Island pollinator community has now emerged.

To summarize my findings, marram had more total pollinators in July, whilst heath was found to contain more total and more diverse pollinators in August. Pollinator diversity was linked to higher numbers of flowers and more diverse flowering plant communities.

Non-bee pollinators were found to account for a majority of pollinator visits across the island, with bees not accounting for the high number of visits expected of them. Bees still provide a sizable number of visits and are important to the plant communities of Sable Island, especially the heath.

Given my results, further research should focus on establishing more knowledge on the role of non-bee pollinators on Sable Island. This should especially be done for ants and flies, which were found in high numbers, but this was the first known research done accounting for their share of pollination services on the island. Due to the observations of *L. sablense* foraging, it may be presumed that their nesting habitat is not far (Greenleaf et al., 2007), and so efforts to locate nests can be based upon the locations the species was found foraging at during this study. For the sole purposes of protection of the at-risk *L. sablense*, marram need not be considered for proposed plans, as neither of the *Lasioglossum* species were found in the community. Previous studies have also noted a preference among Sable Island's two *Lasioglossum* species for the heath community (Lucas, 2018). Marram is now known to house an abundant and diverse pollinator community, including the bee *M. melanophaea*, and future pollinator studies done on the island could look to further establish their knowledge of this community, as past surveys have been more heath-focused. Further research will also allow for more seasoned pollinator researchers to identify true pollinator visits to flowers, and which visits were just coincidental records of species landing on flowers, but not to forage. Expansion of sampling times should also be done to gain an understanding of the pollinator communities both earlier and later in the foraging season, at times not included in our study.

5. CONCLUSION

Diverse pollinator communities are important in the functioning of ecosystems and plant communities (Ollerton et al., 2011). In two plant communities on Sable Island, diverse assemblages of pollinators were discovered. While the island's five native bee species are still important to the ecosystem, there is now knowledge of a large community of non-bee pollinators. These non-bee pollinators are abundant, especially so in the marram community. While marram showed more total pollinator visits in July, heath showed more total visits, average visits, and diversity in August. Links were also found between pollinator visits and diversity and flowering plant abundance and diversity. This research allows for a better understanding of the Sable Island ecosystem and reveals that the pollinator community of marram is more diverse than once thought. This study can be expanded upon by future studies expanding research on non-bee pollinators, and sampling at more times not included in this study.

6. REFERENCES

Applied Geomatics Research Group. (2015). Sable Island, Nova Scotia 2014 topography and land cover atlas. Nova Scotia Community College, Middleton, NS.

Albrecht, M., Schmid, B., Hautier, Y., Müller, C. (2012). Diverse pollinator communities enhance plant reproductive success. *Proceedings of the Royal Society B: Biological Sciences, 279*(1748), 4845-4852. https://doi.org/10.1098/rspb.2012.1621

Armbruster, W. (2017). The specialization continuum in pollination systems: diversity of concepts and implications for ecology, evolution and conservation. *Functional Ecology, 31*, 88-100.

Barbosa, D. (2016). Integrating Studies on Plant-Pollinator and Plant-Herbivore Interactions. *Trends in Plant Science, 21*(2), 125-133.

Biodiversity Institute of Ontario. (2015). *DNA Barcode-based Assessment of Arthropod Diversity in Canada's National Parks: Progress Report for Sable Island National Park*. Report prepared by Bio-Inventory and Collections Unit. University of Guelph, Guelph, ON.

Blüthgen, N., and Klein, A. (2011). Functional complementarity and specialisation: The role of biodiversity in plant–pollinator interactions. *Basic and Applied Ecology, 12*, 282-291. doi:10.1016/j.baae.2010.11.001

Borrvall, C., Ebenman, B., Jonsson, T. (2000). Biodiversity lessens the risk of cascading extinction in model food webs. *Ecology Letters, 3*, 131-136.

Canada National Parks Act. (2017, c.-C. 32). Retrieved from the Justice Laws website https://laws-lois.justice.gc.ca/eng/acts/n-14.01/index.html

Cane, J., Griswold, T., Parker, F. (2007). Substrates and Materials Used for Nesting by North American *Osmia* bees (Hymenoptera: Apiformes: Megachilidae). *Annals of the Entomological Society of America, 100*(3), 350-358.

Carman, K., & Jenkins, D. (2016). Comparing diversity to flower-bee interaction networks reveals unsuccessful foraging of native bees in disturbed habitats. *Biological Conservation, 202*, 110-118.

Catling, P., Freedman, B., Lucas, Z., Blaney, S. (2014). Chapter 9: Vascular Plants of Sable Island in "Final Report to Parks Canada: An Ecological and Biodiversity Assessment of Sable Island." Halifax, NS.

Catling, P., Freedman, B., Lucas, Z. (1984). The vegetation and phytogeography of Sable Island, Nova Scotia. *Proceedings of the Nova Scotian Institute of Science, 34*, 180–247.

