

**Habitat provisioning of wild bee pollinators on Nova Scotia heathlands**

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## **Acknowledgments**

We appreciate the help provided by botanist Caitlin Porter and field assistants Hughstin Grimshaw-Surette in the Ecology of Plants in Communities Lab and Logan Gray. We also thank Doug van Hemessen for granting us access to NCC land near Deep Cove, Bragg Lumber Company Ltd. and Bruce Mowatt for access to blueberry fields, and to both Sheila Dumesh and Dr. Jason Gibbs for expert verification of bee specimens. Thanks to all who helped to coordinate our public talks: Jane Barker at MTRI, Keith Vaughan with the Halifax Field Naturalists, and Ian Avery, President of the Nova Scotia Federation of Anglers and Hunters.

## **Permits**

Permits were obtained for conducting scientific research and sampling bees in Cape Breton Highlands National Park (CBH-2015-18844 – ADDENDUM), Nova Scotia provincial Nature Reserves (RL201606NR), and Nova Scotia provincial Wilderness Areas (RL201603WA). Permission to sample at Deep Cove was obtained from the Nature Conservancy of Canada (granted by Doug van Hemessen).

## **Dissemination of Research**

E. Walker presented these findings to the public at the Mersey Tobeatic Research Institute on 27 November 2016. She has scheduled a public talk to share these results with the Halifax Field Naturalists on 4 June 2017. She will be presenting this research at the AGM of the Nova Scotia Federation of Anglers and Hunters on 25 March 2017. We intend to publish the results of this research in a peer-reviewed scientific journal in 2017. Vouchers will be deposited at the Nova Scotia Museum of Natural History – catalogued data is available from E. Walker.

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## **Project Summary**

Our project examined the abundance and diversity of native bee pollinators present in three heathland habitat types during peak flowering of spring blooming berry species and rare plant species in Nova Scotia. We collected bees, along with their associated floral records, in late May and June within coastal, inland, and highland heathlands. We measured rates of blueberry flower visitation by bees, as well as flower abundance and resulting fruit set, in natural coastal barrens and managed lowbush blueberry fields.

### ***Bee abundance & diversity***

Abundance data from aurally netted and bowl-collected samples indicate potentially low wild bee activity during peak bloom of berry producing species and especially rare boreal *Vaccinium* species in our provincial heathlands. However, high quality pollinators like *Andrena* and *Bombus* are visiting berry-producing plants and *Hudsonia ericoides*. Diverse bee species are present in heathland environments, 97% of which are known pollinators of provincial fruit crops, but low abundances this spring highlight the importance of further monitoring these bee communities. One species has been identified as a tentative new provincial record, *Osmia nigriventris*, which has been examined by both Sheila Dumesh (York University) and Dr. Jason Gibbs (University of Manitoba).

### ***Blueberry visitation & fruit set***

We used blueberry patch visitation rates by native bees and honeybees (*Apis mellifera*) to generate fruit set estimates in natural and commercially managed heathland. Lowbush blueberry fruit set was higher in commercial fields relative to wild coastal barrens. However, estimates of blueberry fruit set calculated from bee visitation rates underestimated observed fruit set in both natural and managed barrens habitat, with both measures indicating suboptimal fruit set. Lower visitation rates and observed fruit set in coastal barrens suggest that reduced pollination services could be limiting wild fruit set in years with poor pollination weather.

### ***Implications for conservation***

Low bee abundance and significant unsampled species diversity indicate that bee communities warrant continued sampling in Nova Scotia heathland habitat. Adverse foraging conditions (low temperatures, wind, rain) may explain the low abundances observed this spring. Consequently, we recommend further research on heathland bee communities to determine the range of annual fluctuations in population size and community composition to improve baseline species inventories and to clarify the risks to pollination services posed by the climate change scenarios predicted for Atlantic Canada. We further suggest expanded monitoring of fruit set in key berry producing shrubs, such as serviceberry (*Amelanchier spp.*), chokeberry (*Photinia melanocarpa*), and huckleberry (*Gaylussacia spp.*), to more precisely quantify wild fruit production in heathlands.

## **Project Objectives**

We identified three primary objectives for this project.

1. Quantify the abundance and identity of wild bee species visiting flowers of key berry-producing shrubs and compile the floral records for each bee species in each of three heathland habitats. We completed 35 capture periods (30 minutes each) in 10 heathland locations to collect these data.
2. Quantify the abundance and identity of wild bee species visiting rare plants, compile bee pollinator records for each rare plant evaluated, and assess potential bee-plant networks unique to each of three heathland habitats. We completed 20 capture periods (30 minutes each) in 7 heathland locations to collect these data.
3. Predict fruit set in heathland and managed lowbush blueberry (*V. angustifolium*) using wild bee visitation rates, to allow for an estimation of the blueberry crop yields. We visited two field sites (4x) and two coastal heathland sites (4x) to collect these data.

## **Project Modifications**

- Expansion of sampling: we originally proposed to sample two sites per heathland type but were able to sample at least three sites per heathland type.
- Modification of blueberry monitoring: due to the distances between sites, we opted to compare only coastal heathlands with commercial blueberry fields, but we intensified the sampling protocol to include flower and berry counts for more precise fruit set determination.

## Methods

### *Heathland bee surveys*

#### *Site selection*

Berry producing plant species bloom in the spring in Nova Scotia. Accordingly, our sampling of wild bees targeted the last week of May and the month of June in 2016. The site-selection process was informed by large-scale provincial data sets (e.g. NSDNR's Spatially Related Forest Resources Information System) and finer-scale previously collected data (e.g. unpublished plant community data, Basquill, Lundholm, & Porter 2010 - 2015). We define heathland here as low-nutrient habitat that is dominated by ericaceous shrubs and features low tree canopy cover, humus-rich soils, and (often) exposed conditions. Coastal heathlands are directly adjacent to the ocean and are influenced by coastal environmental factors. Inland heathlands are not directly impacted by coastal influences (e.g. salt-spray) and are maintained by non-coastal processes (e.g. history of grazing or fire, bedrock exposure, etc.). In Nova Scotia, highland heathlands occur only on Cape Breton Island and can be distinguished by outcrop plant communities that are boreal or alpine in nature; these highland heathlands can be much more extensive than those located on the mainland and are subject to strong winds (les suêtes).

We selected 10 field sites across the province (Figure 1) that represented coastal, inland, and highland heathland habitat with many berry producing plant species (Table 1), and attempted to include sites that featured populations of select rare plant species (Table 1) and sites at which bears had been observed. We considered records of bears or bear foraging as useful (and, for local observers, memorable and obvious) indicators of the importance of the site to dependent consumers.

Given the short amount of time available to select sites (project contract effective 17 May 2016) and obtain relevant permits, we could not satisfy those three criteria for all sites, and we prioritized sampling of berry producing shrubs (Table 2), though rare plant species were located at several sites. Populations of *Hudsonia ericoides* were located at Chebucto Head, Polly's Cove, and Castle Rock. White Point was the only site to host *Shepherdia canadensis*, and the two rare species of *Vaccinium* were located at highland

sites only (Paquette Lake, Mica Hill, Lake of Islands). A population of *V. corymbosum* was located at Comeau's Hill and was included in the bee survey as this is a relatively uncommon species with a southern distribution.

Once identified as a potential bee sampling location, we visited each site prior to the bee survey to verify that the habitat was appropriate (i.e. many berry-producing shrubs, satisfied our definition of heathland, accessible) and to collect coordinates for the most suitable sampling location. Bee sampling activity began at 09:00, so scoping of distant sites (Yarmouth County, Victoria County) could not be completed on the same day as the bee collection.

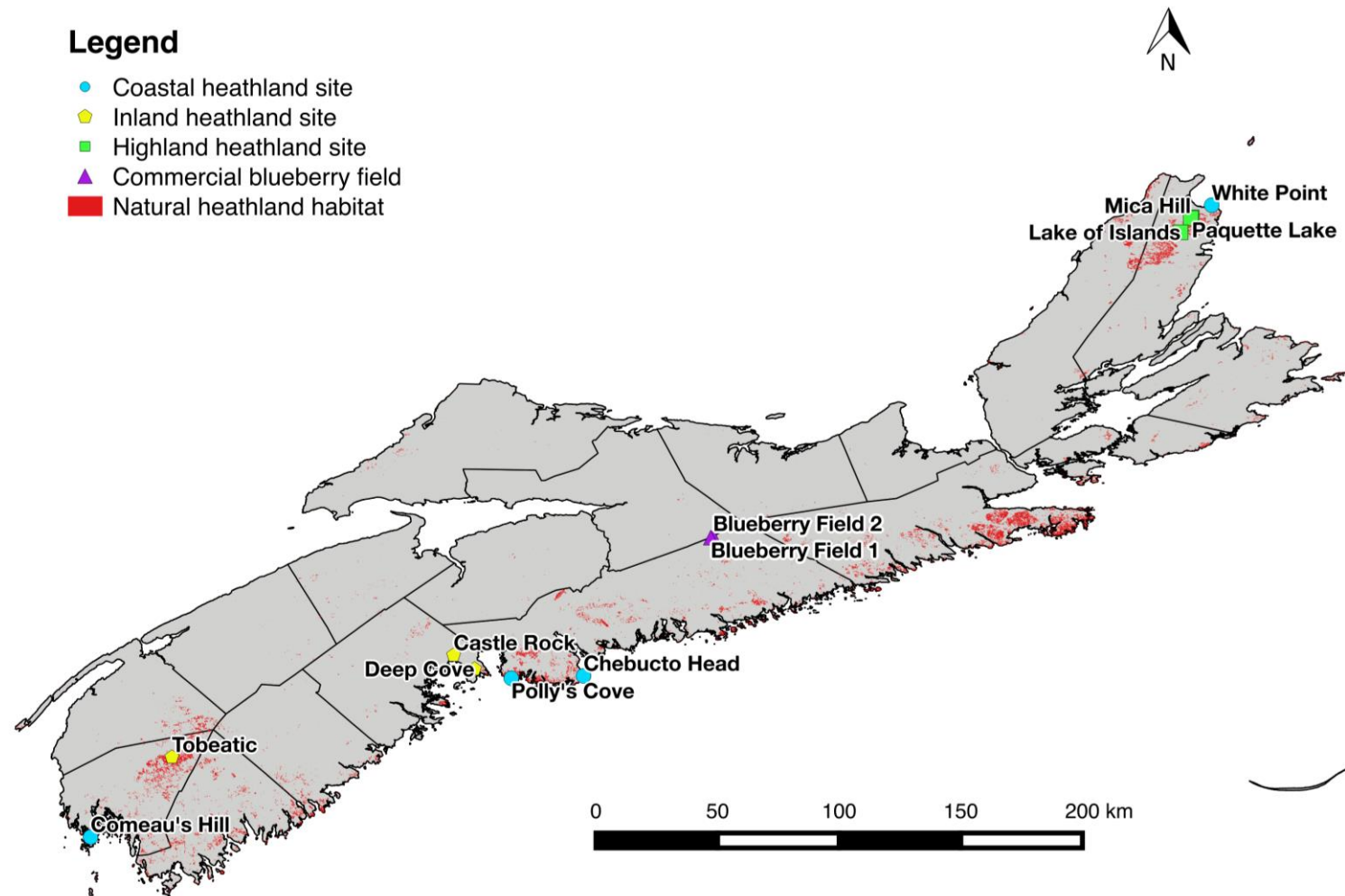
**Table 1.** Some early flowering (May-June) berry-producing plant species and target rare plant species found in Nova Scotia heathland habitat

Berry producing species		Rare species
<i>Amelanchier</i> spp.	<i>Photinia</i> spp.	<i>Hudsonia ericoides</i>
<i>Aralia nudicaulis</i>	<i>Prunus</i> spp.	<i>Shepherdia canadensis</i>
<i>Arctostaphylos uva-ursi</i>	<i>Ribes</i> spp.	<i>Vaccinium boreale</i>
<i>Cornus canadensis</i>	<i>Rubus</i> spp.	<i>V. uliginosum</i>
<i>Gaylussacia</i> spp.	<i>Sambucus racemosa</i>	
<i>Ilex mucronata</i>	<i>Vaccinium</i> spp.	
<i>Maianthemum</i> spp.	<i>Viburnum nudum</i>	

**Table 2.** Field site information for the 2016 heathland bee project.

Site	Survey(s)	Capture dates	Latitude	Longitude	Berry	Rare	Bear
Comeau's Hill	A, B	June 5	43.689794 N	66.015583 W	+		+
Tobeatic	A, B	May 21	44.093486 N	65.604892 W	+		+
Castle Rock	A, B	June 18	44.608222 N	64.181583 W	+	+	
Deep Cove	A, B	June 17	44.538667 N	64.075861 W	+		+
Polly's Cove	A, B, LBB <sup>1</sup>	June 16	44.491373 N	63.889624 W	+	+	
Chebucto Head	A, B, LBB <sup>1</sup>	May 26, June 27	44.503879 N	63.524829 W	+	+	+
Lake of Islands	A, B	June 23	46.744542 N	60.507975 W	+	+	
Paquette Lake	A, B	June 11	46.819639 N	60.451750 W	+	+	
Mica Hill	A, B	June 20	46.815944 N	60.456361 W	+	+	
White Point	A, B	June 10	46.881111 N	60.350806 W	+	+	
Blueberry Field 1	LBB	N/A	45.202122 N	62.881989 W	+		
Blueberry Field 2	LBB	N/A	45.209886 N	62.870267 W	+		

<sup>1</sup>LBB refers to surveys of lowbush blueberry flower, fruit, and bee visitor counts. Lowbush blueberry survey dates not included.



