

Identifying pollinator communities visiting berry-producing
plants on coastal barrens

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Abstract

There is a lack of research on the pollinator communities of flowering plant species within coastal barren habitats. This study examined four closely related plant species in the Ericaceae that have a similar flower structure: *Vaccinium angustifolium*, *Gaylussacia baccata*, *Gaylussacia bigeloviana*, and *Gaultheria procumbens*. They were studied at four coastal barren sites within Halifax County, Nova Scotia. At each site, pollinator collection and observations were carried out, as well as vegetation surveys to identify available foraging resources. Pollinators were identified down to morphospecies. A total of 145 insect pollinators, comprised of 32 morphospecies were collected. Results identified pollinator assemblages. There were significant correlations between all pollinator variables (catches, visits, richness) and the number of flowers on the target species. *G. baccata* and *G. bigeloviana* displayed higher pollinator diversity and had significantly more flowers than the other two target plant species. This study is one of the first to document and record pollinator communities of berry-producing plant species and underlines the importance of understanding plant-pollinator interactions.

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1 Introduction

1.1 Coastal Barrens

Coastal barrens are classified as heathland ecosystems neighbouring marine environments that are dominated by ericaceous vegetation, sparse tree cover, acidic soils, exposed bedrock, and stressful conditions (Oberndorfer & Lundholm, 2009; Balsdon et al., 2011; Porter, 2013). Barren vegetation is heavily influenced by these extreme conditions, resulting in stunted, slow growing plant species that have adapted to live in this ecosystem type (Oberndorfer, 2006; Porter, 2013). *Gaylussacia baccata*, *Vaccinium angustifolium*, *Juniperus communis*, and *Empetrum nigrum* are among the dominant species occurring within barrens, though vegetation communities can widely vary (Oberndorfer & Lundholm, 2009). In spite of the stressful conditions, coastal barren communities still contain high species diversity and provide environments that host a variety of habitats and rare species (Cameron & Bondrup-Nielsen, 2013; Oberndorfer & Lundholm, 2009).

Coastal barren habitats within Nova Scotia occur mainly along the Atlantic Coast and are relatively rare, accounting for less than 3% of the land area of the province (Porter, 2013). Nova Scotia's coastal barren sites include those located within Duncan's Cove Nature Reserve and Peggy's Cove Preservation Area, which are characterized by high winds and insolation, rock exposure, and fluctuating daily weather conditions (Oberndorfer & Lundholm, 2009; Walker, 2016). Coastal barrens are of ecological importance and provide ecological services, yet are largely unprotected and understudied (Oberndorfer & Lundholm, 2009). Coastal barren sites are at risk from threats such as forest encroachment, human disturbances (trail damage, ATVs, etc.), and coastal

development projects (Oberndorfer & Lundholm, 2009; Balsdon et al., 2011).

1.2 Pollinator Communities

Pollinators play a significant role in today's world and are receiving continued attention as concerns about their population escalate. Humans have a heavy reliance on pollinators as they are responsible for pollinating 35% of global food crops (Orford et al., 2015; Sidhu & Joshi, 2016). Pollinator communities consist primarily of bee species, with over 730 species in Canada of which 157 are native to Nova Scotia representing 26 genera and six families. (Sheffield et al., 2003; Packer, 2007). Bees, however, are not the only important pollinator group (Orford et al., 2015; Rader et al., 2016), as butterflies, beetles, moths, flies, and non-insects such as birds and bats all aid in the pollination process and are successful pollinators (Winfree, 2010; Rader et al., 2016).

Aside from crop pollination, wild flowers also rely heavily on pollinators as 78 – 94% are animal pollinator dependent (Willcox et al., 2017). Pollination occurs when pollen is released from the anther and gets carried to the stigma through a transport agent, such as a bee. Once pollen transfer occurs, fertilization takes place, forming seeds and fruits that maintains diversity and species survival (Willcox et al., 2017).

On coastal barrens, pollinators are particularly vital as they help sustain fruit and seed production through pollination in a harsh ecosystem. Currently, there is a lack of knowledge on the coastal barren bee fauna in Nova Scotia (Walker, 2016). Two studies (Walker, 2016 and Walker & Lundholm, 2017) outlined the richness and diversity of bee pollinators within Nova Scotian barrens on particular plant species (e.g., *Vaccinium angustifolium*, *Chamaedaphne calyculata*, *Hudsonia ericoides*). Walker (2016) compared the richness of bee species between urban habitats with coastal barren sites within the

Halifax Regional Municipality. Trends showed greater bee abundance and richness in ground level sites and coastal barren sites compared with sites on green roofs (Walker, 2016). Each bee species collected was identified, providing baseline data for research on pollinators within the coastal barren ecosystem. Walker and Lundholm (2017) also examined the diversity and abundance of wild bee pollinators in Nova Scotia heathland habitats on berry-producing and rare plant species. The results showed that there was little variation amongst inland, coastal, and highland habitat sites, but higher pollinator richness was recorded at more inland barren habitats (Walker & Lundholm, 2017). Inland habitats are less directly impacted by coastal conditions, and this appears to determine which pollinators forage in coastal habitats versus more inland habitats.

1.3 Plant-Pollinator Interactions

1.3.1 Mutualism

One of the most important mutualistic interactions is between flowering plants and their pollinators (Mitchell et al., 2009; Benadi et al., 2012). Just as flowering species rely on their pollinators for reproduction facilitation, pollinators also rely heavily on plants in order to meet their nutritional and dietary needs. Pollen contains a high content of proteins and lipids, which are essential components for larval development in bee species. Nectar also provides the energy required to sustain pollinator functions for adult pollinator species (Moquet et al., 2016).

Research has also provided evidence on the correlation between pollinator and flower abundance (Potts et al., 2003). One study, focusing on similar decline patterns of pollinators and their dependent plant species in Britain and the Netherlands, found trends of declining plant species were linked to their reliance on a declining pollinator

population (Biesmeijer et al., 2006). As reproduction impacts are experienced by plant populations, this in turn reduces the available resources for pollinators (Potts et al., 2003). This relationship outlines the importance of plant-pollinator interactions and how fragile they can be.

1.3.2 Co-Flowering Species

Within plant communities, coexistence frequently occurs among flowering species (Bouman et al., 2017). According to the general niche theory, species are able to coexist if they rely on separate resources, thus limiting competition (Pauw, 2013). Resources such as light, nutrients, and space can all become limiting factors within vegetation communities (Bouman et al., 2017). Certain pollinator species can also be deemed as a limiting resource to a reliant plant species (Pauw, 2013), however studies have shown that pollinator sharing is common within vegetation communities and between closely related species (Rathcke, 1988; Bouman et al., 2017). Coexistence of various flowering species can also enhance pollination success and in turn the plant's overall fitness (Ogilvie & Thomson, 2016). Co-flowering species have the ability to facilitate each other in their pollination services as greater resources for pollinators are expected to attract and sustain pollinator abundances (Moeller, 2004). Floral diversity in a vegetation community can also sustain pollinator communities by providing varied resource availability through different flowering phenologies.

1.3.3 Climate Change Influences

As carbon dioxide levels continue to rise and anthropogenic sources contribute to the global warming crisis, impacts on ecosystems and biological interactions are expected to occur (Fagúndez, 2013). Drought, extreme weather events, and dramatic temperature

shifts are some of the consequences of climate change that influence plants, pollinators, and their interactions (Bartomeus et al., 2011; Phillips et al., 2017). Phenological mismatches is one possible consequence of climate change, directly impacting plant-pollinator interactions (Forrest, 2015). Pollinators must be available during flowering periods in order for mutualistic interactions to occur. If plant cycles or pollinator foraging shifts occur, then pollination success and nutritional benefits may be drastically impacted (Rafferty & Ives, 2011; Forrest, 2015).

Coastal barrens are particularly vulnerable to climate change impacts as vegetation is already experiencing harsh coastal influences (salt spray, high winds) (Fagúndez, 2013). This increases the impact of any type of environmental threat in this habitat (Fagúndez, 2013). Understanding the interactions among plants, pollinators, and their ecosystem is vital, especially in extreme environments such as coastal barrens.

1.4 Objectives

The main objective of this study was to identify the pollinator species foraging on similar flowering species within coastal barren habitats. To date there has been no study that compares the differences in pollinator assemblages found on plant species with similar flowers within Nova Scotia Barrens. The initial prediction was that (1) higher abundances and pollinator richness would be found more inland and lower abundance and richness at more coastal sites within barrens, and (2) target species with higher flower abundances would contain higher pollinator richness.

The overall goal for this project was to provide a greater insight into pollinator foraging on similar flowering species in the Ericaceae and develop an understanding of pollinator community assemblages within the coastal barren habitats of Nova Scotia.

2 Methods

2.1 Study Site

Chebucto Head and Duncan's Cove are two coastal barren sites located within the Duncan's Cove Nature Reserve along the Atlantic Coast of Nova Scotia, situated 40 km southeast of Halifax (Oberndorfer, 2006) (Figure 1; Figure 2). Both areas are dominated by ericaceous species such as black huckleberry (*Gaylussacia baccata*), black crowberry (*Empetrum nigrum*), labrador tea (*Rhododendron groenlandicum*), and contain granite outcrops and sparse tree cover (Oberndorfer & Lundholm, 2009). Both sites are extensively used for hiking and contain near-by coastal developments.

Peggy's Cove and Polly's Cove are coastal barren sites in Peggy's Cove Preservation Area located approximately 45 km southwest of Halifax and 3 km from Peggy's Cove Lighthouse (Figure 3; Figure 4). Dominant vegetation is similar to that of Duncan's Cove and Chebucto Head, with high concentrations of huckleberry species (*Gaylussacia baccata*, *Gaylussacia bigeloviana*). Bog habitats are present throughout with alternations of granite rock exposure and sparse tree cover (Oberndorfer & Lundholm, 2009). Both sites experience disturbances from hiking and ATV use (Oberndorfer, 2006).