Cembrowski, A., Tan, M., Thomson, J., Frederickson, M. (2014). Ants and Ant Scent Reduce Bumblebee Pollination on Artificial Flowers. *The American Naturalist, 183*(1), 133-139. doi:10.1086/674101

DeLong, D. (2017). *Flowering Plant of Sable Island: Field Guide Part 2*. Halifax, NS.

Environment Canada, 2010. Canadian climate normal 1971–2000. Environment Canada, Ottawa, Ontario.

Erskine, J. (1953). The ecology of Sable Island, 1952. *Proceedings of the Nova Scotia Institute of Science, 23*, 120-145.

Fantinato, E., Del Vecchio, S., Giovanetti, M., Acosta, A., Buffa, G. (2017). New insights into plants co-existence in species-rich communities: The pollination interaction perspective. *Journal of Vegetation Science, 29*(6), 6-14. doi:10.1111/jvs.12592

Fenster, C., Armbruster, W., Wilson, P., Dudash, M., Thomson, J. (2004). Pollination Syndromes and Floral Specialization. *Annual Review of Ecology, Evolution, and Systematics, 35*, 475-403. https://doi.org/10.1146/annurev.ecolsys.34.011802.132347

Freedman, B., Stewart, H., Ure, D., Sheppard, J. (2014a). Chapter 1: An Ecological and Biodiversity Assessment of Sable Island in "Final Report to Parks Canada: An Ecological and Biodiversity Assessment of Sable Island". Halifax, NS.

Freedman, B., Catling, P., Lucas, Z., Colville, D., Lacoul, P. (2014b) Chapter 8: Plant Communities of Sable Island in "Final Report to Parks Canada: An Ecological and Biodiversity Assessment of Sable Island". Halifax, NS.

Freedman, B., Lucas, Z., Burgess, N., and Sheppard, J. (2014c). Chapter 17: Recent Anthropogenic Stressors in "Final Report to Parks Canada: An Ecological and Biodiversity Assessment of Sable Island". Halifax, NS.

Freedman, B. (2001). Airphoto Assessment of Changes in Plant Cover on Sable Island, Nova Scotia. Dalhousie University, Department of Biology.

Fontaine, C., Dajoz, I., Meriguet, J., Loreau, M. (2005). Functional Diversity of Plant–Pollinator Interaction Webs Enhances the Persistence of Plant Communities. *PLoS Biology, 4*(1), e1. https://doi.org/10.1371/journal.pbio.0040001

Fründ, J., Linsenmair, K., Blüthgen, N. (2010). Pollinator diversity and specialization in relation to flower diversity. *Oikos, 119*, 1581-1590.

Gallai, N., Salles, J., Settele, J., Vaissière, B. (2009). Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics, 68*(3), 810-821. https://doi.org/10.1016/j.ecolecon.2008.06.014

Gibbs, J. (2014). COSEWIC assessment and status report on the Sable Island Sweat Bee *Lasioglossum sablense* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. ix + 38 pp. (www.registrelep-sararegistry.gc.ca/default_e.cfm).

Greenleaf, S., Williams, N., Winfree, R., Kremen, C. (2007). Bee foraging ranges and their relationship to body size. *Oecologia, 153*(3), 589-596. doi:10.1007/s00442-007-0752-9

Kearns, C., Inouye, D., Waser, N. (1998). Endangered Mutualisms: The Conservation of Plant-Pollinator Interactions. *Annual Review of Ecology and Systematics, 29*, 83-112. https://doi.org/10.1146/annurev.ecolsys.29.1.83

Kevan, P., and Baker, H. (1983). Insects as Flower Visitors and Pollinators. *Annual Review of Entomology, 28*, 407-453.

Klein, A., Vaissière, B., Cane, J., Steffan-Dewenter, I., Cunningham, S., Kremen, C., Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences, 274*(1068), 303-313. doi:10.1098/rspb.2006.3721

Koh, L., Dunn, R., Sodhi, N., Colwell, R., Proctor, H., Smith, V. (2004). Species Coextinctions and the Biodiversity Crisis. *Science, 305*, 1632-1634.

Lucas, Z. (2018). *Additional Notes on Distribution and Foraging Activity of* Lasioglossum *species on Sable Island, Summer 2017.* Report to Parks Canada.

Lucas, Z. (2017). *2016 Bee Inventory and Distribution, Sable Island.* Report prepared for Parks Canada.

Lundberg, J., and Moberg, F. (2003). Mobile Link Organisms and Ecosystem Functioning: Implications for Ecosystem Resilience and Management. *Ecosystems, 6*, 87-98. doi:10.1007/s10021-002-0150-4

Mallinger, R., Gibbs, J., Gratton, C. (2016). Diverse landscapes have a higher abundance and species richness of spring wild bees by providing complementary floral resources over bees' foraging periods. *Landscape Ecology, 31*, 1523-1535. doi:10.1007/s10980-015-0332-z

Mazerolle, D. (2015). *Floristic Survey of Sable Island's Freshwater Pond Habitats and Recommendations for Future Monitoring Efforts.* Atlantic Canada Conservation Data Centre, Report to Sable Island National Park Reserve.