**Figure 1.** Map of sampling locations in Nova Scotia. Extent of natural heathland habitat was mapped using Nova Scotia Department of Natural Resources data (2015) from the Spatially Related Forest Resources information system.



### *Capture, processing, & identification*

The field collection of bees involved both timed aerial net collection and passive bowl trap arrays. The combination of these methods yields a more comprehensive sample of bee diversity (Wilson et al. 2008). Our wild bee sampling protocol followed LeBuhn and co-workers (2003) and was modified to accommodate our project constraints. We only visited one site per day as setup began at 09:00 and collection ceased at 15:00. Although it is preferable to sample bees under favourable conditions (sunny, temperature above 18°C, low wind) (Drummond 2002), these criteria are not frequently met in the spring in Nova Scotia, especially in foggy, windy heathlands. Therefore, we undertook sampling of bees as long as temperatures were not cold (10°C or above) and there was no rain.

Bowl traps consisted of 3.25 oz. portion cups (Solo Cup Company, Illinois, USA) primed with white paint and either left white or painted with fluorescent blue or fluorescent yellow paint. We filled the bowls to half capacity with soapy water (Dawn Ultra dish soap, Proctor & Gamble, Ohio, USA) and deployed them at 09:00. We arranged 30 bowl traps evenly along two 50 m perpendicular transects (5 each of white, blue, and yellow bowls per transect; colour positions randomized). The transects were arranged perpendicular to one another within a site, placed in regions with the densest bloom of berry-producing plants.

Once pan traps were deployed in the morning, we conducted at least four 30-minute net collection periods: two 30-minute net collections occurred in the morning, 09:00- 12:00, and two occurred in the afternoon, 12:00-15:00. At sites that featured populations of rare plant species, we spent one morning collection interval collecting bees from the rare plant species, and the other collecting bees visiting berry-producing plant species. This was repeated in the afternoon. If no rare plants were present at the site, we only sampled bees visiting berry-producing plants. When bees were observed to forage within a site but were not visiting berry-producing species, we collected them on non-berry producing plant species (e.g. *Rhododendron canadense*, *Kalmia latifolia*) to ensure that at least some bees were collected at each site. Our sampling schedule allowed for us to sample wild bees visiting berry-producing plants and/or rare plant species in both the morning and afternoon, as diurnal foraging patterns can differ among bee

species. For bees that were caught with nets, we recorded the floral host and identified each plant to species. During capture, we exposed bees to ethyl acetate then transferred them to glassine envelopes for transport back to the lab. At 15:00, we inspected bowl trap contents and removed all bees, storing them in 70% ethanol until pinned.

Net collected bees returned to the lab were frozen until processed. We washed large and hairy specimens to facilitate identification. We labeled pinned bees by locality, date, habitat, collector, and floral host. E. Walker identified specimens to species using published taxonomies (and revisions) (Bouseman & LaBerge 1978; LaBerge & Ribble 1975; LaBerge 1969; LaBerge 1973; LaBerge 1977; LaBerge 1980; LaBerge 1985; LaBerge 1989; Lavery & Harder 1988; Mitchell 1960; Mitchell 1962; Gibbs 2010; Gibbs 2011; Gibbs et al. 2013; Rehan & Sheffield 2011; Rightmyer et al. 2010). We sent a subset of the bee specimens to the lab of Laurence Packer at York University for expert verification by Sheila Dumesh, and followed up on tentative provincial records of *Lasioglossum* and *Osmia* by sending these specimens to Dr. Jason Gibbs at the University of Manitoba. We assigned bees to guilds according to Sheffield and co-workers (2013), and determined social vs. solitary ground-nesting habits for *Lasioglossum* according to Gibbs' (2013) suggestion that *Lasioglossum* featuring black-coloured integument (*L. (Hemihalictus) s.l.*) tend to be solitary ground-nesting species whereas the metallic integument species of *L. (Dialictus)* (*sensu* Michener 2007; Gibbs 2011) tend to exhibit colonial (eusocial) nesting lifestyles, as studies of sociality have not been performed for many of these species.

#### *Assessment of foraging conditions*

We only recorded weather conditions as field notes due to lack of instrumentation, but it was apparent that this spring featured many low temperature, rainy, and/or windy days, representing typical conditions for June in Nova Scotia. To better characterize the foraging conditions experienced by wild bees in Nova Scotia, we accessed Environment Canada historical weather data for June 2016 from four weather stations that were located relatively near to regions that were sampled in this project and for which relatively complete recent records were available: Yarmouth RCS, Shearwater RCS, Upper Stewiacke RCS, and Ingonish RCS.

Minimum daily temperature, total daily rainfall, and maximum wind speed all impact bee foraging activity. Maximum daily wind speed values presented in this report represent either the maximum wind gust recorded by Environment Canada for a given date or, when those data were not available, the maximum hourly wind speed reported for that date. Minimum daily temperatures presented in this report represent the minimum daily temperature recorded by Environment Canada at a given weather station between sunrise and sunset for June 2016 (05:00 -20:00). There is limited literature on the impact of temperature on species included within the bee fauna of Nova Scotia; however, several studies have explored the thermal limits of non-native congeners of bee species in Nova Scotia (Appendix A). Very limited literature describes the wind speed or precipitation limits of different bee species; based on a review of the literature and observations by Drummond (2002) of bees foraging on lowbush blueberry blooming in Maine, we considered minimum daily temperatures below 15°C, wind speeds above 30 km/h, and rainfall events above 1.0 mm to represent adverse foraging conditions for bees.

## ***Blueberry monitoring***

### *Site selection*

This phase of the project involved the counting of flowers and fruit of lowbush blueberry (*Vaccinium angustifolium*) in natural heathland and cultivated fields. We also monitored rates of wild bee visitation to lowbush blueberry in cultivated fields and natural heathland according to a standardized protocol (Drummond, 2002) to determine the pollinator force present. Together, we used these observations to calculate an estimate of percent berries at harvest and the observed fruit set for the plants in these different environments.

Site selection began mid-May 2016 and peak lowbush blueberry bloom began June 1, 2016. Due to these time constraints, we secured access to only one commercial blueberry farm, located in Dean, NS and owned by Bragg Lumber Company, Ltd., which was accessible via day trips from Halifax. We included two coastal heathlands, Polly's Cove and Chebucto Head, for comparison, chosen for ease of access. The commercial blueberry farm covered 210 acres and has been in use for over 30 years; it is actively managed to reduce pest populations (Bumper, Proline, Fontelis, Switch, Pristine applied in 2016), to increase soil fertility and stimulate plant growth (200 lbs fertilizer applied in 2015, mowed in 2014), and to improve pollination (four honeybee hives supplied per acre).

At all sites, we delineated ten monoculture patches of lowbush blueberry measuring 1 yd x 1 yd with flagging tape. Within Polly's Cove and Chebucto Head, we identified and flagged patches as they were encountered via pedestrian survey, as monoculture patches of lowbush blueberry were relatively uncommon in natural heathland. At the farm, we established two sites (with ten patches each) to sample both field margin/forest adjacent (blueberry field 1) and field center (blueberry field 2) environments to capture variation within a large commercial farm. The two sites within the farm were separated by 1.5 km. Within each of the two blueberry field locations, patches were separated by at least 5 meters.

### *Monitoring protocol*

We monitored bees between June 1-7, 2016 (once at each site) in monoculture patches of blueberry on days without rain and with temperatures that were not cold (10°C or above). Our monitoring protocol followed that of Drummond (2002). To reduce the impact of having a human monitor present, counts only started once bees appeared to forage normally within each patch (wait time of at least two minutes). We recorded the number of honeybees, bumblebees, and other native bees entering each monoculture patch of lowbush blueberry during a 60 second observation period. We monitored five patches in the morning (09:00-12:00) and five in the afternoon (12:00-15:00) at each site. We calculated estimated harvestable percentage of blueberries using the bee visitation rates, following Drummond (2002) using the equation:

$$\% \text{ Berries} = 14.5 + 7.8(N_{\text{honeybees}}) + 17.7(N_{\text{native bees}})$$

Along with bee monitoring, we identified and marked six blueberry clones using flagging tape within each patch. On each clone, we tagged five stems with embroidery floss. We recorded the number of flowers on each stem of every tagged clone (June 1-7, 2016) for all patches, for a total of 300 stems per site (1200 stems overall). After petal fall in June, we counted immature fruits (June 28 – July 6, 2016) on all previously tagged stems at all sites, excluding all stems that had been grazed or affected by botrytis blight. We calculated initial percent fruit set (prior to summer drop) following the equation:

$$\% \text{ Fruit} = \left( \frac{N_{\text{fruit}}}{N_{\text{flowers}}} \right) \times 100$$

Although this cannot predict the final percentage of berries available at the final harvest, it does constrain the maximum percent fruit possible for a given site in a given year and indicates the percentage of flowers that were successfully pollinated.

### ***Statistical analysis***

To assess bee inventory completeness and species richness across all heathland habitats, we generated sample-based and individual-based species accumulation curves ( $n = 10$  sampling events) with estimated richness (100 runs without replacement) using EstimateS 9.1.0 (Colwell 2005). We performed all other data analyses using RStudio version 0.98.1102 (R Core Team 2014). All means reported in-text are associated with one standard error (mean  $\pm$  SE). We assessed differences in proportions of bee guilds among

heath types by calculating and comparing means and 95% confidence intervals. We performed non-metric multidimensional scaling (NMDS) to visualize variation in bee community composition across heathland habitats. We transformed bee abundance data using the Wisconsin double standardization technique and generated Bray-Curtis dissimilarity coefficients from these data, with singletons removed (2 dimensions, stress = 0.12), and ordinated the bee communities via NMDS using the vegan package in R (Oksanen et al. 2007). We centered plots of weighted averages on the mean of the axes and displayed ellipses representing 95% confidence regions for each site using the vegan and ggplot2 packages in R (Oksanen et al. 2007; Wickham 2009). To determine whether bee communities differed significantly ( $\alpha = 0.05$ ) among heathland habitats, we conducted permutational multivariate non-parametric ANOVA (PERMANOVA) of differences (adonis function in the vegan package in R, 1000 permutations) on bee abundance data. We used one-way analysis of variance to test for differences in the percentage of immature fruit set by lowbush blueberry in commercial farm and coastal heathland sites. Due to non-normality of residuals, we performed a Kruskal-Wallis test to assess both differences in the percentage of immature fruit set by lowbush blueberry and bee visitation rates to lowbush blueberry in commercial farm and coastal heathland sites. We assessed differences in rates of bee capture on rare and berry-producing plant species across three heathland habitats using Kruskal-Wallis tests due to non-normality of residuals.