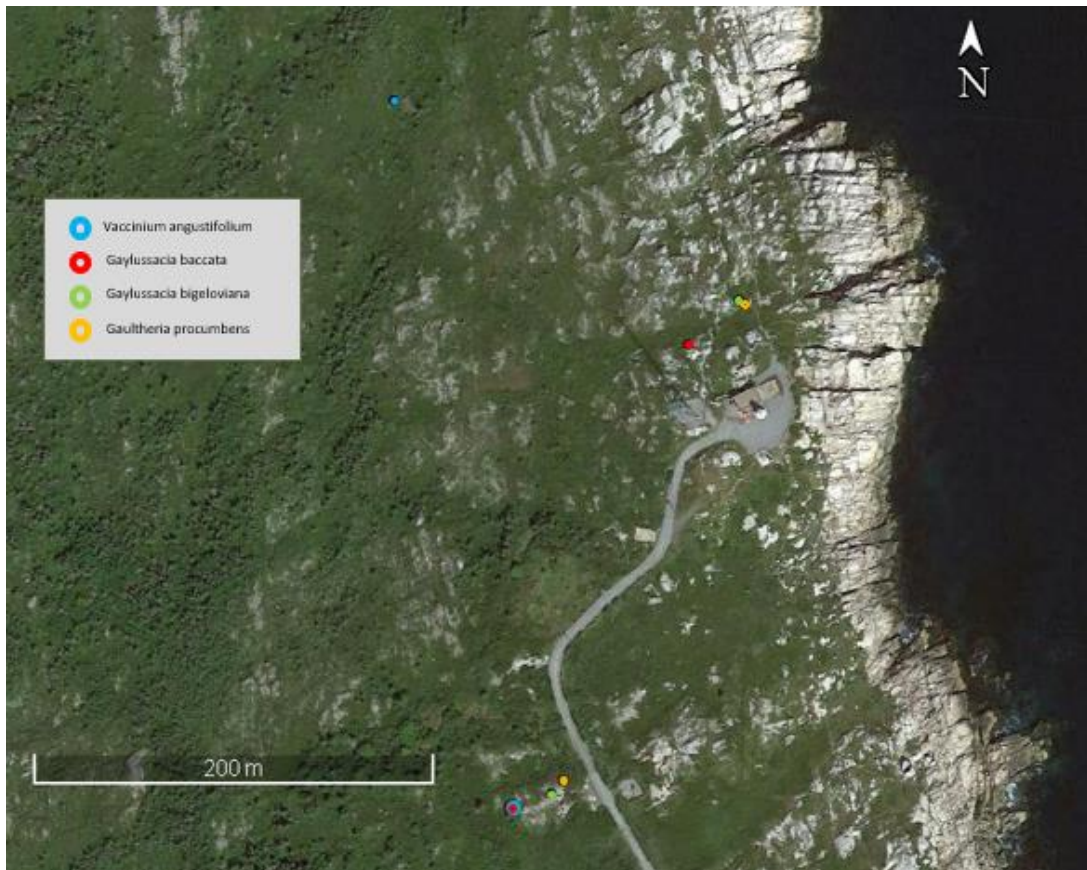


Figure 1. Chebucto Head coastal barren site. Sampled plots for each target plant species are represented by coloured circles (n=8).

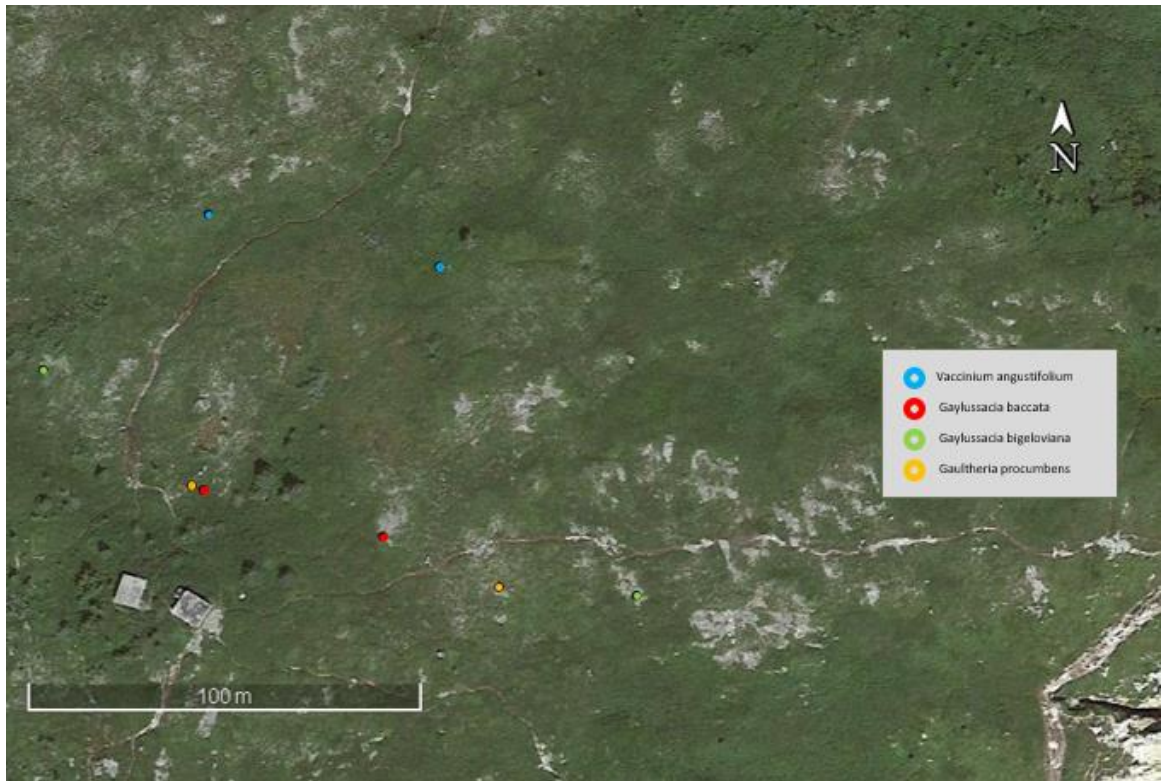


Figure 2. Duncan’s Cove coastal barren site. Sampled plots for each target plant species are represented by coloured circles (n=8).

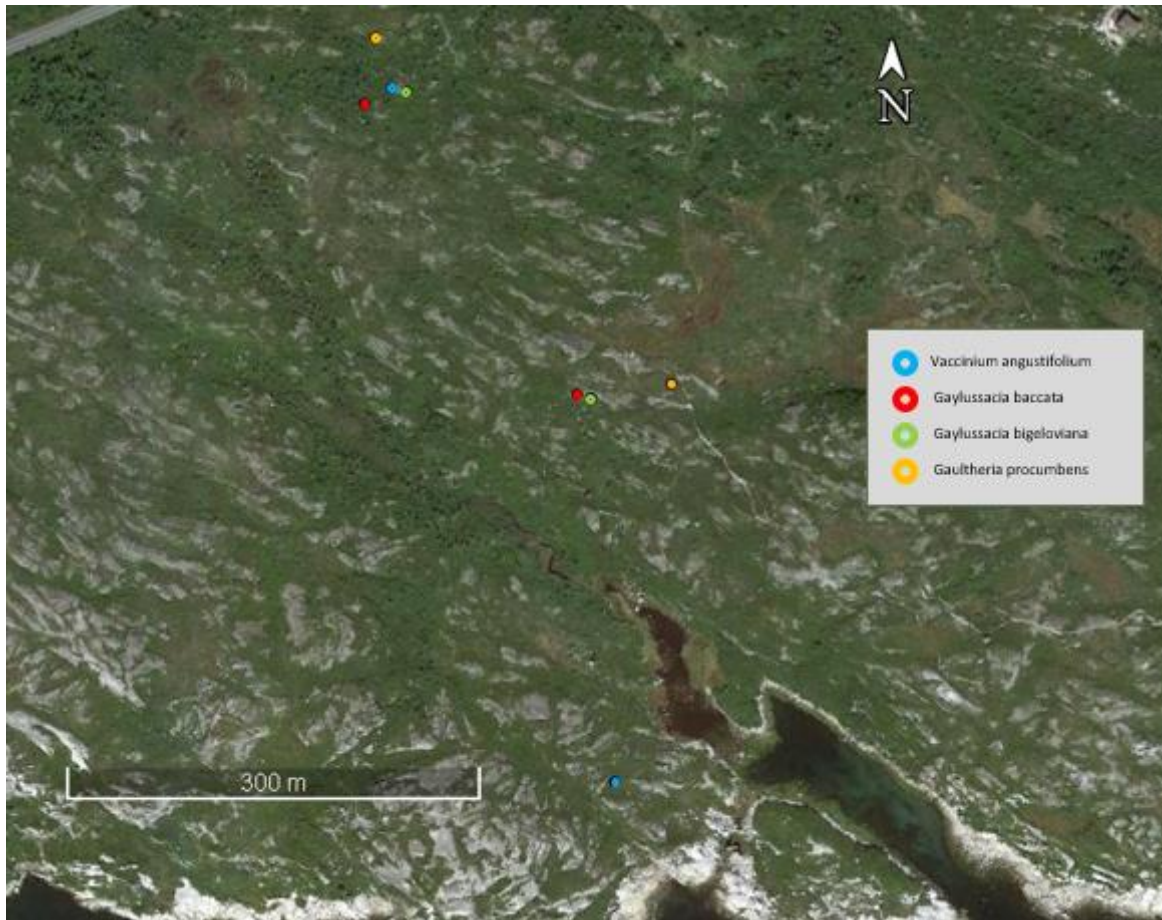


Figure 3. Polly's Cove coastal barren site. Sampled plots for each target plant species are represented by coloured circles (n=8).

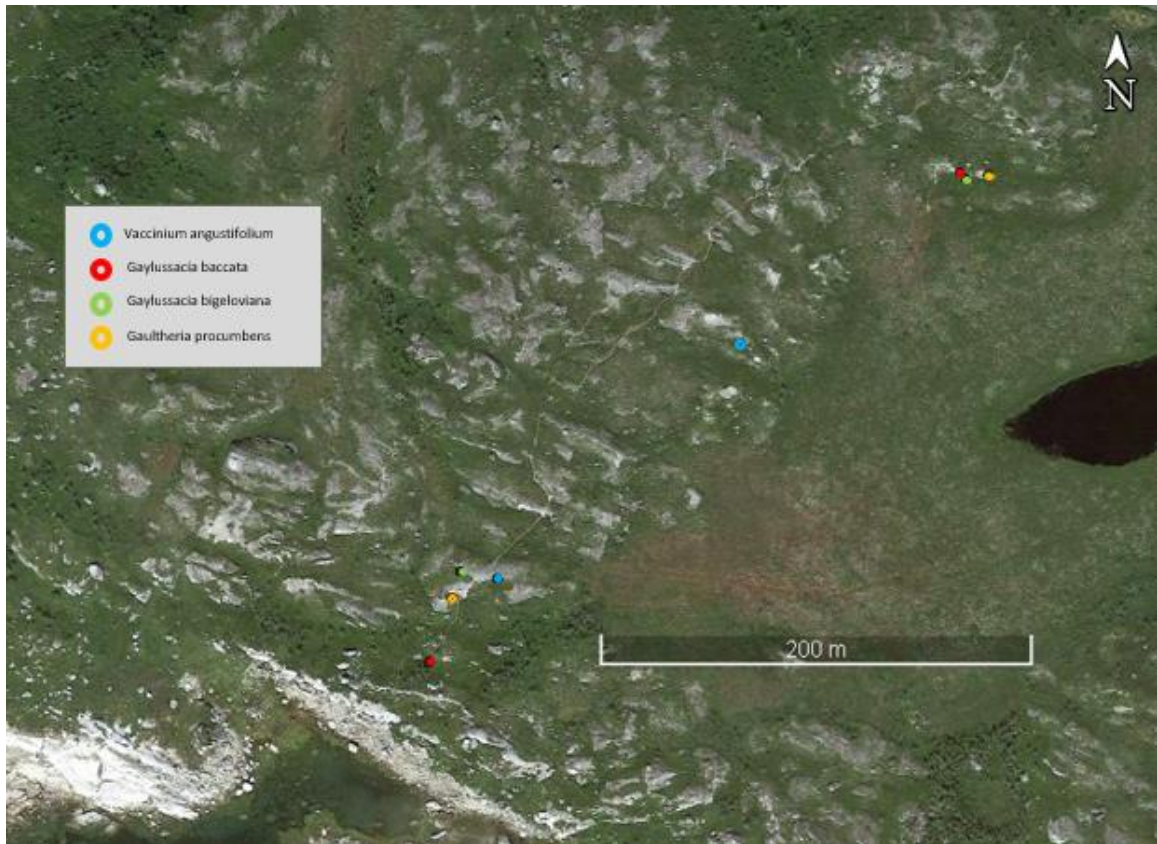


Figure 4. Peggy's Cove coastal barren site. Sampled plots for each target plant species are represented by coloured circles (n=8).