Ollerton, J., Winfree, R., Tarrant, S. (2011). How many plants are pollinated by animals?. *Oikos, 120*, 321-326. doi:10.1111/j.1600-0706.2010.18644.x

Parks Canada Agency. (2016). *Species at Risk Site Analysis*. Report for Sable Island National Park Reserve. Parks Canada Agency, Mainland Nova Scotia Field Unit. 35 pp.

Potts, S., Biesmeijer, J., Kremen, C., Neumann, P., Schweiger, O., Kunin, W. (2010). Global pollinator declines: trends, impacts and drivers. *Trends in Ecology & Evolution, 25*(6), 345-353. doi: 10.1016/j.tree.2010.01.007

Rader, R., Bartomeus, I., Garibaldi, L., Garratt, M., Howlett, B., Winfree, R., Cunningham, S., Mayfield, M., Arthur, A., Andersson, G., et al.. (2015). Non-bee insects are important contributors to global crop pollination. *Proceedings of the National Academy of Sciences, 113*(1), 146-151. doi:10.1073/pnas.1517092112

R Core Team. (2018). R: A language and environment for statistical computing (Version 3.5.2). R Foundation for Statistical Computing. Vienna, Austria. Retrieved from: https://www.r-project.org/

Robinson, S., Losapio, G., Henry, G. (2018). Flower-power: Flower diversity is a stronger predictor of network structure than insect diversity in an Arctic plant–pollinator network. *Ecological Complexity, 36*, 1-6. https://doi.org/10.1016/j.ecocom.2018.04.005

Rostás, M., and Tautz, J. (2010). Ants as Pollinators of Plants and the Role of Floral Scents. Chapter in *All Flesh Is Grass*, pp. 149-161.

RStudio. (2018). RStudio: Integrated Development Environment for R (Version 1.1.463). Boston, MA. Retrieved from: https://www.rstudio.com/

Sargent, R., and Ackerly, D. (2008). Plant–pollinator interactions and the assembly of plant communities. *Trends in Ecology & Evolution, 23*(3), 123-130. https://doi.org/10.1016/j.tree.2007.11.003

Sauve, A., Thébault, E., Pocock, M., Fontaine, C. (2016). How plants connect pollination and herbivory networks and their contribution to community stability. *Ecology, 97*(4), 908-917.

Sheffield, C., Kevan, P., Smith, R., Rigby, S., Rogers, R. (2003). Bee Species of Nova Scotia, Canada, with New Records and Notes on Bionomics and Floral Relations (Hymenoptera: Apoidea). *Journal of the Kansas Entomological Society, 76*(2), 357-384.

Ssymank, A., Kearns, C., Pape, T., Thompson, F. (2008). Pollinating Flies (Diptera): A major contribution to plant diversity and agricultural production. *Biodiversity, 9*(1 & 2), 86-89.

Stalter, R., and Lamont, E. (2006). Historical and Extant Flora of Sable Island, Nova Scotia, Canada. *The Journal of the Torrey Botanical Society, 133*(2), 362-374.

St. John, H. (1921). Sable Island, with a catalogue of its vascular plants. *Proceedings of the Boston Society of Natural History, 36*, 1-103.

Thomann, M., Imbert, E., Devaux, C., Cheptou, P. (2013). Flowering plants under global pollinator decline. *Trends in Plant Science, 18*(7), 353-359.

Tissier, E., McLoughlin, P., Sheard, J., Johnstone, J. (2013). Distribution of vegetation along environmental gradients on Sable Island, Nova Scotia. *Ecoscience, 20*(4), 361-372.

Tuell, J., and Isaacs, R. (2010). Weather During Bloom Affects Pollination and Yield of Highbush Blueberry. *Journal of Economic Entomology, 103*(3), 557-562. https://doi.org/10.1603/EC09387

Vanbergen, A., Baude, M., Biesmeijer, J., Britton, N., Brown, M., Brown, M., Bryden, J., Budge, G., Bull., J., Carvell, C., et al.. (2013). Threats to an ecosystem service: pressures on pollinators. *Frontiers in Ecology and the Environment, 11*(5), 251-259. doi:10.1890/120126

Walker, E., and Lundholm, J. (2017*). Habitat provisioning of wild bee pollinators on Nova Scotia heathlands*. Report prepared for Nova Scotia Habitat Conservation Fund.

Welsh, D. (1975). Population, behavioural and grazing ecology of the horses of Sable Island. Ph.D. thesis, Dalhousie University, Halifax, NS.