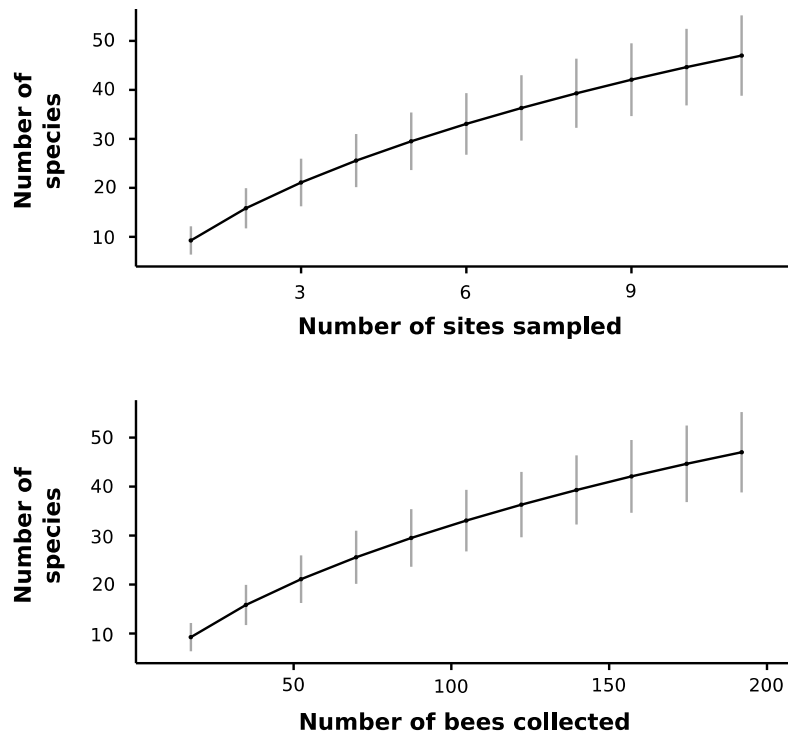
## Results

### *Heathland bee diversity & abundance*

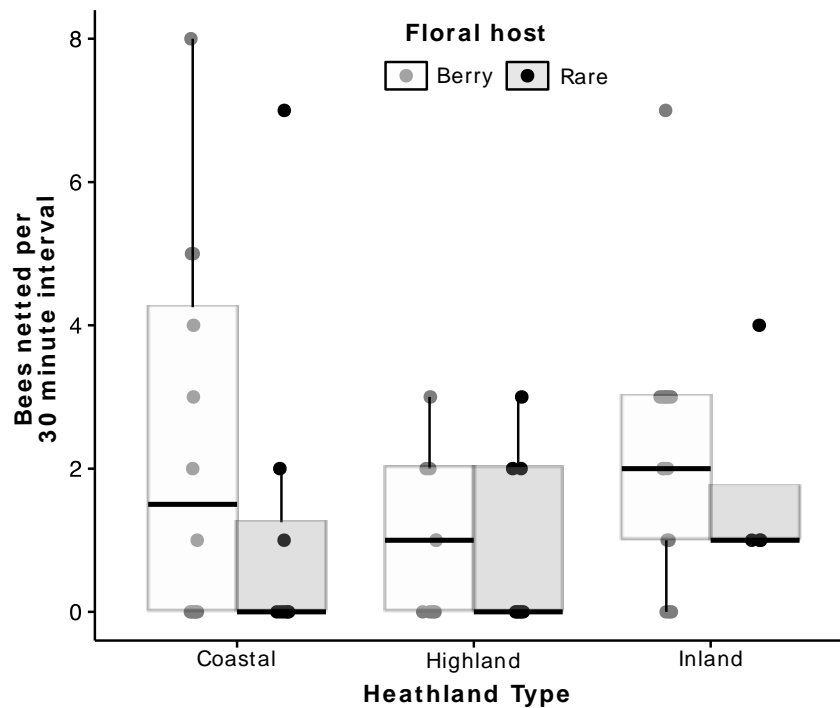
We collected a total of 193 bees, comprising nine genera and 43 species, from 10 heathland collection locations (Table 2, Figure 1) from 21 May – 27 June 2016. Species richness was similar across heathland habitat types, with the greatest number of bee species recorded in inland habitat ( $11.7 \pm 2.7$ ) and the fewest in coastal habitat ( $8 \pm 2.8$ ) surveyed here, with highland heathlands displaying intermediate bee species richness ( $9 \pm 1$ ). When we combine all sampling periods, species accumulation curves indicate that significant bee diversity remains unsampled (Figure 2). Our collection includes a putative new provincial record for *Osmia nigriventris*. Our surveys also detected a species

previously listed as undetected in North American collections (Colla et al. 2012), *Osmia laticeps* (last recorded in Nova Scotia in 1932 – species determination by M. Rightmyer).

Abundance of bees was low overall, with zero bees netted during 22 of 55 (40%) collection periods and zero bees collected in bowl traps on 2 of 11 collection days. The number of bees caught per site in bowls ranged from 0-30 bees per day, while netting yielded 0-11 bees per 30-minute collection interval when we considered all floral hosts (including non-berry plant species). Bowls captured the most bees in coastal sites ( $7.4 \pm 5.7$ ; total 37) relative to inland ( $3.7 \pm 1.9$ ; total 11) and highland ( $2.7 \pm 0.3$ ; total 8) sites, although bowl contents (30 bees) from a single day (26 May 2016) skewed the mean bowl yield within coastal heathland habitat. Bee capture rates differed significantly among heathland types sampled here ( $\alpha = 0.05$ ,  $p = 0.0456$ ,  $df = 2$ ), but we did not detect significant differences between any heathland pairs when we performed pairwise comparisons. Aerial net capture yielded the most bees per 30-minute collection interval in inland heathlands ( $3.1 \pm 0.7$ ), while net collection in highland ( $1.6 \pm 0.5$ ) and coastal ( $1.9 \pm 0.7$ ) heathlands returned similar abundances of bees. Aerial net capture of bees on rare plants in bloom yielded catches of zero bees per collection interval more frequently (10 of 20 intervals, 50%) than did collection intervals focused on berry-producing plants (12 of 35 intervals, 34%) (Figure 3).



**Figure 2.** Individual and sample-based species accumulation curves across all heathland sites; error bars = 95% confidence intervals.

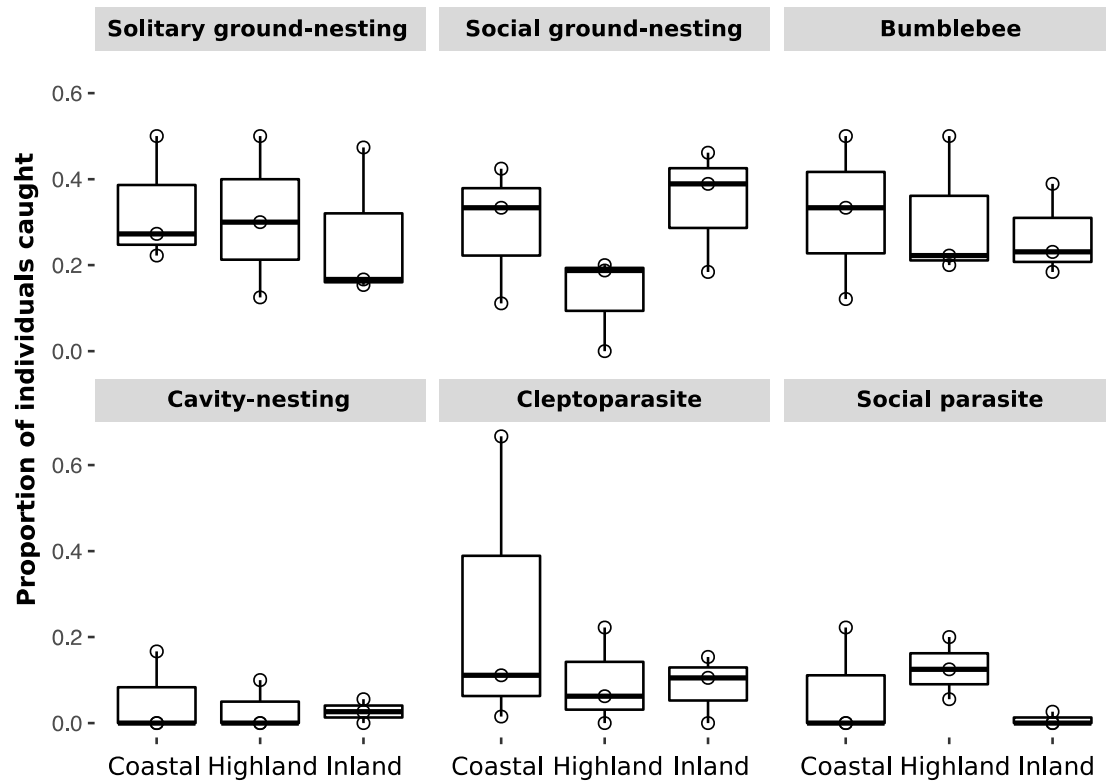


**Figure 3.** Total bees netted on focal floral hosts (berry-producing or rare) per 30-minute collection period, by heathland habitat type (Berry:  $n = 12$  coastal,  $n = 14$  inland, and  $n = 9$  highland sites; Rare:  $n = 8$  coastal,  $n = 4$  inland,  $n = 8$  highland sites).

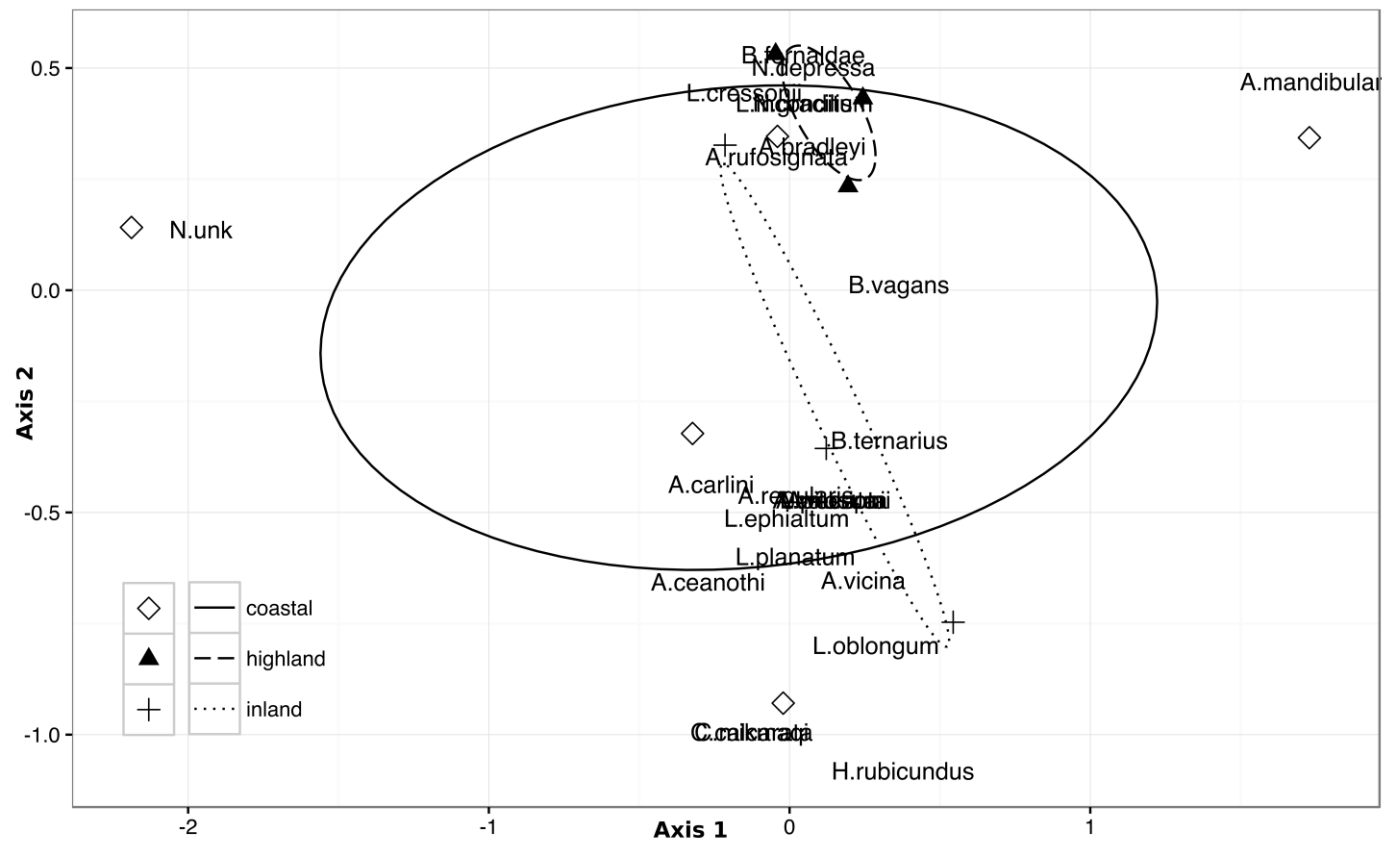


Overall, solitary ground-nesting bees ( $30 \pm 0.5\%$ ), bumblebees ( $30 \pm 0.05\%$ ), and social ground-nesting bees ( $29 \pm 0.05\%$ ) were the best-represented guilds and cavity-nesting species the worst represented ( $9 \pm 0.04\%$ ) guilds within the heathlands sampled here. Among heathland habitat types, we found significantly fewer social ground-nesting bees and significantly more social parasites in highland heathlands ( $13 \pm 0.06\%$ ,  $13 \pm 0.04\%$  respectively) relative to inland heathlands ( $35 \pm 0.08\%$ ,  $0.9 \pm 0.009\%$  respectively) with coastal sites displaying an intermediate abundance of both bee guilds (Figure 4).