2.2 Target Species

Lowbush blueberry (*Vaccinium angustifolium*), black huckleberry (*Gaylussacia baccata*), dwarf huckleberry (*Gaylussacia bigeloviana*), and wintergreen (*Gaultheria procumbens*) were the four target plant species from which pollinators were collected during sampling periods. *V. angustifolium* is a small deciduous shrub consisting of white bell-shaped flowers that bloom late May to mid June (Munro et al., 2014). *G. baccata* and *G. bigeloviana* are both shrub species from the same genus. *G. baccata* leaves are leathery with golden glands on the underside and have red bell-shaped flowers that bloom in early to mid June. *G. bigeloviana* contains similar leaves which taper to a small sharp point and produces white flowers of a similar shape that also begin blooming in June (Munro et al., 2014). *G. procumbens* is a low growing shrub (<20cm in height), with a wintergreen fragrance in the leaves and fruit. White bell-shaped flowers hang under the leaves and bloom July to August (Munro et al., 2014). Figure 5 displays the target plant species of focus.

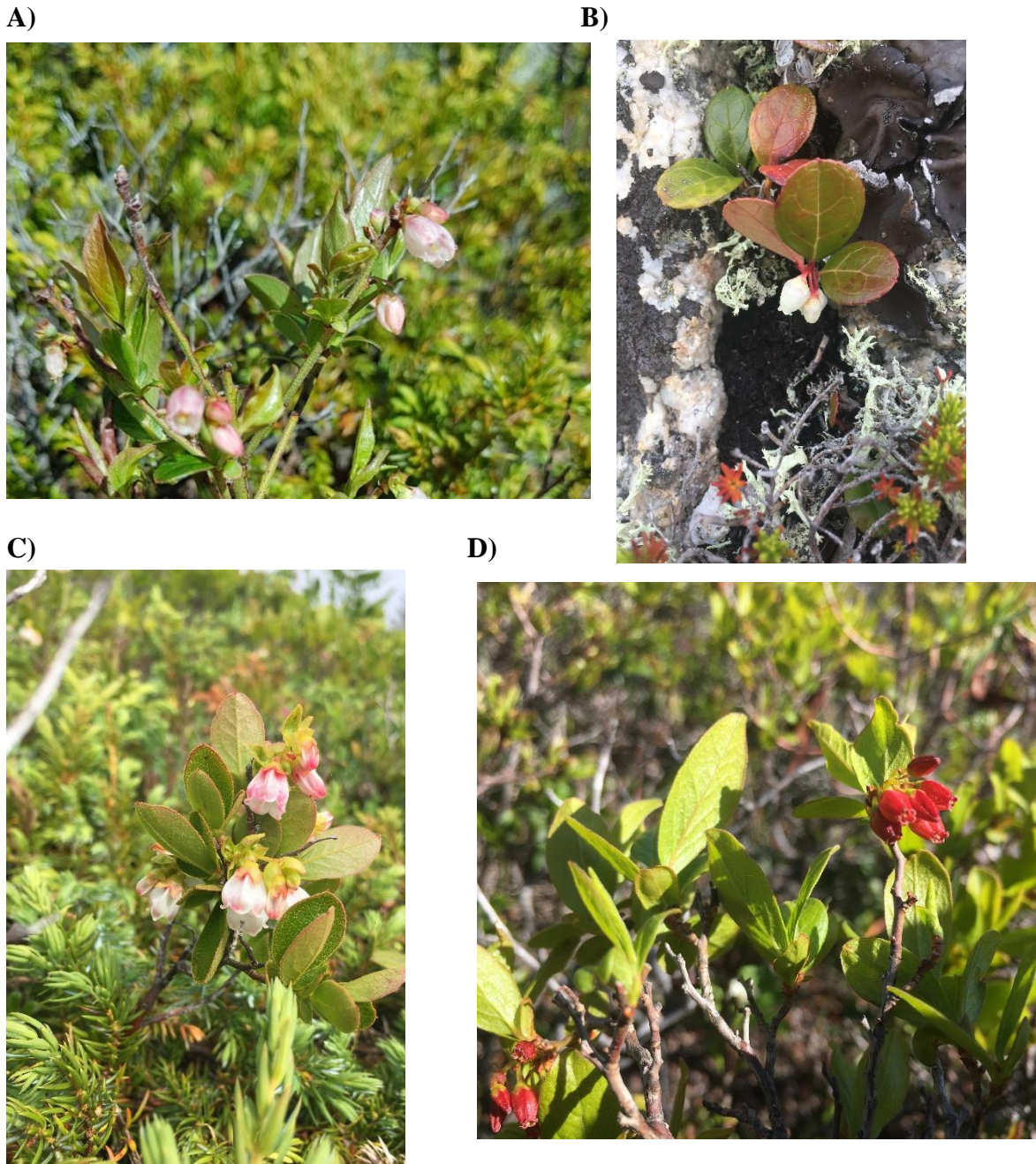


Figure 5. A) *V. angustifolium* B) *G. procumbens* C) *G. bigeloviana* D) *G. baccata*. All photos were taken during sampling periods of the target plant species by the collectors.

2.3 Experimental Design

2.3.1 Plot Selection

Plot selection was determined based upon the presence of the target plant species in bloom. At each coastal barren site, two plots were selected that were dominated by one of the targeted plant species; one closer to the coast (approximately < 200 m from the coastline) and one more inland (approximately > 200 m from the coastline). This was replicated at all four coastal barren sites, totalling eight plots per focal plant species (n=8 per species). Coastal and inland plot positions were generally within close proximity of the other target plant species' plots so that environmental conditions were similar among plots for the different target species within a coastal or inland location within site. This was proven difficult to achieve for *V. angustifolium* as few areas within the sites contained blooming individuals, so plots chosen were the best available option.

2.3.2 Pollinator Collection

Data collected were obtained from timed pollinator observations at 5 m x 5 m plots dominated by one of the four focal plant species at each site with a 10-meter buffer (Figure 6). Sampling protocol followed Walker and Lundholm (2017), with modifications made to fit the specific goals of this project. Sampling was conducted only under favourable conditions (sunny, low wind, no rain, and higher temperatures (>10 °C)) to ensure optimal foraging conditions for pollinators (Drummond, 2016; Walker & Lundholm, 2017). Temperature was recorded before sampling to ensure conditions were being met.

Observation and collection periods began at solar noon (12:00pm) for optimal sun exposure and lasted for 2 hours; a single observation and collection period was used for

each target species at each sampling location. Each pollinator species observed visiting the flowers of the target plant species was captured through targeted sweep netting to ensure that pollinators obtained are ones specifically pollinating the plant species being studied. Once captured, pollinators were transferred into a sealed 50mL tube for transport back to the lab and stored in the freezer for later identification.

Pollinator visits were also recorded. A visit consisted of any pollinator entering the plot and stopping or a pollinator that was missed as a catch within the timed sampling period. Visits were used to represent pollinator activity for the target plant species.

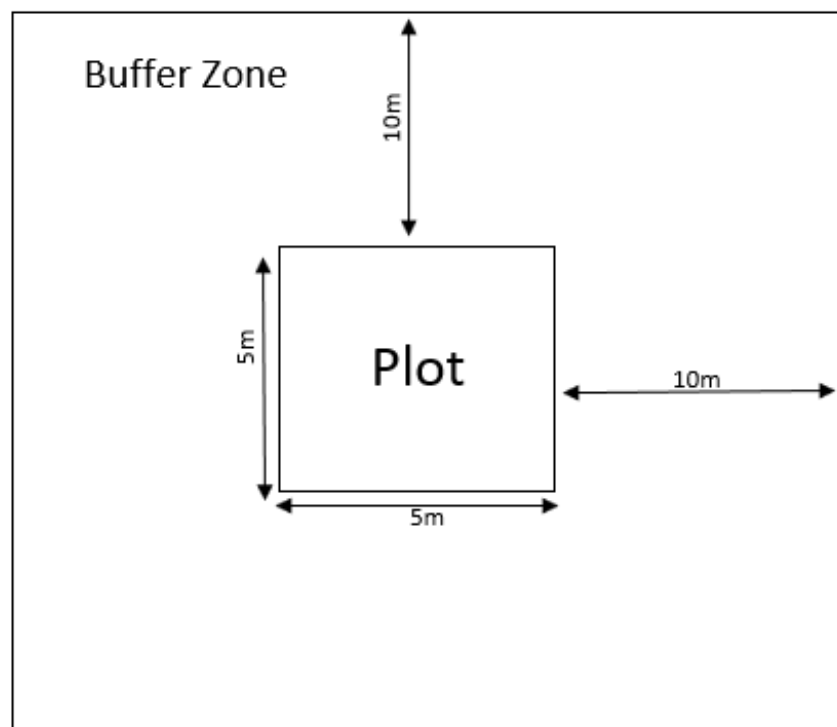


Figure 6. Sampling design of 5 m x 5 m plot with extended 10 m buffer zone. Pollinator collection occurred within the 'plot' and vegetation survey took place in both 'plot' and 'buffer zone'. Design replicated for all sampled plots at each position across all sites (n=32).

2.3.3 Vegetation Surveys

Other observations included a list of present flowering species that occurred in each plot and buffer zone, as well as the number of flowers of the target plant species within the sampled plots. An estimate number of flowers present on each co-flowering species and total species count was recorded to represent the surrounding floral resources pollinators have access to and that are co-existing with the targeted plant species.