*Lasioglossum* (32%), *Bombus* (26%), and *Andrena* (23%) were the most common genera found in heathland habitat in late May and June, and *Bombus vagans* (33) was the most abundant bee, followed by *Lasioglossum ephialtum* (27), and *Lasioglossum planatum* (12). Of the 47 bee species collected, 22 were singletons (47%) (Table 3). A PERMANOVA on the bee species composition of all three heathland habitat types revealed no significant differences ( $\alpha = 0.05$ ,  $p = 0.4$ ,  $df = 2$ ); species abundance ordination revealed significant species overlap for coastal-highland and coastal-inland site pairs, while the species abundances within highland sites appeared to be more distinct from inland sites (Figure 5).



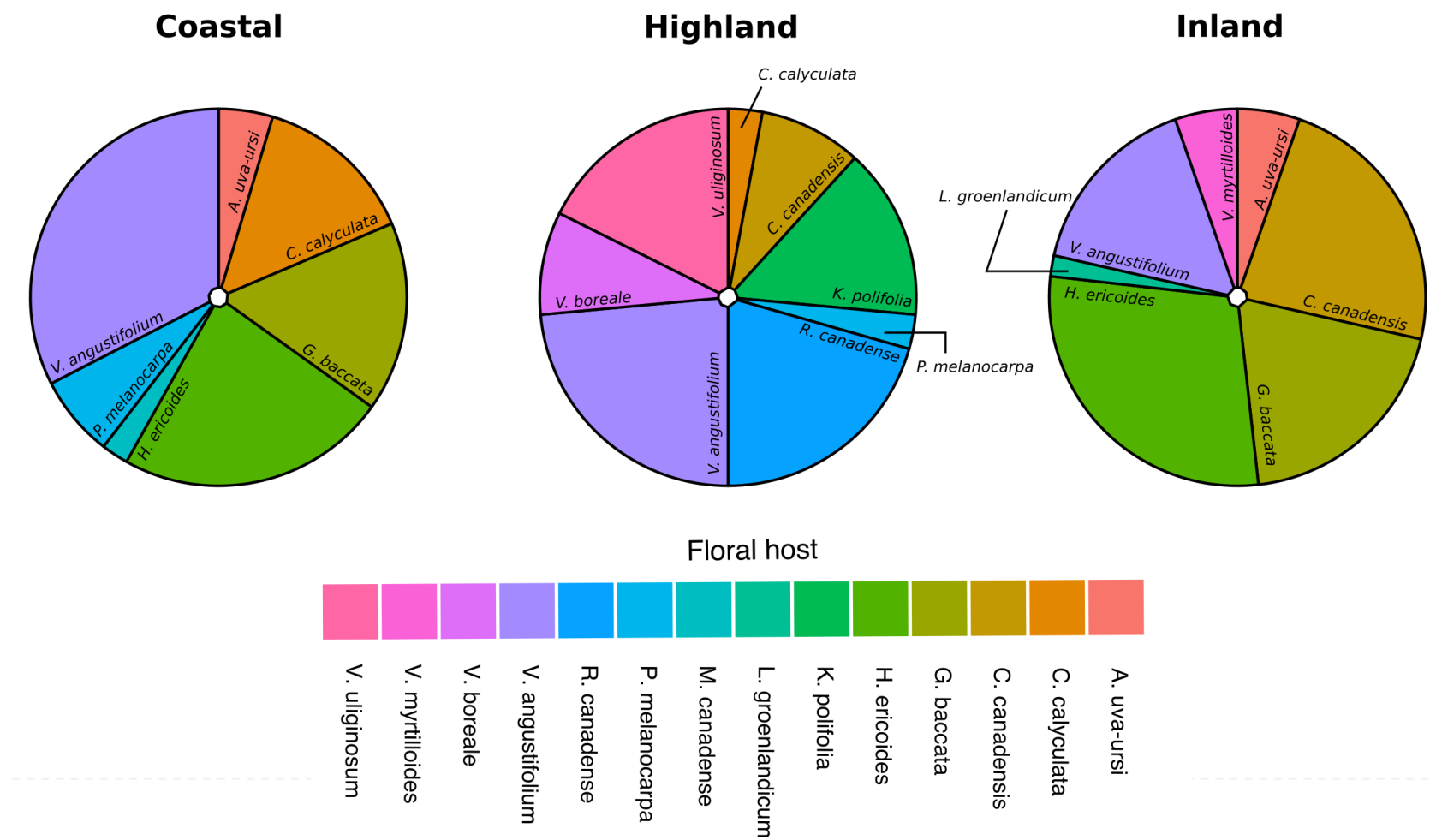
**Figure 4.** Guild structure of heathland bee communities according to proportion caught with combined collection methods at each heathland type ( $n = 3$ ).



**Figure 5.** NMDS ordination of bee species abundances in coastal, inland, and highland heathland habitat. Ellipses represent 95% confidence regions; data centered on axes means, singletons removed.

### ***Floral host associations***

Several berry-producing plant species featured flowers that attracted diverse bee species (Figure 6, Table 3). Excluding the 10 parasitic species we collected, 32 of the 33 non-parasitic species found in heathlands in this study (97%) have been collected previously in lowbush blueberry fields in NS, NB, PEI, or ME, and 19 non-parasitic species have also been found in apple orchards in the Annapolis Valley (Table 3). We frequently captured bees on lowbush blueberry in all heathland habitats, with a total of 16 bee species visiting this host. Bees visited several berry-producing plants across heathland sites, including *Gaylussacia baccata* (black huckleberry), *Photinia melanocarpa* (black chokeberry), *Arctostaphylos uva-ursi* (bearberry), and *Cornus canadensis* (bunchberry). However, bees were also attracted to ericaceous species that do not produce berries, such as *Chamaedaphne calyculata* (leatherleaf), *Rhododendron canadense* (Rhodora), and *Kalmia polifolia* (pale bog laurel). Several bee species repeatedly visited rare species. We repeatedly captured *Andrena carlini*, *A. ceanothi*, *A. regularis*, and *A. w-scripta* on *H. ericoides*; in total, this rare plant was visited by four species of *Andrena*, one bumblebee, one small carpenter bee, three parasitic *Nomada*, and five halictid bees. Although *A. rufosignata* was the only repeat visitor to *V. uliginosum*, together *V. uliginosum* and *V. boreale* were visited by four species of *Andrena*, three species of bumblebee, and one small halictid species.



**Figure 6.** Proportion of spring bee visits to all recorded floral hosts according to heathland habitat type.

**Table 3.** Bee species floral associations and abundances by heathland habitat type. **Bolded** bee species are known to specialize on lowbush blueberry pollen during bloom, (\*\*) denotes bee species known to forage within lowbush blueberry fields and/or on lowbush blueberry, (\*\*\*) denotes bee species known to forage within both lowbush blueberry fields and apple orchards, † denotes singletons.

Bee species		Floral hosts (Number of bees visiting host sp.)			Abundance		
		Berry	Non-berry	Rare	Coastal	Inland	Highland
<b>Andrenidae</b>							
<i>Andrena</i>	<i>algida</i> **†	<i>C. canadensis</i> (1)				1	
	<b><i>bradleyi</i>***</b>	<i>V. angustifolium</i> (1)	<i>C. calyculata</i> (2)	<i>V. uliginosum</i> (1)	1		3
	<b><i>carlini</i>***</b>			<i>H. ericoides</i> (3)	2	1	
	<b><i>ceanothi</i>**</b>	<i>V. angustifolium</i> (2), <i>G. baccata</i> (1)		<i>H. ericoides</i> (2)	5		
	<i>cressonii</i> ***	<i>C. canadensis</i> (3)				3	
	<b><i>mandibularis</i>***</b>			<i>V. uliginosum</i> (1)	1		1
	<i>melanochroa</i> ***†				1		
	<b><i>regularis</i>***</b>	<i>C. canadensis</i> (2)	<i>L. groenlandicum</i> (1)	<i>H. ericoides</i> (4)	1	6	
	<b><i>rufosignata</i>***</b>	<i>G. baccata</i> (2), <i>P. melanocarpa</i> (1), <i>V. angustifolium</i> (1)		<i>V. boreale</i> (1), <i>V. uliginosum</i> (2)	2	2	3
	<b><i>vicina</i>***</b>	<i>C. canadensis</i> (2), <i>G. baccata</i> (1), <i>M. canadense</i> (1), <i>V. angustifolium</i> (1)	<i>C. calyculata</i> (1)		3	4	
	<i>w-scripta</i> ***			<i>H. ericoides</i> (5)		5	
<b>Apidae</b>							
<i>Bombus</i>	<b><i>bimaculatus</i>***†</b>	<i>A. uva-ursi</i> (1)			1		
	<b><i>fernaldae</i>**</b>	<i>C. canadensis</i> (1), <i>V. angustifolium</i> (3)	<i>K. polifolia</i> (2)	<i>V. boreale</i> (1)	2		5

	<i>insularis</i> **†	<i>V. angustifolium</i> (1)			1	
	<i>perplexus</i> ***†	<i>V. angustifolium</i> (1)		1		
	<i>sandersoni</i> ***†		<i>K. polifolia</i> (1)			1
			<i>C. calyculata</i> (1),	<i>H. ericoides</i> (1),		
	<b><i>ternarius</i>***</b>	<i>G. baccata</i> (2)	<i>R. canadense</i> (1)	<i>V. uliginosum</i> (1)	1	3
		<i>A. uva-ursi</i> (2),				
		<i>C. canadensis</i> (3),				
		<i>G. baccata</i> (8),				
		<i>P. melanocarpa</i> (1),				
		<i>V. angustifolium</i> (1),	<i>K. polifolia</i> (2),			
	<b><i>vagens</i>**</b>	<i>V. myrtilloides</i> (3)	<i>R. canadense</i> (2)	<i>V. boreale</i> (1)	9	14
<i>Ceratina</i>	<i>calcarata</i> ***		<i>C. calyculata</i> (2)		5	10
	<i>mikmaqi</i> **		<i>C. calyculata</i> (1)	<i>H. ericoides</i> (1)	5	
<i>Nomada</i>	bidentate spp.	<i>A. uva-ursi</i> (1)			1	1
	<i>cressonii</i> †			<i>H. ericoides</i> (1)		1
	<i>depressa</i>		<i>R. canadense</i> (1)	<i>H. ericoides</i> (1)	1	1
	<i>gracilis</i>	<i>V. angustifolium</i> (1)				2
	<i>luteoloides</i> †			<i>H. ericoides</i> (1)		1
	cf.					
	<i>cressonii/depressa/</i>					
	<i>townesi/capillata</i>	<i>V. angustifolium</i> (1)			1	2
						1
<hr/>						
<b>Halictidae</b>						
<i>Augochlorella</i>	<i>aurata</i> ***	<i>C. canadensis</i> (3)		<i>H. ericoides</i> (1)		4
		<i>G. baccata</i> (1),				
<i>Halictus</i>	<i>rubicundus</i> ***	<i>V. angustifolium</i> (1)			1	1
<i>Lasioglossum</i>	<i>cressonii</i> ***	<i>A. uva-ursi</i> (1),			1	1

		<i>P. melanocarpa</i> (1)					
		<i>G. baccata</i> (1),		<i>H. ericoides</i> (1),			
	<i>ephialtum</i> **	<i>V. angustifolium</i> (3)		<i>V. uliginosum</i> (1)	18	5	4
		<i>C. canadensis</i> (1),					
		<i>G. baccata</i> (1),					
	<i>inconditum</i> **	<i>P. melanocarpa</i> (1),					
		<i>V. angustifolium</i> (2)	<i>R. canadense</i> (2)		1	1	7
	<i>laevissimum</i> ***†	<i>V. angustifolium</i> (1)			1		
	<i>oblongum</i> ***			<i>H. ericoides</i> (1)	1	2	
	<i>pilosum</i> **			<i>H. ericoides</i> (2)		2	
	<i>planatum</i> **	<i>V. angustifolium</i> (1)		<i>H. ericoides</i> (2)	10	4	1
	<i>tenax</i> **†					1	
	<i>versans</i> †				1		
<i>Sphecodes</i>	<i>atlantis</i> †		<i>R. canadense</i> (1)				1
	<i>ranunculi</i> ***†					1	
<b>Megachilidae</b>							
<i>Osmia</i>	<i>inermis</i> **†	<i>V. angustifolium</i> (1)				1	
	<i>laticeps</i> †				1		
	<i>nigriventris</i> †						1
	<i>proxima</i> **†	<i>G.baccata</i> (1)				1	

**Note:** Bees captured using bowl traps are not associated with a floral host; therefore, counts in the habitat columns will not always reflect sum of counts on floral hosts.

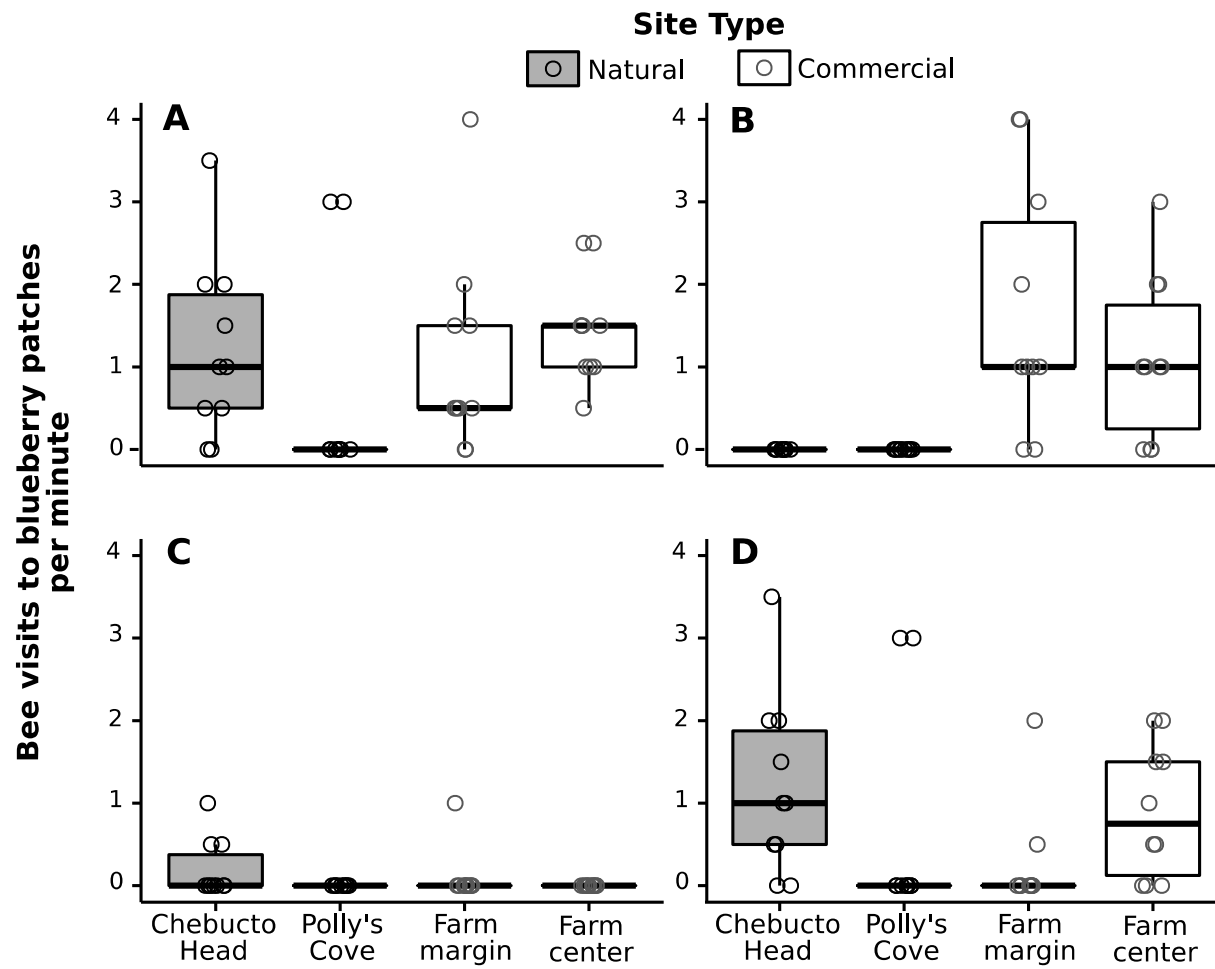
**Note:** Foraging preferences of bee species from: Bushmann & Drummond 2015; Cutler et al. 2015; Hicks 2011; Lomond & Larson 1983; Moisan-Deserres et al. 2014a, 2014b; Müller 2010; Nilsson 2009; Russo et al. 2015; Sheffield et al. 2003; Stubbs et al. 1992



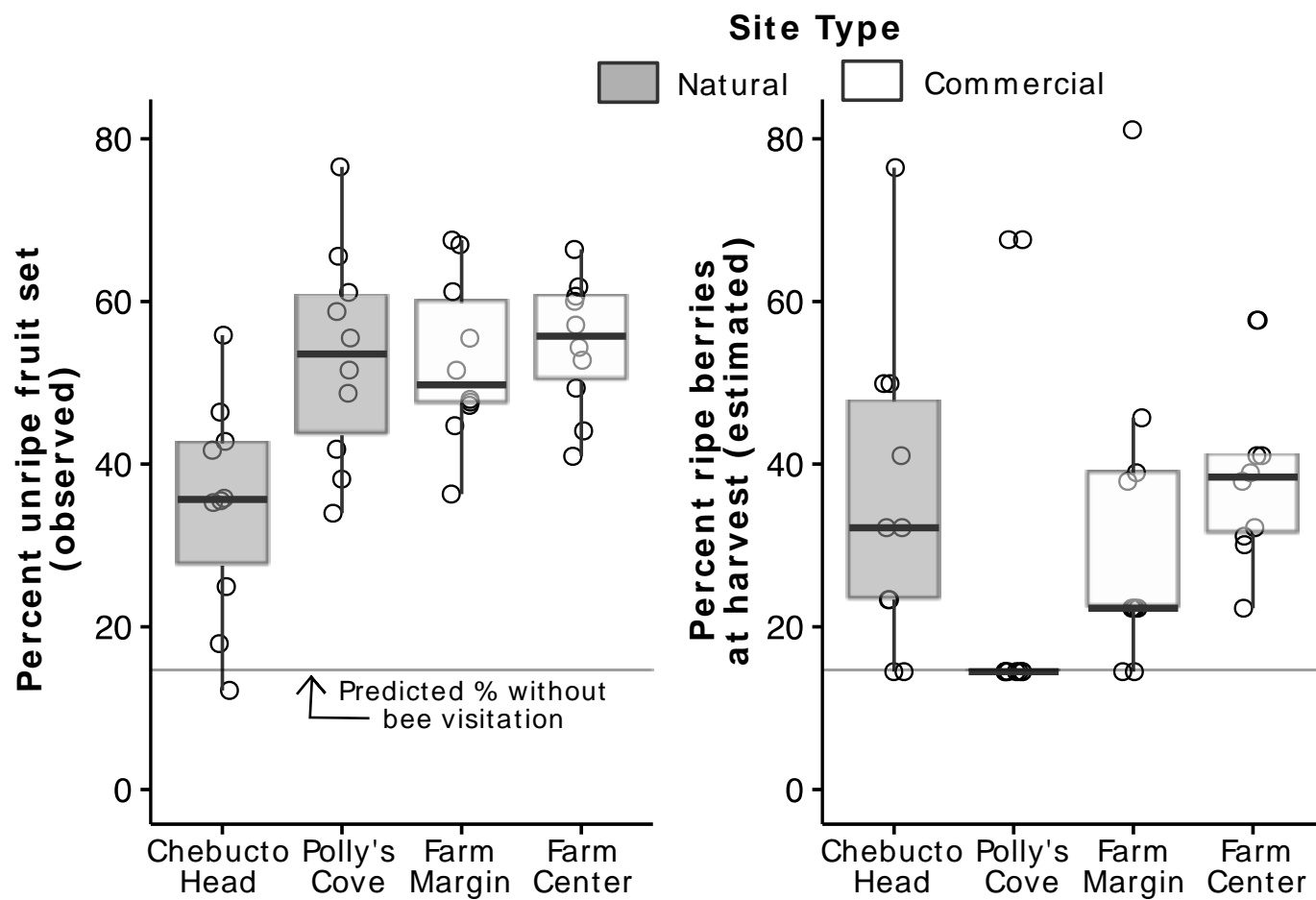
### ***Lowbush blueberry visitation & fruit set***

The number of bees we observed visiting lowbush blueberry per minute differed among the sites monitored and by bee type (Figure 7). When we combined visits from all bees, visitation rates were not significantly different within commercial ( $1.3 \pm 0.2$ ) or natural ( $0.9 \pm 0.3$ ) lowbush blueberry patches. While this trend was reversed when we excluded honeybees it remained non-significant, with visitation rates of native bees to commercial blueberry patches ( $0.6 \pm 0.2$ ) lower relative to those observed in natural heathland ( $0.9 \pm 0.3$ ). We did not observe any honeybees foraging at lowbush blueberry in either natural coastal heathland site monitored here, and we observed very few bumblebees foraging in lowbush blueberry patches monitored at any site (Figure 7).

As calculated from flower and immature fruit counts, observed percent fruit set (prior to drop) was significantly lower ( $\alpha = 0.05$ ,  $p = 0.0227$ ,  $df = 3$ ) in natural coastal heathland ( $44 \pm 3.6\%$ ) relative to commercial blueberry farm patches ( $54 \pm 2\%$ ). Immature fruit set was lowest at Chebucto Head (35%) relative to all other sites (53-55%) (Figure 8). Mature fruit set at harvest (as predicted from bee visitation rates) did not differ significantly ( $\alpha = 0.05$ ,  $p = 0.1613$ ,  $df = 3$ ) between commercial and natural lowbush blueberry patches, ranging from a minimum of 25% ( $\pm 7.1\%$ ) at Polly's Cove and a maximum of 39% ( $\pm 3.6\%$ ) at the center of the commercial blueberry field (Figure 8). Of the lowbush blueberry patches monitored at Polly's Cove, 80% were predicted to provide at most 14.5% mature fruit, contributing to the low overall estimate of mature fruit set for that site.