2.4 Pollinator Preparation and Identification

Captured pollinators that accumulated pollen or mold went through a washing process to produce clean specimens. Pollinators were individually put in vials with soapy water and regular warm water, then dried and pinned. Each pin contained a label with site name, location coordinates, position, date of capture, and initials of collectors. All specimens were stored in the freezer until identification. Pollinator preparation followed methods of Droege's manual (2015).

Pollinator identification was completed using the Discoverlife online interactive keys with assistance from Packer and co-workers' key (2007). Due to time constraints, specimens were identified down to genus and morphological species (morphospecies). Morphospecies consists of specimens that grouped together based on their shared similarities and labeled according to their shared highest classification with an attached alphabetical lettering (ex. Diptera a).

2.5 Foraging Conditions

Both temperature and precipitation rates can have an impact on pollinator activity (Walker & Lundholm, 2017). Monthly mean temperatures (°C) and total precipitation (mm) were collected between the years 2008 and 2018 by Environment Canada. The

closest weather station to the sampled sites with available data for these dates was the Halifax International Airport weather station. Months April to August were chosen to represent the weather conditions experienced during the sampling months pollinators were collected for this study.

2.6 Statistical Analysis

Statistical analysis were completed using R and RStudio, version 1.1.463. To determine normality of the raw data, variables were examined visually. Visits and number of target plant species flowers were the only variables not normally distributed and were transformed to be as close to normal as possible. The transformation method used was natural logarithm. Tukey Pairwise post-hoc tests were used to determine which target plant species or position, depending on the main effect, differed significantly from one another.

For pollinator assemblage variables, pollinator catches required the use of a mixed model to account for the random effects of site; fixed effects were target plant species and position (coast vs inland). Three models were examined and compared: Gaussian, Poisson, and Negative-Binomial using the glmer function in RStudio. The Anova function identified the best fit model. Next, significant effects were identified through a second model selection process which took the least complicated model that had a better fit than the null model (null model only included random effects) as the “best” model, then Tukey Pairwise post-hoc tests were completed based on the best selected model. A model using Negative-Binomial distribution was selected for the “catches” variable. For the number of pollinator visits, transformed data were used and a summary of the data indicated no variance attributable to random effects, so the lm function was used in

RStudio. A Two-way ANOVA analysis determined the main effect and a Tukey Pairwise post-hoc test was completed to identify significance between groups.

Pollinator richness followed the same process as pollinator visits, although data were not transformed and the lmer function was used due to the presence of variance attributable to random effects (site).

For vegetation survey variables, co-flowering species and surrounding available flowers both followed the same process as pollinator richness with the use of non-transformed data and the lmer function with site as the random effect. For number of target species flowers, data were transformed. An ANOVA test determined both species and position as being significant main additive effects (the model with the interaction effect between species and position did not fit better than the additive model). From this, it was decided that two graphs would be produced to best illustrate the species effect and the position effect for the number of target flowers. Tukey Pairwise post-hoc tests were completed for both effects to determine which groups differ significantly from one another.

Correlation tests used the Pearson correlation method to determine the relationship between pollinator and floral variables. Variables were transformed if data were not normally distributed.

All results were considered significant when $P \leq 0.05$.

3 Results

3.1 Pollinator Assemblage

A total of 145 pollinators, containing 32 morphospecies were collected over the 32 sample periods across all sites (Table 1). *V. angustifolium* consisted of six catches, *G. baccata* contained 44, *G. bigeloviana* had 76, and *G. procumbens* had 19 catches. Bee species made up 75% of the accumulated catch, followed by fly species (17%), beetles (3%), moths (2%), wasps (2%), and a leafhopper (other) (1%) (Figure 7).

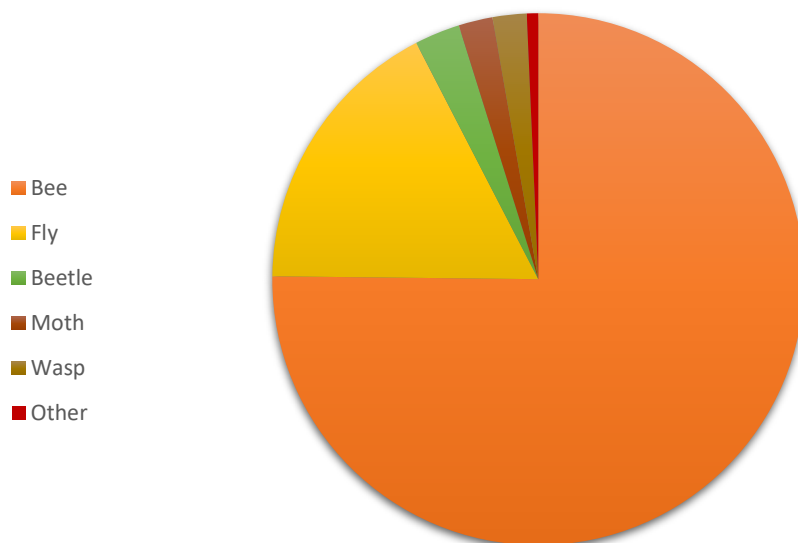


Figure 7. Classification breakdown of the 145 pollinators captured for all target plant species at each position across all sites.

Pollinator catches showed significant variation among the target plant species but did not contain a position effect (inland vs coast) (Figure 8). Lack of homogeneity within residuals led to the use of a Negative-Binomial model with a significant fixed effect in target plant species. A Tukey Pairwise post-hoc test showed a significant difference

between *G. baccata* and *V. angustifolium* ($P=0.0011$), *G. bigeloviana* and *G. procumbens* ($P=0.0121$), and *G. bigeloviana* and *V. angustifolium* ($P<0.0001$). *G. bigeloviana* was not significantly different from *G. baccata*, but noticeable variation in ranges can be seen compared to the other three target species. Variation amongst means can also be noticed throughout each target species with *G. bigeloviana* having the highest and *V. angustifolium* with the lowest. Although position was not significant, Figure 9 displays a noticeable trend of higher catch rates at more inland plots versus more coastal for all target plant species.

Pearson's correlation tests used transformed data for pollinator catches and found that catches and the number of target species flowers are significantly correlated with a positive correlation coefficient of 0.438 and a p-value of 0.0122 (Table 5). Pollinator catches was not significantly correlated with the number of co-flowering species or the number of surrounding flowers.

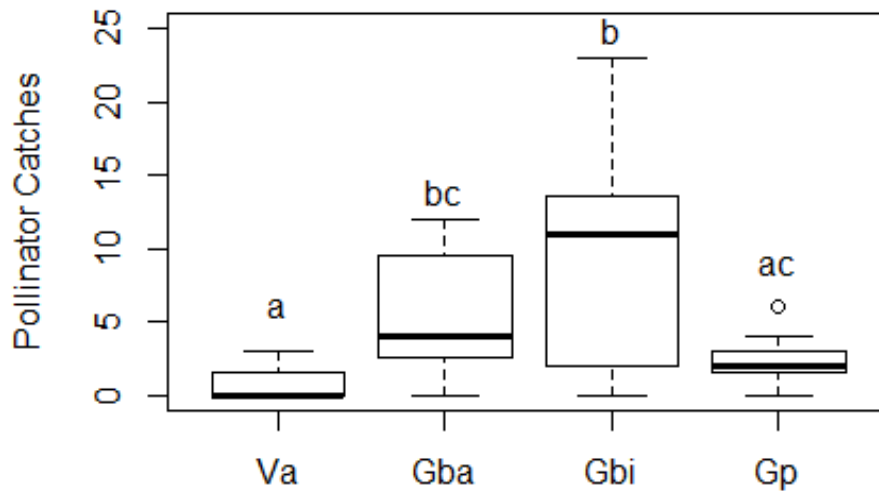


Figure 8. Number of pollinators caught for each of the target plant species. “Va” is *V. angustifolium* sampled between June 13 and June 22, 2018. “Gba” is *G. baccata* sampled between June 26 and July 3, 2018. “Gbi” is *G. bigeloviana* sampled between July 6 and July 12, 2018. “Gp” is *G. procumbens* sampled between August 3 and August 10, 2018. Bars that share a letter are considered not to be significantly different.

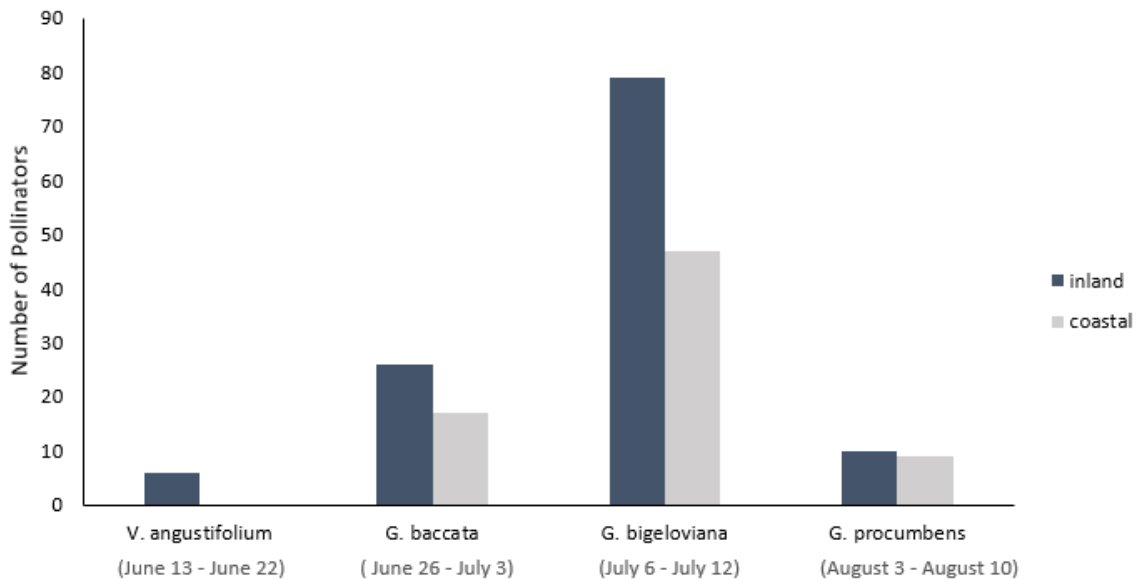


Figure 9. Total number of pollinators caught at inland versus coastal positions for all target plant species across all four sites.

Pollinator visit data were not normally distributed and so transformations were made. A Two-way ANOVA test was completed that showed a significant effect only in plant target species ($P=0.00089$), with no significant effect in position ($P=0.9666$). Tukey Pairwise post-hoc test showed *G. procumbens* having significantly different pollinator visits than the other three target species (Figure 10). *G. baccata*, although not significantly different from *V. angustifolium* or *G. bigeloviana*, had higher ranges in pollinator visits.