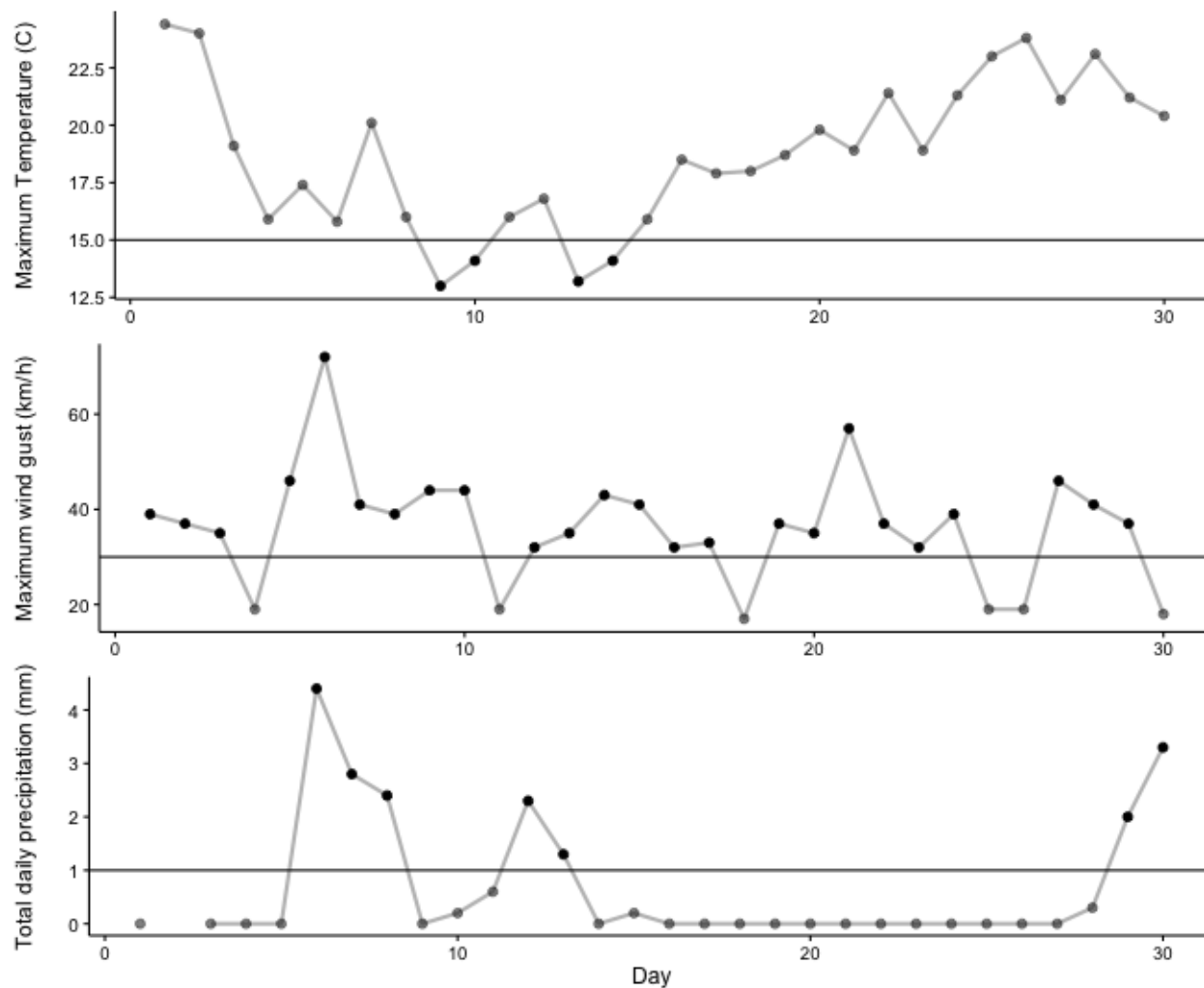
**Figure 7.** Count of bees visiting lowbush blueberry patches per minute in both commercial fields and natural heathland. A: all bees, B) honeybees only, C) bumblebees only, D) all native bees (i.e. honeybees excluded).



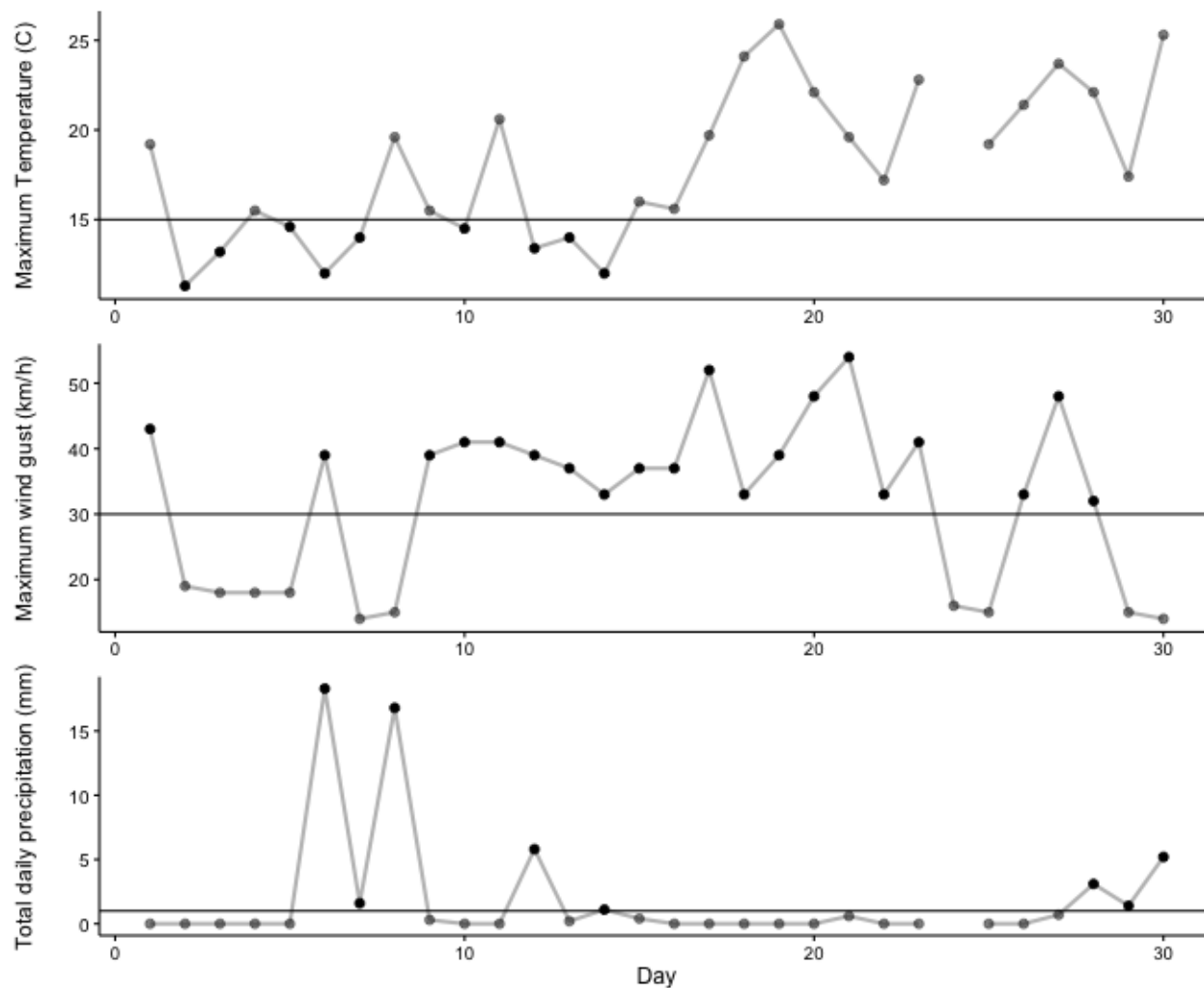
**Figure 8.** Observed percent unripe blueberry fruit set and estimated percent ripe berries at harvest. Unripe fruit set calculated from flower vs. fruit count in June-July; percent berries at harvest estimated from bee visitation rates according to Drummond (2002). Line indicates expected percent fruit set without any visitation from bees (14.5%).

### ***Weather & foraging limits***

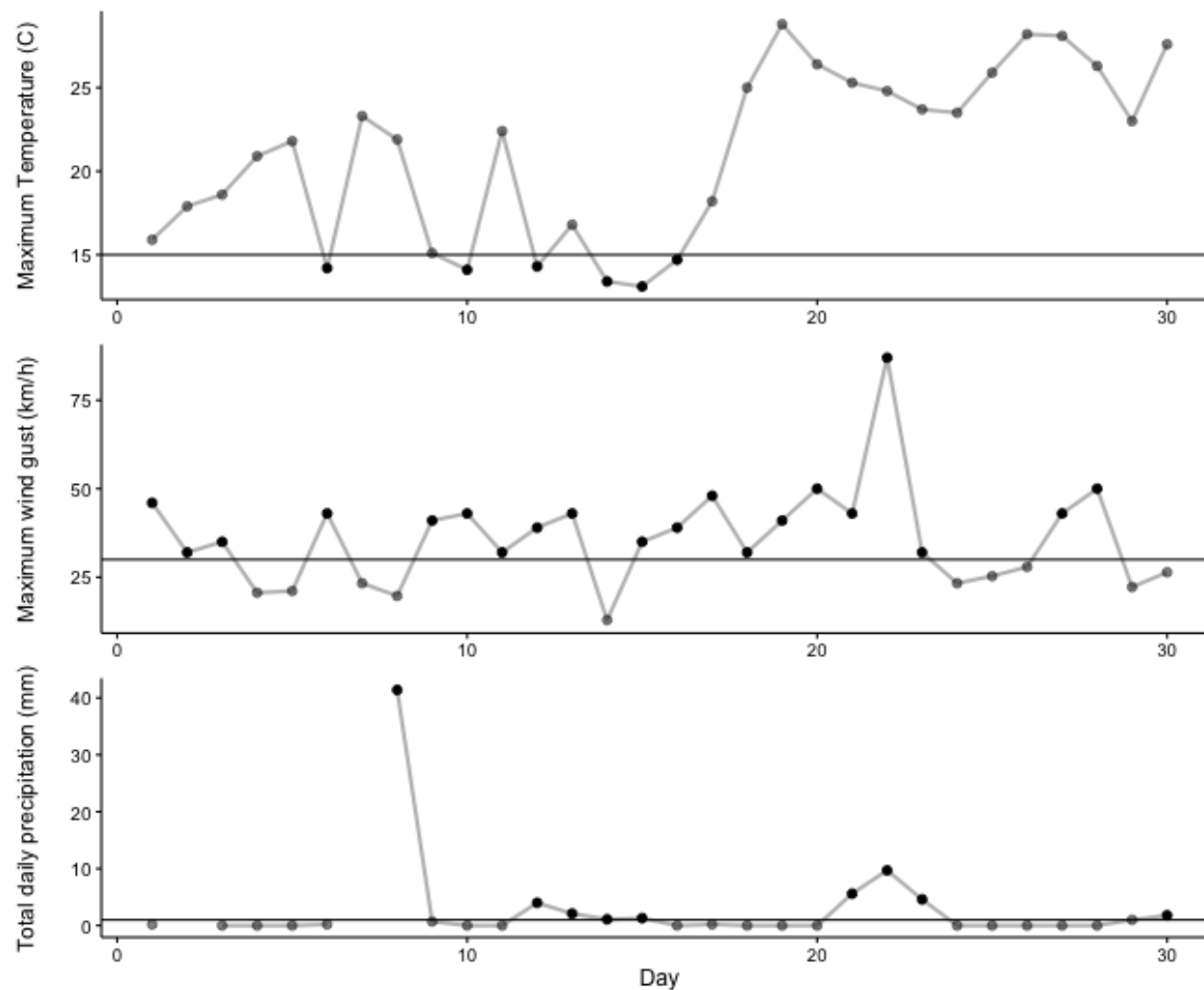
Weather conditions were cool, windy, and/or wet for much of June at Yarmouth RCS, Shearwater RCS, Upper Stewiacke RCS, and Ingonish RCS (Figures 9-12). At the Yarmouth RCS weather station, only four days in June (4, 18, 25, 26) presented optimal foraging conditions (all three weather condition categories within a favourable range). Wind conditions were the most common contributor to adverse foraging conditions, as wind frequently gusted above 30 km/h. However, only four days displayed maximum daytime air temperatures below the 15°C foraging threshold (Figure 9). At Shearwater RCS, optimal foraging conditions were present for only 3 days in June (10% of the month). Windy conditions prevailed for 67% of the month of June, and Shearwater RCS experienced more cold days (9) than Yarmouth RCS (Figure 10). Of all the stations, Upper Stewiacke RCS experienced the greatest number of optimal foraging days (7), with wind contributing most frequently to adverse foraging conditions (Figure 11). Optimal foraging conditions were present at Ingonish RCS for 6 days in June, and unlike the other three locations, bees were primarily grounded by low temperatures (14 days) and/or rain (13 days) (Figure 12). When we considered all weather stations together, twice as many rainy days occurred in the first 15 days of June (6) than in the last 15 (3). Furthermore, no days with maximum temperatures below 15°C occurred after June 17.