Pearson's correlation tests used transformed data for pollinator visits and found that visits were significantly correlated with all three floral variables (Table 5).

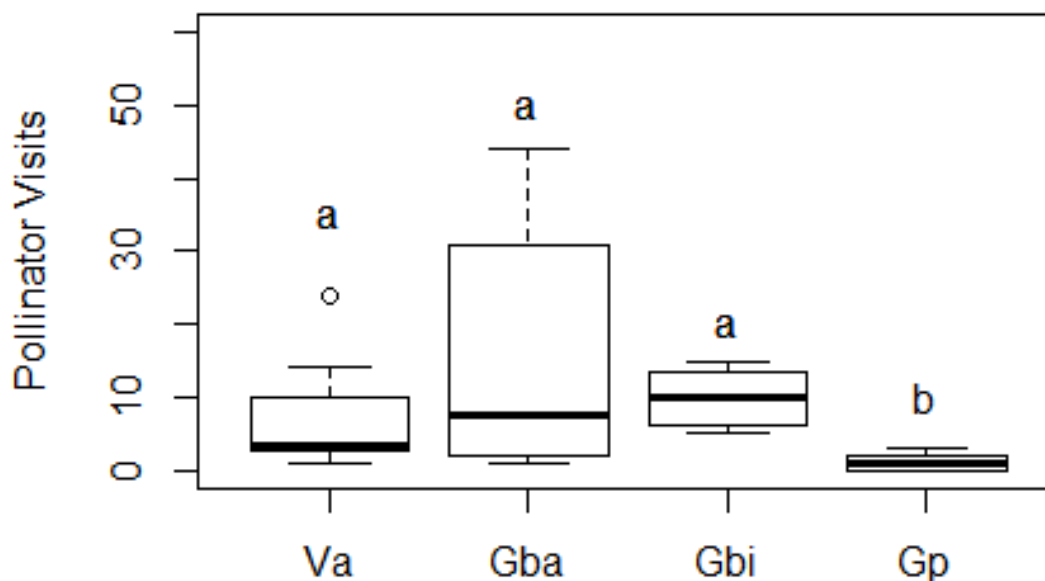


Figure 10. Number of pollinator visits for each of the target plant species. “Va” is *V. angustifolium* sampled between June 13 and June 22, 2018. “Gba” is *G. baccata* sampled between June 26 and July 3, 2018. “Gbi” is *G. bigeloviana* sampled between July 6 and July 12, 2018. “Gp” is *G. procumbens* sampled between August 3 and August 10, 2018. Bars that share a letter are considered not to be significantly different.

3.2 Pollinator Richness

Species richness of pollinators varied amongst the target plant species. *V. angustifolium* and *G. procumbens* contained the lowest pollinator richness levels with four and five species making up their catches, respectively. *G. baccata* and *G. bigeloviana* had higher pollinator richness numbers with 18 and 21 morphospecies, respectively. Each target species contained one morphological species that was found in higher abundances. *V. angustifolium* had the highest presence of morphospecies *Diptera k* (50%), *G. baccata* and *G. bigeloviana* both had *Andrena a* (49% and 37% respectively), and *G. procumbens* had *Bombus a* (68%) as the dominant pollinator morphospecies (Figure 11).

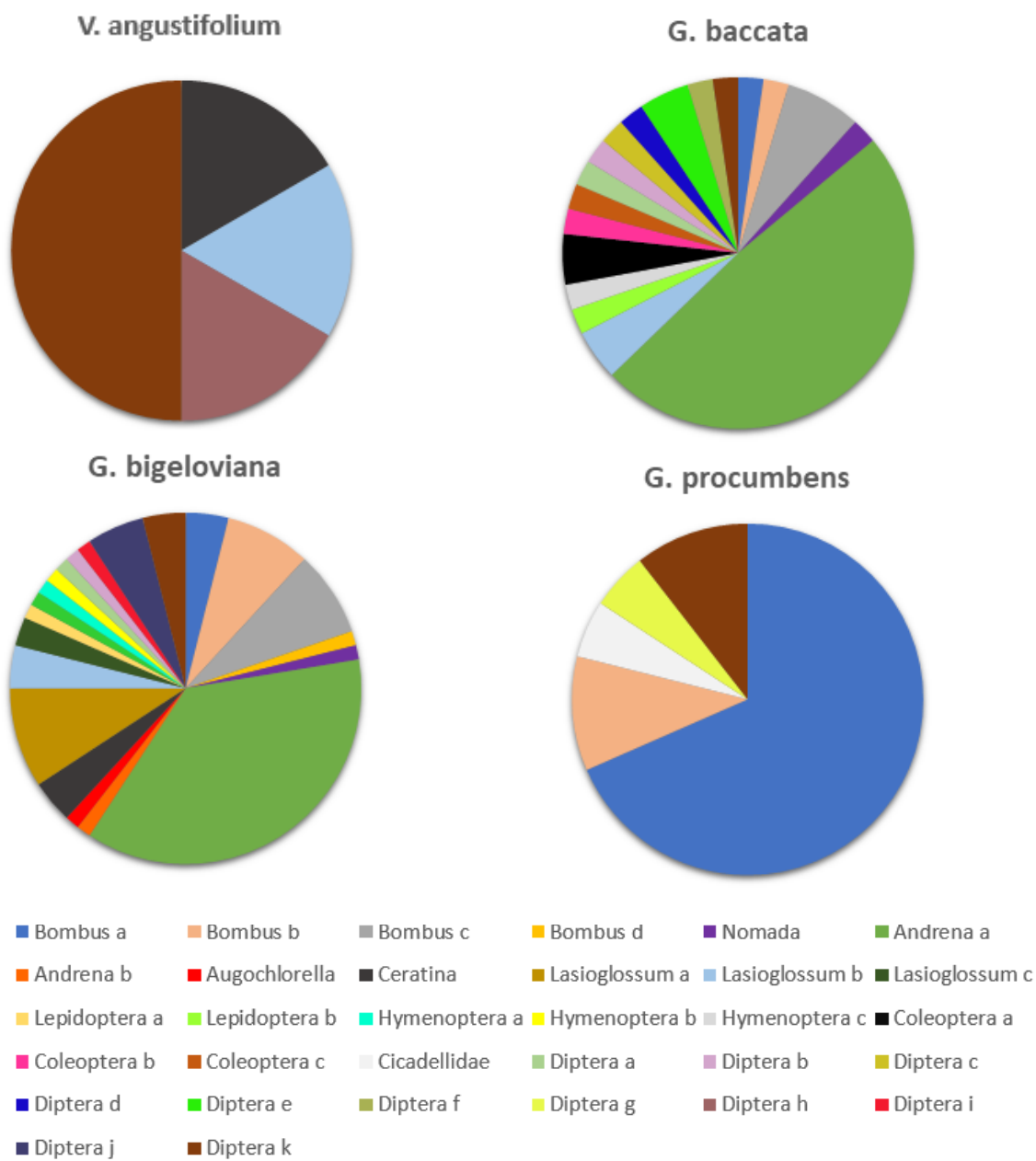


Figure 11. Pollinator morphospecies breakdown for pollinators caught during sampling periods for each of the target plant species.

For pollinator richness, an ANOVA test found a main effect for target plant species ($P=0.00638$), but no main effect of position. Pollinator richness was significantly different between *G. bigeloviana* and *V. angustifolium* ($P=0.0242$). *G. bigeloviana*, although not significantly different from *G. baccata* and *G. procumbens*, contained larger ranges for pollinator richness (Figure 12). *V. angustifolium* experienced a lower pollinator richness mean than that of the other target species.

Pearson's correlation tests used transformed data for pollinator richness and found a significant positive correlation with the number of target species flowers (correlation coeff. = 0.437, p -value = 0.0123) (Table 5). Pollinator richness was not significantly correlated with the number of co-flowering species or the number of surrounding flowers.

Table 2 sums up pollinator richness, catches, and visit data collected for each target plant species.

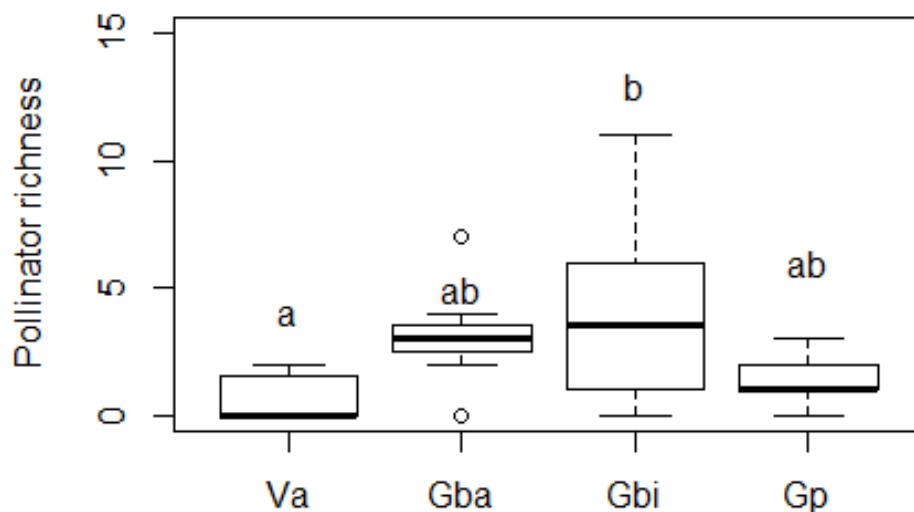


Figure 12. Pollinator morphospecies richness for each of the target plant species. “Va” is *V. angustifolium* sampled between June 13 and June 22, 2018. “Gba” is *G. baccata* sampled between June 26 and July 3, 2018. “Gbi” is *G. bigeloviana* sampled between July 6 and July 12, 2018. “Gp” is *G. procumbens* sampled between August 3 and August 10, 2018. Bars that share a letter are considered not to be significantly different.

Table 2. A summary of total pollinator richness, catches, and visit data obtained from each of the target plant species at both sampled positions across all sites (n=8 sample periods per species).

	<i>V. angustifolium</i>		<i>G. baccata</i>		<i>G. bigeloviana</i>		<i>G. procumbens</i>	
	Inland	Coast	Inland	Coast	Inland	Coast	Inland	Coast
Catches	6	0	26	17	45	31	10	9
Visits	42	15	84	42	35	44	4	5
Pollinator Richness	4	0	10	10	15	13	3	4

Table 1 displays the variation and similarities in morphospecies obtained from the target plant species. *V. angustifolium* shared pollinator species with each of the other plant species and also contained one pollinator only found in *V. angustifolium* (*Diptera h*). *G. baccata* had eight pollinators not found foraging on the other plant species. *G. bigeloviana* had 10 morphospecies found only during its sampling period, while *G. procumbens* had two morphospecies (Table 3).

Table 3. Morphospecies found only on the target plant species during sampling.

Plant species	Morphospecies
<i>V. angustifolium</i>	Diptera h
<i>G. baccata</i>	Hymenoptera c; Coleoptera a; Coleoptera b; Coleoptera c; Diptera c; Diptera d; Diptera e; Diptera f
<i>G. bigeloviana</i>	Bombus d; Andrena b; Augochlorella; Lasioglossum a; Lasioglossum c; Lepidoptera a; Hymenoptera a; Hymenoptera b; Diptera i; Diptera j
<i>G. procumbens</i>	Cicadellidae; Diptera g

Shared pollinators also occurred between the target plant species. *Andrena a* was not only the top pollinator caught, but was also only found on both the *Gaylussacia* species. *G. baccata* and *G. bigeloviana*, although shared pollinators with both *V. angustifolium* and *G. procumbens*, contained the highest number of shared pollinators between the two with six pollinators being found only during their sampling periods. *V. angustifolium* and *G. procumbens* both had the most shared pollinators with the *Gaylussacia* species. Only one species was found foraging on all four target species; *Diptera k* (possible flesh fly, within the *Sarcophagidae* family).

3.3 Vegetation Survey

Several co-flowering species were available during each sample period of the target flowers (Table 4). *Sibbaldiopsis tridentata* was the only species found flowering throughout each of the four target plant species plots over the entire sampling time. *G. baccata* and *G. bigeloviana* had the most co-flowering species present while *G. procumbens* had the least.

Table 4. Co-flowering plant species identified during sample periods for each target plant species.

Co-flowering Species	June 13 - June 22	June 26 - July 3	July 6 - July 12	August 3 - August 10
	V. <i>angustifolia</i>	G. <i>baccata</i>	G. <i>bigeloviana</i>	G. <i>procumbens</i>
<i>Kalmia polifolia</i>	x	x		
<i>Vaccinium angustifolia</i>	x	x		x
<i>Photinia melanocarpa</i>	x	x		
<i>Prunus pensylvanica</i>	x	x		
<i>Rhododendron canadense</i>	x	x		
<i>Trientalis borealis</i>	x	x	x	
<i>Hudsonia ericoides</i>	x	x		
<i>Sibbaldiopsis tridentata</i>	x	x	x	x
<i>Ledum groenlandicum</i>	x	x	x	
<i>Cornus canadensis</i>	x	x	x	
<i>Vaccinium vitis-idaea</i>	x			
<i>Maianthemum canadense</i>	x			
<i>Cypripedium acaule</i>	x			
<i>Gaylussacia baccata</i>	x	x	x	
<i>Arctostaphylos uva-ursi</i>		x		
<i>Sarracenia purpurea</i>		x	x	x
<i>Alnus viride</i>		x		
<i>Rubus hispidus</i>		x	x	
<i>Kalmia angustifolia</i>		x	x	
<i>Gaylussacia bigeloviana</i>		x	x	
<i>Vaccinium macrocarpon</i>		x	x	
<i>Melampyrum lineare</i>			x	x
<i>Viburnum nudum</i>		x	x	
<i>Calopogon tuberosus</i>			x	
<i>Trifolium repens</i>			x	
<i>Trifolium pratense</i>			x	
<i>Gaultheria procumbens</i>				x
<i>Rosa virginiana</i>			x	
<i>Oenothera biennis</i>			x	
<i>Spiraea alba</i>			x	x
<i>Arethusa bulbosa</i>			x	
<i>Solidago bicolor</i>				x
<i>Oclemena nemoralis</i>				x
<i>Ilex glabra</i>				x

An ANOVA test determined a significant main effect in target plant species ($P=0.000806$), but no main effect in position for the number of surrounding flowers. A Tukey Pairwise post-hoc test found a significant difference between *G. baccata* and *G. procumbens* ($P=0.0415$), and *G. bigeloviana* and *G. procumbens* ($P=0.0016$). *V. angustifolium* was not significantly different from any of the other three target species. A much larger range in surrounding flowers in *G. bigeloviana* was experienced, as seen in Figure 13.

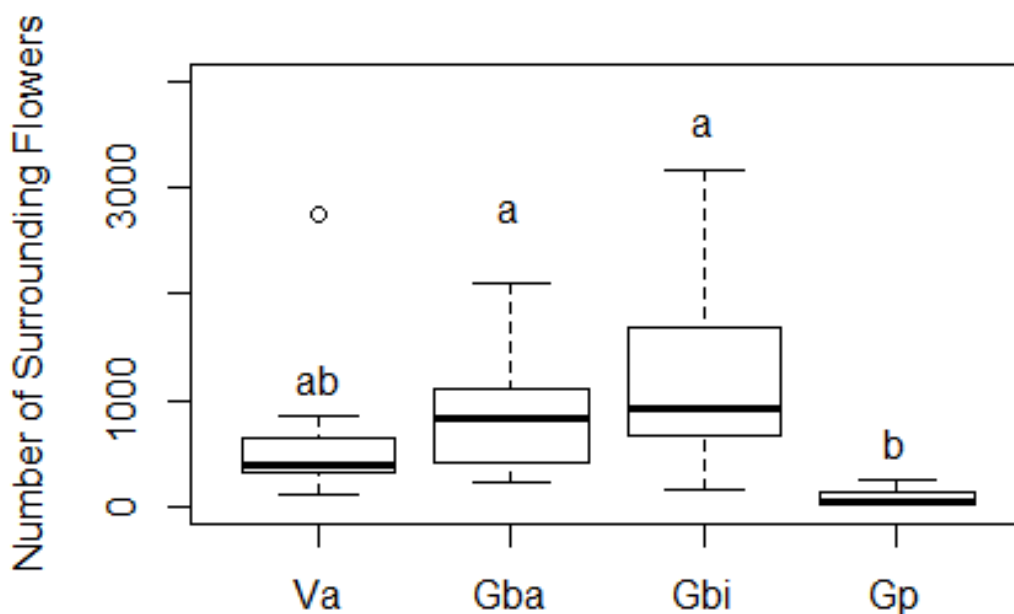


Figure 13. Number of surrounding flowers present during sampling for each of the target plant species.

“Va” is *V. angustifolium* sampled between June 13 and June 22, 2018. “Gba” is *G. baccata* sampled between June 26 and July 3, 2018. “Gbi” is *G. bigeloviana* sampled between July 6 and July 12, 2018. “Gp” is *G. procumbens* sampled between August 3 and August 10, 2018. Bars that share a letter are considered not to be significantly different.

Lack of normality in the number of target flowers data resulted in the use of transformed data. ANOVA showed significant main effects in both target species ($P < 0.0001$) and position ($P = 0.001713$), but no interaction effect between the two. This result determined that the additive model was best (position + target species). A Tukey Pairwise post-hoc test on the target species effect showed that *G. baccata* and *G. bigeloviana* were not significantly different ($P = 0.8861$), as well as *V. angustifolium* and *G. procumbens* showing no significant difference ($P = 0.9997$) (Figure 14). A much larger range in the number of target flowers can be seen in *G. bigeloviana* compared to the other target plant species. The Tukey Pairwise post-hoc test showed a significant difference between inland and coastal position ($P = 0.0017$). Inland plots had a slightly larger average number of target species flowers compared with the coastal plots (Figure 15).

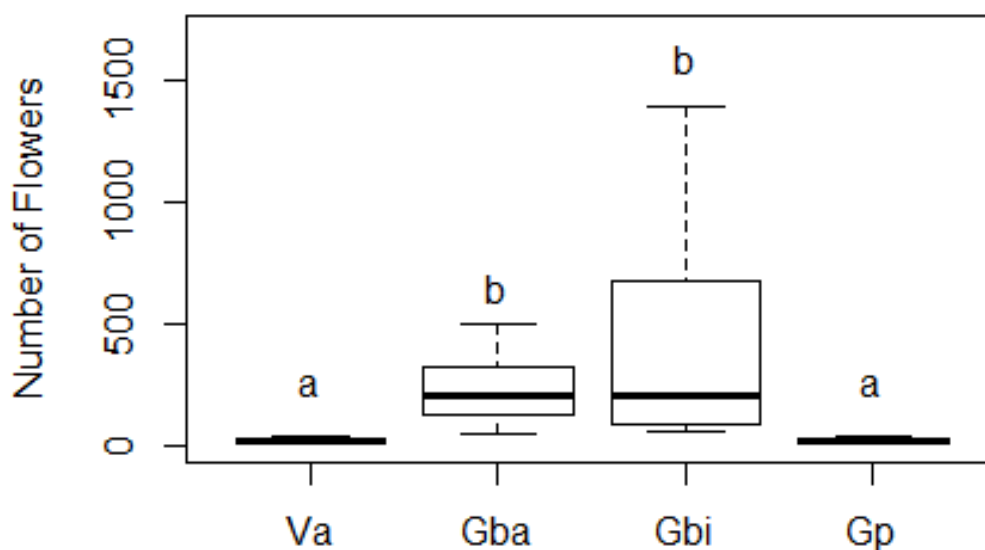


Figure 14. Number of flowers present on each of the target plant species. “Va” is *V. angustifolium* sampled between June 13 and June 22, 2018. “Gba” is *G. baccata* sampled between June 26 and July 3, 2018. “Gbi” is *G. bigeloviana* sampled between July 6 and July 12, 2018. “Gp” is *G. procumbens* sampled between August 3 and August 10, 2018. Bars that share a letter are considered not to be significantly different.

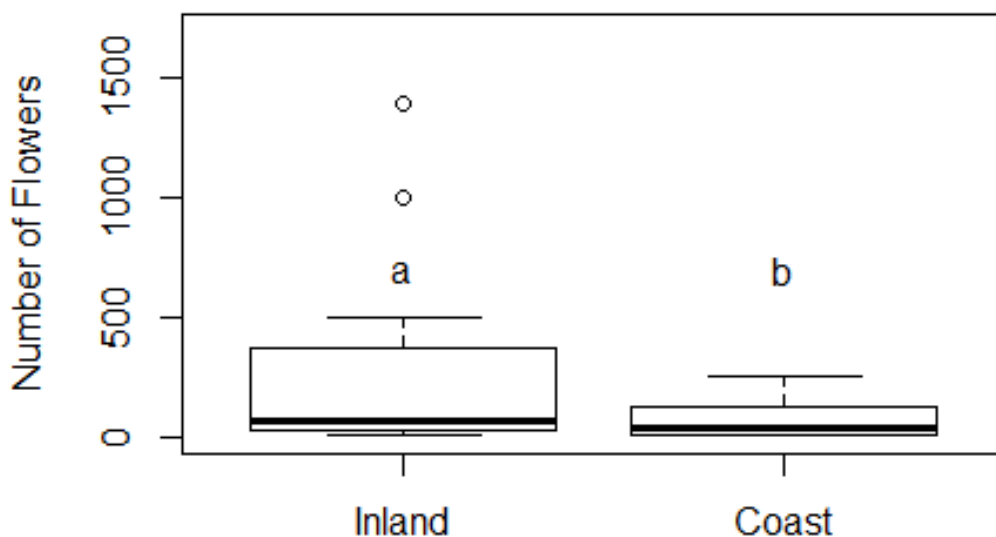


Figure 15. Number of flowers present on each of the target plant species within both inland and coastal positions. Bars with different letters are considered to be significantly different.