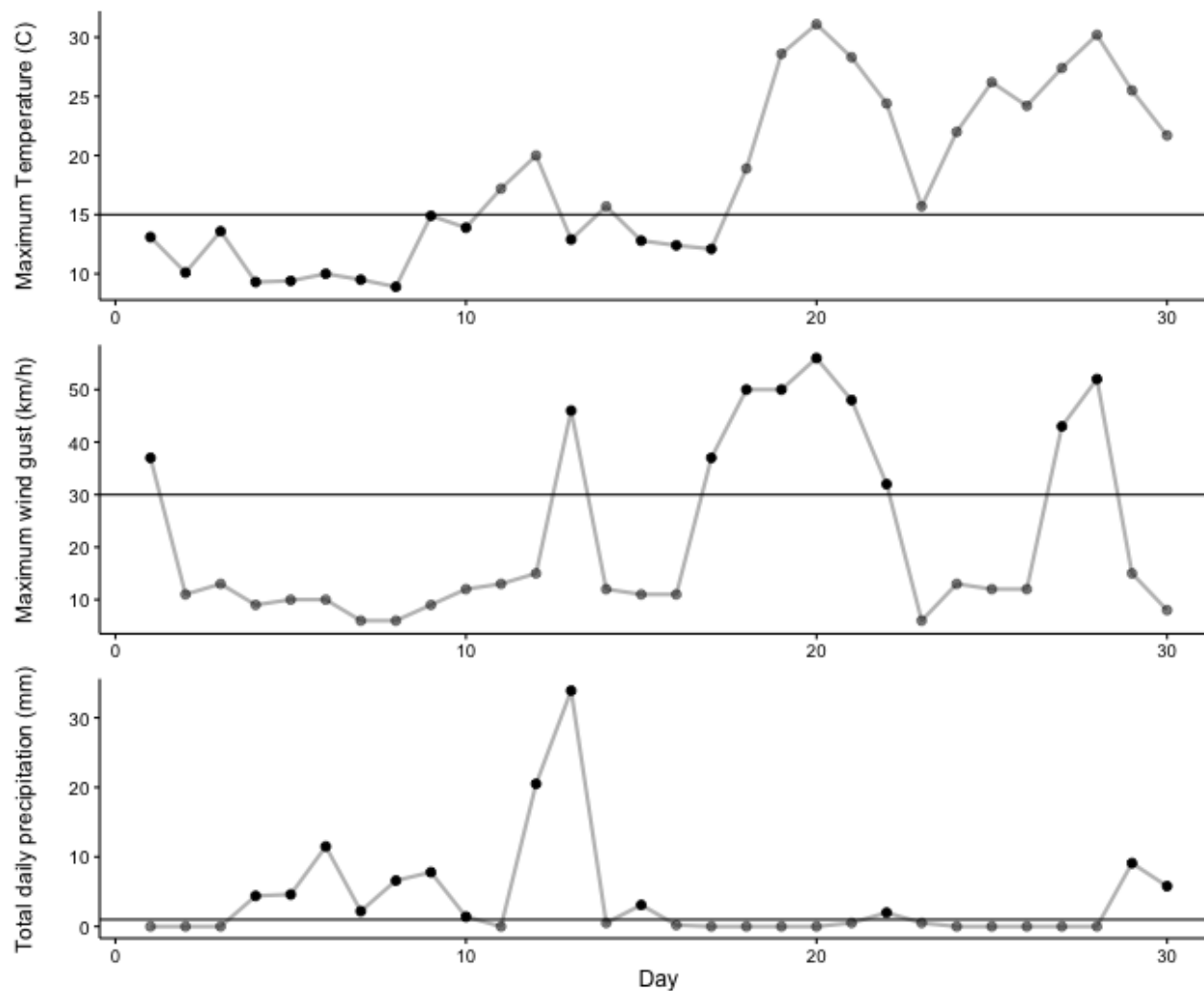
**Figure 9.** Daily weather conditions at Yarmouth RCS weather station (Environment Canada) in June 2016. Solid lines indicate adverse condition thresholds: maximum temperature  $<15^{\circ}\text{C}$ ; Maximum wind gust  $>30\text{ km/h}$ , total daily precipitation  $>1.0\text{ mm}$ . Black dots indicate days with adverse conditions; grey dots indicate favourable foraging conditions.



**Figure 10.** Daily weather conditions at Shearwater RCS weather station (Environment Canada) in June 2016. Solid lines indicate adverse condition thresholds: maximum temperature <15°C; Maximum wind gust >30 km/h, total daily precipitation > 1.0 mm. Black dots indicate days with adverse conditions; grey dots indicate favourable foraging conditions.



**Figure 11.** Daily weather conditions at Upper Stewiacke RCS weather station (Environment Canada) in June 2016. Solid lines indicate adverse condition thresholds: maximum temperature <15°C; Maximum wind gust >30 km/h, total daily precipitation > 1.0 mm. Black dots indicate days with adverse conditions; grey dots indicate favourable foraging conditions.



**Figure 12.** Daily weather conditions at Ingonish RCS weather station (Environment Canada) in June 2016. Solid lines indicate adverse condition thresholds: maximum temperature  $<15^{\circ}\text{C}$ ; Maximum wind gust  $>30\text{ km/h}$ , total daily precipitation  $>1.0\text{ mm}$ . Black dots indicate days with adverse conditions; grey dots indicate favourable foraging conditions.



## Discussion

### *Bee diversity & abundance*

Our surveys revealed a putative new provincial record of *O. nigriventris* and included a species (*O. laticeps*) that was previously ‘undetected’ in North American museum collections since the 1990s. These findings, coupled with significant unsampled diversity and a high proportion of singletons, suggest that further surveying of native bees in heathland habitat is warranted. The high proportion of parasitic species in our samples additionally hints at high bee species diversity within heathlands (Sheffield et al. 2013).

Despite this diversity we detected low abundances of bees during spring bloom of berry-producing plants, a pattern typical of environments with cold springs and adverse weather, such as high elevation habitats (García-Camacho & Totland 2009; Pyke et al. 2011). In these types of environments, low spring abundances of bees can lead to pollen limitation (Kudo & Suzuki 2002) and fruit set, as has been observed for June-blooming forest herbs in New Brunswick (Barrett & Helenurm 1987). The low abundances we observed could limit pollination services to spring-blooming plant species in heathland habitat. On Kent Island (located in the Bay of Fundy), exclusion of pollinators resulted in ~25% reduction of mean fruit set of species common to the heathlands studied here (Wheelwright et al. 2006), indicating that a decrease in visitation by bee pollinators could affect fruit set in heathland plants. Data reported by Bushmann & Drummond (2015) demonstrated higher rates of capture in Maine blueberry fields (approximately 7-18 bees per half-hour) relative to our capture rates in Nova Scotia heathland (0-11 bees per half-hour).

Low abundances of bumblebees and the emergence of workers mid-June indicate that queens are actively founding bumblebee colonies in May and early June. As a result, queens are the only bumblebees available to pollinate in the early spring and must divide their energy between foraging and brooding (Pyke et al. 2011). We observed many social parasites (particularly in highland heathlands) actively foraging in June, which suggests high occupancy by their hosts (non-parasitic bumblebees). Previous work in Nova Scotia coastal heathlands demonstrated that bumblebee abundance increased significantly

between June and August (Walker 2016). Thus, delayed colony development, especially in northern heathlands (e.g. highland habitat in Cape Breton) will limit the number of bumblebees available to pollinate spring blooming plants. Relative to their workers, pollination services rendered by queen bumblebees result in more seeds per fruit, but fewer fruits overall (Kudo & Kawai 2011).

We observed fewer social, ground-nesting bees within highland heathlands relative to inland habitat. This trend may also stem from colony development, as foundresses may have been rearing the first generation of worker daughters at the time our collections took place. It is also possible that colder temperatures in the highlands favour solitary lifestyles in socially polymorphic bee species (e.g. *Augochlorella aurata*, several species of *Lasioglossum*) (Packer et al. 1990; Sheffield et al. 2014). Thus, we would expect to see fewer individuals of these species if no worker generations are being reared or if worker generations have not yet emerged to forage. Ordination of species abundance indicated that bee community composition differs most between inland and highland heathland habitats. It is likely that inland sites experience more mild spring conditions relative to highland sites in Cape Breton, which often experience a delay in spring flowering time relative to the Nova Scotia mainland, impacting the bee communities living within these habitats.

Few cavity-nesting bees were collected, and those we did detect nested in pithy plant stems (*Ceratina spp.*), under rocks (*Osmia inermis*), or in dead wood that has been bored by other insects (*Osmia nigriventris*), (Müller 2010; Rightmyer et al. 2010, Packer 2007). Locations far from the forested margins of heathlands may offer few nesting opportunities for bees that occupy cavities in wood. Some species of *Osmia* appear robust to adverse weather and can forage in cold temperatures, light rain, and moderate wind (Vicens & Bosch 2000). Members of this genus also overwinter in adult form, tend to fly early in the spring, and forage on species that occurred at our sites (Müller 2010; Sheffield et al. 2003; Stubbs et al. 1992; Stubbs et al. 1994). Our detection of very low abundances of spring-flying *Osmia* may stem from inadequate nesting opportunities within the heathlands sampled, or inappropriate capture techniques (net and bowl); perhaps trap nests would have better sampled this group of bees (Stubbs et al. 1997).

### ***Floral associations***

Lowbush blueberry was visited by the greatest diversity of bee pollinators of all floral hosts encountered during this project. Other berry-producing plants did not receive visits from as many bee species, and all berry-producing plants in bloom were competing for pollinators with abundant co-flowering species that do not produce berries (e.g. *Rhododendron canadense*, *Kalmia polifolia*). In our study, *Andrena*, *Lasioglossum*, and *Bombus* were frequent visitors to all berry-producing species, and almost all of the non-parasitic bee species that we collected in heathlands in the spring are known to visit lowbush blueberry (Table 3). Therefore, despite covering a relatively small portion of Nova Scotia (3%) heathlands represent a storehouse of important blueberry pollinators and other berry-pollinating bee species. The most common (i.e. most abundant) bee visitors are likely providing the greatest pollination services to local plants (Winfrey et al. 2015). Lowbush blueberry relies on bees capable of sonication for cross-pollination and maximal fruit set; maintaining reservoirs of such pollinators is therefore an important safeguard against localized declines or annual fluctuations within agricultural landscapes.

Among our focal rare species, we were unable to sample repeatedly on *Shepherdia canadensis* or *Vaccinium boreale*, though the early flowering period of *S. canadensis* and the small size of its flowers likely favor visitation by fly pollinators. We observed high rates of non-detection on one focal rare plant species, *Vaccinium uliginosum*. At most, we captured three bees during 30-minutes of continuous capture on *V. uliginosum*. Decreased attention from bees can lead to pollen limitation in rare species (Kunin & Iwasa 1996). Deposition of pollen from co-flowering species (e.g. from more abundant ericads) can further reduce fertilization of rare plant species (Carvalho et al. 2014; Van Rossum et al. 2013) and many of our provincial ericaceous species share pollinators (Reader 1975; Rathcke 1988), as we observed here. *V. boreale* and *V. uliginosum* both inhabit highland heathlands in Cape Breton, often occurring on exposed outcrops of bedrock that represent local topographic maxima. Often it is extremely windy on the raised outcrops this species inhabits, which may limit both the foraging time available to bee pollinators and the pollination services received by bee-pollinated species. Bumblebees have been shown to only collect nectar when *V. uliginosum* host populations are small (Mayer et al. 2012) and their fidelity is positively related to patch

size (Van Rossum et al. 2012); thus, the smaller patches of *V. uliginosum* on these outcrops appear to be receiving infrequent, low quality visits from bumblebees.