For number of co-flowering species (other species flowering at the same time as the target species), an ANOVA test showed a significant main effect of target species ($P < 0.0001$), but no significant interaction between species and position, and no significant main effect of position. A Tukey Pairwise post-hoc test showed *G. procumbens* to be the only species with significantly lower numbers of co-flowering species compared with the other target species ($P < 0.001$), and no significant difference found between *V. angustifolium*, *G. baccata*, and *G. bigeloviana* for the number of co-flowering species present (Figure 16).

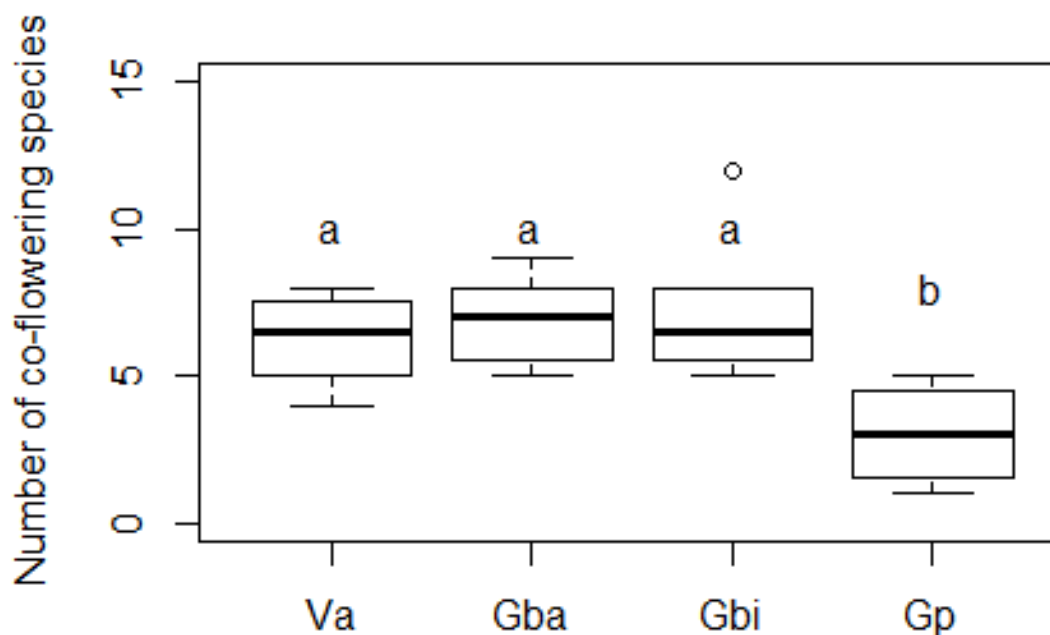


Figure 16. Number of co-flowering species present with each of the target plant species. “Va” is *V. angustifolium* sampled between June 13 and June 22, 2018. “Gba” is *G. baccata* sampled between June 26 and July 3, 2018. “Gbi” is *G. bigeloviana* sampled between July 6 and July 12, 2018. “Gp” is *G. procumbens* sampled between August 3 and August 10, 2018. Bars that share a letter are considered not to be significantly different.

Table 5. Correlation tests using the Pearson correlation method to determine the relationship between pollinator variables and floral variables. Bolded values are significantly correlated.

Pollinator Variables	Floral Variables					
	Target Flower Numbers		Co-Flowering Species		Surrounding Flowers	
	p-value	Corr. Coeff	p-value	Corr. Coeff	p-value	Corr. Coeff
Catches	0.0122	0.438	0.885	-0.0266	0.497	0.124
Visits	0.0174	0.418	0.0385	0.368	0.00254	0.515
Pollinator Richness	0.0123	0.437	0.984	-0.004	0.394	0.156

3.4 Environmental Factors

Mean monthly temperatures displayed a trend of low temperatures in April and May and higher temperatures in June, July and August between years 2008 and 2018 (Table 6). April experienced a drop-in temperature from 2017 to 2018 (5.2°C to 4.1°C) with a slight increase in May temperatures (10.2°C to 10.7°C). Over the recorded years, August of 2018 experienced the highest monthly temperature of 21°C.

Monthly total precipitation did not show noticeable trends between the recorded years (Table 7). The highest total monthly precipitation was experienced in August of 2008 with 299.4 mm of rainfall, with the next highest rainfall experienced in April of 2018 with 204.2 mm. Total precipitation was lowest in the year 2014 with 365.9 mm of rain between April and August, and higher precipitation rates were experienced in years 2008, 2009, 2011, and 2018 between months April and August.

Table 6. Monthly mean temperature (°C) at Halifax Intl A weather station (Environment Canada) between April and August from years 2008 to 2018.

Year	Monthly Mean Temperature (°C)				
	April	May	June	July	August
2008	5.5	9.5	15.6	20.6	18.2
2009	5.4	10.8	15.6	17.6	19.9
2010	7.3	11.1	15.2	19.8	19.4
2011	4.9	10.6	13.7	18.8	18.5
2012	6	11.8	14.6	20	20.7
2013	5	10.4	16.1	21	18.9
2014	4.3	9.3	15.4	20.2	18.4
2015	2	11.4	13.3	18.6	20.7
2016	3.6	10.7	14.4	19.5	19.6
2017	5.2	10.2	15.7	18.6	18.8
2018	4.1	10.7	13.6	20.8	21

Table 7. Monthly total precipitation (mm) at Halifax Intl A weather station (Environment Canada) between April and August from years 2008 to 2018.

Year	Monthly Precipitation (mm)				
	April	May	June	July	August
2008	60.2	134.1	69.1	79.5	299.4
2009	158.8	88.6	149.3	71	179.6
2010	39.9	48	99.6	125.2	65.3
2011	124.2	124.2	144.3	94.3	135.6
2012	91.4	101.8	75.1	58.5	54.1
2013	67.7	99.8	173.6	110.9	67.3
2014	142.7	31.9	111.7	78.8	0.8
2015	103.3	57	154.1	117.4	76.1
2016	159.5	100.1	72.5	73.4	44.5
2017	91	156	69.3	145	93.7
2018	204.2	63.1	178.1	65.9	58

Table 1. Morphospecies of each pollinator collected and identified for all four target plant species at each position across all sites.

Order	Family	Genus	Morpho Spp.	<i>V. angustifolia</i>		<i>G. baccata</i>		<i>G. bigeloviana</i>		<i>G. procumbens</i>	
				Inland	Coast	Inland	Coast	Inland	Coast	Inland	Coast
Hymenoptera	Apidae	Bombus	A	0	0	0	1	2	1	8	5
Hymenoptera	Apidae	Bombus	B	0	0	1	0	6	0	0	2
Hymenoptera	Apidae	Bombus	C	0	0	0	3	5	1	0	0
Hymenoptera	Apidae	Bombus	D	0	0	0	0	1	0	0	0
Hymenoptera	Apidae	Nomada		0	0	1	0	0	1	0	0
Hymenoptera	Andrenidae	Andrena	A	0	0	16	5	14	14	0	0
Hymenoptera	Andrenidae	Andrena	B	0	0	0	0	1	0	0	0
Hymenoptera	Halictidae	Augochlorella		0	0	0	0	0	1	0	0
Hymenoptera	Apidae	Ceratina		1	0	0	0	3	0	0	0
Hymenoptera	Halictidae	Lasioglossum	A	0	0	0	0	6	1	0	0
Hymenoptera	Halictidae	Lasioglossum	B	1	0	0	2	1	2	0	0
Hymenoptera	Halictidae	Lasioglossum	C	0	0	0	0	1	1	0	0
Lepidoptera			A	0	0	0	0	0	1	0	0
Lepidoptera			B	0	0	1	0	1	0	0	0
Hymenoptera			A	0	0	0	0	0	1	0	0
Hymenoptera			B	0	0	0	0	1	0	0	0
Hymenoptera			C	0	0	0	1	0	0	0	0
Coleoptera			A	0	0	2	0	0	0	0	0
Coleoptera			B	0	0	0	1	0	0	0	0
Coleoptera			C	0	0	0	1	0	0	0	0
Hemiptera	Cicadellidae			0	0	0	0	0	0	0	1
Diptera			A	0	0	1	0	0	1	0	0
Diptera			B	0	0	0	1	1	0	0	0
Diptera			C	0	0	1	0	0	0	0	0
Diptera			D	0	0	1	0	0	0	0	0
Diptera			E	0	0	1	1	0	0	0	0
Diptera			F	0	0	0	1	0	0	0	0
Diptera			G	0	0	0	0	0	0	1	0
Diptera			H	1	0	0	0	0	0	0	0
Diptera			I	0	0	0	0	1	0	0	0
Diptera			J	0	0	0	0	1	3	0	0
Diptera			K	3	0	1	0	0	3	1	1

4 Discussion

4.1 Pollinator Assemblage

Although catches primarily consisted of bee species, a variety of pollinator species contributed to the make up of pollinator communities for each of the target plant species (Figure 7). Rader et al., (2016) outlined the importance of non-bee pollinators and their valuable contributions to the pollination process and found that it was not exclusively bee species that make up pollinator communities, a trend also displayed by this present study.

For all target plant species, proximity to the sea was not the significant main effect regarding pollinator catches. This was not the predicted result that species would be influenced by a position effect (inland versus coastal positioning). Although not statistically significant, there was a trend towards higher catch rates at more inland plots than at more coastal plots (Figure 9).

Of the four plant species, the pollinator catch abundance was highest in *G. baccata* and *G. bigeloviana* with a large range in numbers being found in *G. bigeloviana* (Figure 8). *G. baccata* and *G. bigeloviana* also differ significantly from *V. angustifolium* and *G. procumbens* in having a greater number of flowers per plot during flowering periods when pollinators were sampled (Figure 14). This result agrees with the findings of Potts and co-workers (2003) that there is a positive relationship between bee abundances and flower abundances. This may explain the higher pollinator abundance seen on the two species of *Gaylussacia*. This was also supported through the statistical test that found pollinator variables (richness, catches, and visits) to be positively correlated with the number of target flowers. *V. angustifolium*, although not significantly different from *G. procumbens*, had the lowest pollinator catches among the four sampled plant species. *V.*

angustifolium was the first species to be sampled, with collection periods beginning early June (spring season). Walker and Lundholm (2017) found fewer bee species foraging on berry-producing plants in coastal barrens during the spring, which was also seen in this present study. Several co-flowering species were available during the time of *V. angustifolium* sampling (Table 4), and lower flower availability on *V. angustifolium* could be the main contributor to low catch abundances for this plant.

Pollinator visits provided a different picture from pollinator catch results (not all pollinators observed visiting flowers in the plots could be captured). *G. procumbens* was the only target plant species that was significantly different in terms of the number of visits (being lower than the other species) (Figure 10). Moeller (2004) highlighted the importance of co-flowering plant species which can collectively draw in pollinators to the target species, thus sustaining pollination resources for a vegetation community. The plots where *V. angustifolium*, *G. baccata*, and *G. bigeloviana* was sampled, all had an abundance of co-flowering species (Table 4), while *G. procumbens* had fewer co-flowering species available during sampling periods. The lower number of *G. procumbens* pollinator visits and catches could be due to a lack of attractiveness within the plots and lack of other flowering species being available. Statistical analysis found visits to be positively correlated with the number of target flowers, co-flowering species, and the surrounding flowers (Table 5), which confirmed these findings. *G. baccata* had the greatest range in the number of pollinator visits, an interesting finding as both *Gaylussacia* species had a large number of catches, but *G. bigeloviana* had fewer visits. It is difficult to determine if *G. baccata* had a higher number of pollinator visits on some occasions and low numbers on others (giving the wide range), because of a high

pollinator presence or if it was the results of the way visits was estimated (including both pollinators stopping in the plot and/or ones that were missed as a catch). Regardless, visitation rates enable an understanding of pollinator activity for each of the target plant species that can be linked to the vegetation community and its attraction qualities for pollinators.

4.2 Morphospecies

The main pollinator group encountered in this study were two bee genera: *Andrena* (34.5% of total catches) and *Bombus* (25.5% of total catches), as well as flies that belong to the order *Diptera* (17.2% of total catches). The genus *Andrena* are bees within the *Andrenidae* family. Commonly called ‘miner bees’, they can be found nesting in the ground and foraging in early spring (Moisset & Buchmann, 2011). As a result, it was expected that *Andrena* would be a member of the *V. angustifolium* pollinator community. However, this was not found in this study but was found in the study by Walker & Lundholm (2017).

The *Bombus* genus, known as Bumble bees, are within the *Apidae* family. Bumble bees are ground nesters that are highly rated for their pollination services and ability to forage in harsh conditions over longer periods (Packer et al., 2007; Moisset & Buchmann, 2011). Bumble bee morphospecies were found foraging on three of the four target plant species, except *V. angustifolium*. Conversely, Walker & Lundholm (2017) did record *Bombus* foraging on *V. angustifolium*, although the frequency was found to be low. The lack of *Bombus* species found on *V. angustifolium* in the present study could be linked to weather conditions during the *V. angustifolium* flowering season. In 2018, the June monthly mean temperature was 13.6 °C with 178.1 mm of total precipitation. Compared

With data recorded since 2008, these were colder and wetter conditions than normal and could have affected spring flowering plants in 2018 (Table 6 and 7). The wetter and colder spring can also affect the ability of pollinators to pollinate (Walker & Lundholm, 2017). This may also be why *Andrena* was not found foraging in spring on *V. angustifolium* in the present study.

Both *Andrena* and *Bombus* bee species are able to perform buzz pollination; a technique where high frequency of flight muscles vibrates the flower and causes the release of pollen (Jesson et al., 2014). This process is important for species such as *V. angustifolium* as it results in high pollen transfer. However, since neither of these pollinators were among those foraging on *V. angustifolium* during sampling periods, implications for subsequent fruit production could occur (Jesson et al., 2014).

As mentioned earlier, non-bee pollinators play a significant role in pollination and make up a portion of the pollinator communities (Orford et al., 2015). This trend was noted in the present study and *Diptera* morphospecies were commonly collected pollinators on all four target plant species (see Table 1 and Table 3). The results illustrate the importance of identifying all members of the pollinator communities. Some pollinator species are only detected during certain times of the year on some of the target plants. *Andrena a* was only found on the *Gaylussacia spp.*, which shows that its foraging is most abundant, and possibly limited, to particular plant species that bloom during late June to mid July within Nova Scotian coastal barren habitats. The findings in Table 3 imply that the diversity in plant species in coastal barrens is important as it provides vital resources for pollinators.

4.3 Pollinator Richness

Although not significantly different from *G. baccata* and *G. procumbens*, *V. angustifolium* experienced the lowest richness in pollinator species (Figure 12). *V. angustifolium* had high numbers of co-flowering species available during sampling periods compared with both *G. baccata* and *G. bigeloviana*, but exhibited low flower numbers during its blooming period. Correlation tests determined a positive correlation between pollinator richness and the number of target flowers. Low richness can be due to the lack of flowers present on the *V. angustifolium*. As mentioned, the low collection of bees in spring has been observed previously in coastal barren habitats (Walker & Lundholm, 2017). This may be why fly species made up most of the pollinator composition for *V. angustifolium* in the present study (Figure 11).

G. baccata and *G. bigeloviana* experienced the highest richness in their pollinator communities. Higher catch rates, number of flowers on the target species, and number of co-flowering species all likely contributed to this outcome. *G. procumbens* did not differ significantly from any of the other target plant species, although did contain lower pollinator richness compared to that of *G. baccata* and *G. bigeloviana*. *G. procumbens*' primary pollinator was *Bombus a* (Figure 11). Walker (2016) found that bumblebees had higher abundances between June and August, a finding that is supported with this present study as no *Bombus* species were captured during early spring sampling with the highest abundance being caught in August (Table 1).

The second hypothesis was supported here. Pollinator richness was highest in the target plant species that had higher flower numbers present during their flowering periods. *G. bigeloviana* plots were significantly higher than *V. angustifolium* in pollinator

richness as well as number of flowers during its peak flowering time. Potts et al., (2003) identified high pollen availability to be an important factor contributing to the size and richness of a bee community. Similar trends can be seen in *G. baccata* who also had higher pollinator richness counts and higher flower numbers, while *G. procumbens* experienced low flower numbers and pollinator richness.

4.4 Vegetation

Number of flowers was the only variable which differed significantly by position (inland vs coastal) as well as target species. Balsdon et al. (2011) found vegetation located within coastal barrens contained thicker stems and leaves, as well as stunted growth compared to that of close by forests. This relates to the common characteristic experienced by coastal barrens where vegetation is adapted to harsh environmental conditions. Harsh coastal conditions can explain why flower numbers were fewer in the more coastal plots.

Table 4 provides data on the co-flowering species available with the target plant species, as well as the overlap in flowering periods of the target plant species. *V. angustifolium* flowering extends into both *G. baccata* and *G. procumbens* flowering periods. There is an outlier at only one location during one sampling period where a small number of *V. angustifolium* flowers occurred within a buffer zone. *G. baccata* flowering period overlapped with that of *V. angustifolium* sampling and also extended into *G. bigeloviana*'s flowering period. *G. bigeloviana* was found to be flowering at the same time as *G. baccata*. In contrast, *G. procumbens* was only found flowering during its own sampling period (August 3 – August 10). Having an overlap in flowering periods can

increase the attractiveness of a vegetation community for pollinators, as well as providing a diversity of resources.

4.5 Environmental Relevance

Pollinator species were shared amongst the sampled target plant species, although some only foraged on one of the target species (Table 3). This information is important because it identifies specialization within the pollinator communities and highlights the importance of each of the target plant species. If the target plant species was lost to the site, the pollinators foraging during that time of year may have to shift to a new species in order to receive the required resources. This outlines the importance of biodiversity protection within coastal barrens. Ogilvie & Forrest (2017) found that declines in floral availability and plant species may cause significant challenges for pollinators that specialize or are dependent on particular plants, which highlights the importance of coastal barren vegetation communities.

A concern identified through this study was the absence of important pollinators not found foraging during sampled *V. angustifolium*. Identifying these abnormal results, along with pollinator-plant specialization, can assist in conservation efforts and restoration of coastal barren ecosystems.

4.6 Limitations

Although findings of the present study contribute to understanding the pollinator fauna and function in Nova Scotian coastal barren habitats, there are limitations to the conclusions. First, this study only sampled pollinators at noon to maximize chances of catching as many species as possible. Drummond (2016) observed that a wide diversity of pollinators foraged in the middle of the day when temperatures are usually warm.

However, particular pollinator species forage at different times throughout the day (early morning to night). Thus, some pollinator species could have been missed by only sampling at one time in the day (Drummond, 2016). Having shorter collection periods scattered at times throughout the day could provide a better representation of the pollinator communities for each of the target plant species.

Another limitation was that pollinators were not identified down to species level, due to difficulty of identification. Identifying pollinators down to species would reveal more information about the pollinator communities and whether particular pollinators were associated with each of the four target plant species. However, the results obtained are still important for assessing pollinator assemblages on berry-producing plants belonging to the Ericaceae of the Nova Scotia coastal barrens.

5. Conclusion

This study is perhaps the first to identify and document the pollinators that directly forage on members of the Ericaceae within coastal barren habitats of Nova Scotia. The results of this study indicate that sharing of pollinators occurs between the congener species (*G. baccata* and *G. bigeloviana*), as similar pollinator species were found during both sampling periods. Pollinator sharing can benefit plant species and assist in the overall fitness of vegetation communities (Moeller, 2004). The target plant species were also found to have some pollinator species that only foraged on their flowers and not found on other target species. Specialization within pollinator communities, for the target plant species, highlights the importance of their existence (both target plant species and pollinators) within the coastal barren vegetation community.

An important finding with this study, although not the main objective, was the documentation of co-flowering species and their flowering periods within the sampled coastal barren sites. Identifying the co-flowering plant species' season provides valuable information for understanding the vegetation community within coastal barren habitats.

Identifying pollinator species and their plant interactions is important as it increases public awareness and provides a greater understanding of the vital ecological services provided by pollinators. Weather conditions are predicted to become wetter during the spring season for Atlantic Canada as a result of climate change and foraging conditions for early pollinators may be affected (Vasseur & Catto, 2008). This increased pressure from climate change is expected to have a negative impact on coastal barrens and the biological interactions occurring within (Fagúndez, 2013). Thus, documenting the current situation and knowing about the pollinator and plant species is important for this

habitat. As this study was limited to identifying pollinator assemblages in a single season, further research is still needed to effectively portray the composition of pollinator communities of berry-producing plants in the Ericaceae to provide more insight into pollinator systems occurring in coastal barrens habitats of Nova Scotia.

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