In contrast, a relatively diverse bee pollinator assemblage visited *Hudsonia ericoides*. Several andrenid bees repeatedly visited this rare plant, as did their parasites (*Nomada*) (Packer et al. 2007). We observed many *Nomada* frequently searching near *H. ericoides* for hosts (though we did not catch those which failed to alight on flowers), indicating that *Andrena* are important pollinators of this provincially rare plant. *H. ericoides* has a more southern distribution within the province, which likely improves its window of opportunity for pollination, and we observed more favourable pollination dynamics for this species in inland heathlands that were not affected by coastal winds. Additionally, *H. ericoides* presents a simple floral morphology and its yellow colouration stands out from that of primarily pink and white co-flowering species (though we have no data on UV reflectance patterns). These floral attributes may allow foragers to effectively locate even small populations of this species.

### ***Blueberry visitation & fruit set***

Pollination of lowbush blueberry in commercial blueberry fields and coastal heathland was assessed through bee observation (visits/minute) and counts of flowers and fruit. Based on commercial fruit set targets (~60% fruit set), both measures indicated that pollination rates were suboptimal in managed fields and in natural heathland. Pollen limitation, and a subsequent reduction in fruit set, has been previously documented in Nova Scotia lowbush blueberry fields (Fulton et al. 2015). Immature fruit set (calculated from flower and fruit counts) represents the maximum possible fruit set, as yield of harvestable berries decreases following mid-summer fruit drop, foraging by pests (birds, mammals), insect damage (e.g. blueberry spanworm), or fungal pathogens (e.g. mummy berry). Thus, final berry yield is likely even lower than we predicted in coastal heathlands, which do not receive beneficial inputs (e.g. mowing, spraying, fertilization) to support higher yields. Mature fruit set estimated from bee visitation rates did not correspond with observed immature fruit set – indeed, at one coastal heathland site (Polly’s Cove), fruit appeared to be set through self-fertilization alone. However, flower and fruit counts indicated that pollination services were better provisioned at that site than

expected based on bee visits alone. This indicates that flower and fruit counts, which represent an integrated assessment of pollinator activity throughout the bloom period, are needed to corroborate fruit set estimates based on bee visitation rates. Weather conditions impact bee foraging and, ultimately, the rates of bee visitation recorded by observers; in locations that experience spring seasons dominated by fluctuating weather conditions, flower and fruit counts represent a more reliable indicator of pollination services. Our results from both measures suggest that fruit set is suboptimal in the coastal heathlands monitored, perhaps due to poor weather.

### ***Pollination Outlook***

Our project revealed a low abundance of bees during the spring bloom period of berry-producing species in heathland habitat but a high proportion of visits from effective pollinators like *Andrena*, *Bombus*, and *Lasioglossum* (Javorek et al. 2002). Social dynamics (delayed colony establishment) and poor weather conditions (3-6 optimal foraging days in the month of June) likely suppressed pollination activity by bees in heathlands in the spring of 2016. Our work characterized a single spring pollination season; therefore, we do not know if the pollination dynamics observed here are typical for Nova Scotia heathland habitat. Bee populations have been shown to vary dramatically between sampling years (fluctuation of 2-10 times their initial size) (Drummond 2002). Short-term population declines may be attributed to poor foraging conditions experienced by parental generations (limiting total offspring), extreme weather (e.g. spring cold snap, harsh winter), interactions with competing species, shifting land use, pesticide use, or changing plant phenology (Frankie et al. 1998, Oertli et al. 2005, Kevan 1975). Consequently, further sampling is required to determine if our observation of a low abundance of spring-flying bees is representative.

Weather conditions during spring 2016 greatly reduced the number of optimal foraging days on which wild bees could collect floral resources and during which plants could be pollinated. Our data on lowbush blueberry suggest that spring pollination may be low for this plant species and others that rely effective cross-pollination by bees (see Kevan et al. 1993 for pollinator-dependent plant species); Lomond and Larson (1983) described a similar pollination scenario for Newfoundland heathlands. In the wild

blueberry extension update delivered at the Wild Blueberry Producers Association of Nova Scotia Annual General Meeting (Truro, 18 November 2016), Peter Burgess noted that June 2016 was the worst pollination season of the last three years in Nova Scotia. The Natural Resources Council of Canada has predicted that spring conditions in Atlantic Canada will become wetter (Vasseur & Catto 2008). Wetter spring conditions will reduce the number of optimal foraging days in May and June, with the potential to further impact pollination services provided to spring-blooming species and later fruit development, though some species can extend their bloom period in response to poor weather (Southwick & Southwick 1986). Beyond spring conditions, elevated atmospheric CO<sub>2</sub> can negatively impact pollen quality (Ziska et al. 2016) and increased temperatures later in the summer, coupled with low water availability, can reduce nectar availability (Takkis et al. 2015); these changes will impact foraging choices made by pollinators (Rathcke 1988, Ruedenauer et al. 2016).

The tolerance limits of our native bee species to adverse weather conditions are not known, and it is likely that some species are robust to cold weather, fog, light rain, and high winds. The minimum temperature at which a bee can take flight is dependent on solar radiation; on days that are cool and sunny, bees are able to take flight at lower ambient temperatures relative to cool and cloudy days (Vicens & Bosch 2000). Bumblebees are known to be tolerant of cold temperatures, wind, and even light rain (Stone & Willmer 1989, Tuell & Isaacs 2010); however they appeared in low abundance in heathlands in early spring while queens were busy brooding. Better resolution of the tolerance limits of our native species of *Andrena* and *Lasioglossum* would improve our understanding of spring pollination services provided by heathland bee communities. Furthermore, the increased pollination efficacy of these bee taxa (relative to European honeybees) may buffer their provisioning of pollination services despite low abundances (Javorek et al. 2002; Garibaldi et al. 2013).

In addition to bees, other insects may provide important pollination services in heathlands, as they do in agricultural contexts (Rader et al. 2016). A dense aggregation (~100 burrows) of solitary digger wasps (*Crabro latipes*) was located along a gravel path at Polly's Cove. These wasps were observed to forage on nearby *Photinia melanocarpa* flowers, visiting several flowers in succession. Although they appeared to provision

larvae with captured adult deer fly (*Chrysops spp.*), adult digger wasps may play an important role in heathland pollination. Another wasp, *Vespula acadica*, was captured while nectaring on *V. boreale* in a highland heathland during this study. Many syrphid flies (Syrphidae, incl. *Volucella bombylans*) and bee flies (Bombyliidae) were observed across the heathland habitats studied here and visited berry-producing species and rare species, including *V. uliginosum* and *V. boreale*. Botanist Caitlin Porter has also observed skippers (Hesperiidae) in provincial heathlands. These additional pollinator taxa (and others) likely supplement the pollination services provided by bees to heathland plant species.

## **Recommendations**

Pollination services provided by bees to spring-flowering plant species in Nova Scotia heathlands may be limited. Further sampling of heathland bees is recommended to uncover undetected species, given that limited sampling here revealed several species of interest, and to determine typical population sizes through multi-year data sets.

### ***For land & resource managers***

- Extend bee surveying for multiple years within managed heathlands to establish a robust baseline estimate of bee populations.
- Expand fruit set monitoring of wild berry-producing species (e.g. serviceberry, chokeberry, huckleberry) to identify species that are not receiving adequate pollination.
- Monitor pollination of rare plant species within conservation lands (especially rare *Vaccinia* and other rare plants occurring in highland heathlands), including non-bee pollinators.
- Use forest pest control agents that will not affect bee populations in forest-adjacent habitat.

***For wild blueberry producers:***

- Monitor weather conditions during blueberry bloom, visitation rates by wild bees, and fruit set to assess long-term pollinator trends and vulnerabilities in individual commercial fields. Determine which native species are the most common in your fields – these bees will contribute most significantly to pollination of your crop.
- Continue research to a) identify effective and robust native pollinators and b) improve habitat provisioning for these species within commercial fields, as adverse weather conditions are expected to worsen with climate change. Honeybees are easy to manage and have a long history pollinating agricultural crops, but stocking fields with these hives is a major cost for producers and these bees are unlikely to fly in poor weather.
- Support protection of heathlands to maintain reservoirs of effective pollinator populations for provincial fruit crops. Given that these habitats are not suitable for intensive agriculture or forestry, experience challenging weather conditions that select for particularly hardy bee species, and support diverse bee pollinators that are known to selectively forage on ericaceous plants including *Vaccinium*, they represent important refuge habitat worthy of conservation effort.



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## Appendix A. Foraging tolerances of several bee species under various weather conditions

Bee species	Minimum Flight Temperature (°C)	Wind Speed	Rain	Source
<i>Andrena carlini</i> & <i>regularis</i>	13	N/A	Foraging occurred in “mild” rain	LaBerge & Schrader 1978
<i>Andrena clarkella</i>	8	N/A	N/A	Stone & Willmer 1989
<i>Andrena fulva</i>	12	N/A	N/A	Stone & Willmer 1989
<i>Andrena nigroaenea</i>	9	N/A	N/A	Stone & Willmer 1989
<i>Apis mellifera</i>	15	Flew in 16 km/h wind	N/A	Tuell & Isaacs 2010
<i>Apis mellifera</i>	12	N/A	N/A	Vicens & Bosch 2000
<i>Apis mellifera</i>	13	Unaffected by recorded wind speeds: max. 30.8 km/h; mean 8.9 km/h	N/A	Frier et al. 2016
<i>Bombus edwardsii</i> (workers and queens)	2.5	N/A	N/A	Stone & Willmer 1989
<i>Bombus impatiens</i>	10	Flew in 16 km/h wind	N/A	Tuell & Isaacs 2010
<i>Bombus lapidarius</i>	9,4	N/A	N/A	Corbet et al 1993, Stone & Willmer 1989
<i>Bombus pascuorum</i>	6	N/A	N/A	Corbet et al 1993
<i>Bombus spp.</i> queens	0	N/A	N/A	Heinrich 2004
<i>Bombus spp.</i>	5	Unaffected by recorded wind speeds: max. 30.8 km/h; mean 8.9 km/h	N/A	Frier et al. 2016
<i>Bombus terrestris</i>	6,3	N/A	N/A	Corbet et al 1993, Stone & Willmer 1989
<i>Bombus terricola</i>	5	N/A	N/A	Stone & Willmer 1989
<i>Bombus vosnesenskii</i> (queen)	2, 6	N/A	N/A	Stone & Willmer 1989, Heinrich 2004



<i>Bombus vagans</i>	5	N/A	N/A	Stone & Willmer 1989
<i>Colletes cunicularius</i>	10	N/A	N/A	Stone & Willmer 1989
<i>Megachile rotundata</i>	13.5, 16.5	Flew at wind speeds up to 25.7 km/h	N/A	Corbet et al 1993 ref Lerer et al 1982 Stubbs et al. 1994
<i>Megachile willoughbiella</i>	16	N/A	N/A	Stone & Willmer 1989
<i>Osmia cornuta</i>	10	Unaffected by moderate wind (26 km/h), few females flew in 50 km/h wind (no other bee species observed at this speed)	0.9 mm/h	Vicens & Bosch 2000
<i>Osmia ribifloris</i>	10	Flew at wind speeds up to 24.1 km/h		Stubbs et al. 1994
<i>Osmia rufa</i>	5	N/A	N/A	Stone & Willmer 1989
Most native bees and honeybees	16	N/A	N/A	Heinrich 2004
Other native species	<10	Decreased flower visitation rates at speeds above 11 km/h	N/A	Inouye & Pyke 1988
Other native species	15	Flew in 16 km/h wind	N/A	Tuell & Isaacs 2010