



# Wild bee and pollen comparison of ground level urban habitat, green roofs and coastal barrens in Halifax, Nova Scotia

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## ABSTRACT

Green roofs offer an integrated response to sustaining ecosystem services in urban settings. Surprisingly, however, few studies have compared arthropod richness and abundance at urban ground level and green roofs to other habitats. The main objective of this study was to compare the composition and pollen collecting habits of bee communities visiting green roof, urban, and coastal barren habitats in the Halifax Region of Nova Scotia. We found that relative to ground level habitats, green roof wild bee communities were less abundant and species rich, but shared species with all habitat types. Pollen collection of bumble bees on green roofs was similar to that observed in urban and barren habitats. These results suggest that green roofs may offer harmonized solutions to multiple urban problems. Our study also yielded new provincial record, *Hylaeus affinis* Smith (Hymenoptera: Colletidae), for Nova Scotia.

## INTRODUCTION

Ecosystem services are beneficial functions provided by natural ecosystems to humans (Daily and Matson 2008). Many essential services, such as pollination, are severely threatened due to immense anthropogenic changes. For example, the process of urbanization can erode the ability of an ecosystem to provide these services (Grimm et al. 2008), which necessitate the provisioning of costly artificial services in cities. In recent decades, many beneficial ecosystem services provided by green roofs have been catalogued, the foremost being mitigation of stormwater runoff and reduction of building energy expenditure (Oberndorfer et al. 2007; Clark et al. 2008). Though several benefits have been well characterized, the potential ecological benefits associated with green roof habitat provisioning for urban fauna, such as birds, bats, spiders, and insects, are far less clear (Williams et al. 2014).

Given their mobility and presence in urban environments, bees are potential beneficiaries of habitat provided by green roofs. Moreover, bees offer substantial support to flowering plants through cross-pollination. Recent studies have shown that diverse and abundant garden forage and heterogeneous nesting sites appear to support urban bee populations (Pereira-Piexoto et al. 2014). It has also been suggested that green space (including gardens and parks) in urbanized areas may serve as refugia for certain bumble bee species (Goulson et al. 2010). Therefore, well-provisioned gardens may attract and support many bee taxa living in an urbanized environment, and increasing the total garden area planted with native species can draw more bees to these urban gardens (Fukase and Simons 2016).

The potential attractiveness of native plants in urban settings (Fukase and Simons 2016) suggests that native-planted green roofs may offer unique resources not typically found in ground level gardens and may even attract bees not commonly found in the urban matrix. Surprisingly, the role of native-planted green roofs in provisioning nectar and/or pollen to urban bees remains relatively unknown. Furthermore, comparisons of pollen provisioning between urban, green roofs, and wild habitats are severally lacking in the literature.

Coastal barrens, also known as heathland habitats, are considered to be one of the most culturally significant habitats in Nova Scotia (Oberndorfer et al. 2007), with many located within a one-hour drive from the Halifax Regional Municipality. While investigations of barren vegetation assemblages and associated environmental characteristics

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have been completed (Cameron and Bondrup-Nielsen 2013), very few surveys of coastal barren bee fauna have been conducted in Nova Scotia (Walker et al. 2021). Fewer still have compared species composition to habitats within the same region. Without descriptions of coastal barren bee fauna, assessments of associations between coastal barren plant species and wild bee species on native-planted green roofs would be incomplete.

Our main objective was to describe the bee fauna of coastal barrens located within the Halifax Regional Municipality, and to compare these bee communities to those found within the city at ground level and green roof locations that contained two native barren plant species, three-toothed cinquefoil (*Sibbaldia tridentata* (Aiton) Paule & Soják (Rosaceae)) and white goldenrod (*Solidago bicolor* L. (Asteraceae)). Our second objective was to determine the direct use of green roof resources by native bees by conducting pollen load analyses on bumble bees (*Bombus* spp. Latreille (Hymenoptera: Apidae)). We predicted that bee communities would be most abundant and species rich in coastal barrens, moderately abundant and species rich at urban ground level sites, and least abundant and species rich at urban green roof sites. We further predicted that bee community composition would differ between urban and coastal barrens locations, and that green roof bee communities and their pollen load contents would most closely resemble those of ground level urban sites.

## METHODS

### Sites

During two sampling periods in 2014, wild bees were collected from three site types: green roof, urban ground level, and coastal barren locations within the Halifax Regional Municipality, NS (Table 1). Please see supplemental materials for detailed site descriptions. Two locations were sampled within each site type during each collection day (six locations per day), except where noted (Table 1). The collection periods coincided with the flowering period of two native plant species, *Sibbaldia tridentata* and *Solidago bicolor*, which have established and spread successfully on an experimental green roof in Halifax, and which occur in plant communities in local coastal barren habitat. *Sibbaldia tridentata* is a perennial creeping shrub with white, five-petaled, perfect flowers arranged in branched cymes; it flowers from June to July (Munro et al. 2014). *Solidago bicolor* is a perennial forb with a terminal multi-flower capitulescence (10–15 cm in length) of small, centrally located yellow, perfect disk flowers surrounded by white, pistillate ray flowers, which

**Table 1.** Bee collection locations by site type and focal plant species bloom time.

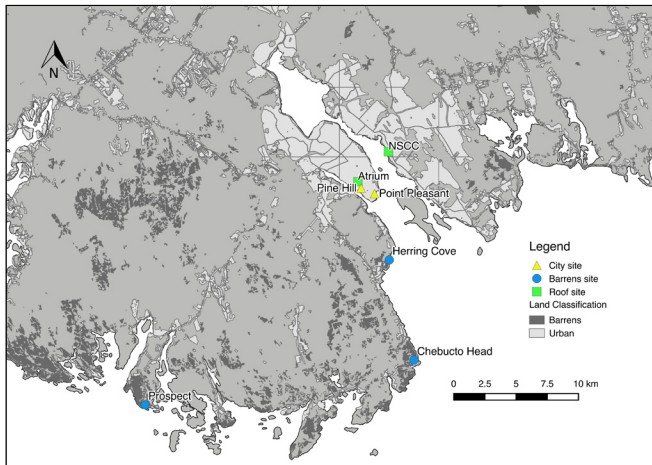
Focal species	Site Types			Period
	Green roof	Urban ground	Coastal barrens	
<i>S. tridentata</i>	Atrium, NSCC	Pine Hill, Point Pleasant	Chebucto Head, Herring Cove	June 23 – July 2
<i>S. bicolor</i>	Atrium, NSCC	Pine Hill, N/A	Chebucto Head, Prospect	August 5 – 12

blooms August to September (Munro et al. 2014). The first bee collection period (June 23 – 25, June 28 – 29, and July 2, 2014) occurred while *Sibbaldia tridentata* was in bloom at all sites, the second (August 5, and August 11–12, 2014) while *Solidago bicolor* was in bloom.

Bees were collected at a total of seven sites over the summer (Table 1). In this study, we define locality as coastal barren, green roof, and urban ground level habitat, and site as specific areas of each distinct habitat (i.e. NSCC green roof, Pine hill, and Prospect). Sites of each locality were selected based on the presence of the two focal plant species and the classification of each location as either urban or barrens in the Spatially Related Forest Resources (SRFR) information system, maintained by the Nova Scotia Department of Natural Resources (NSDNR 2015) (Figure 1). These site requirements limited the number of sites available for monitoring: within Halifax Regional Municipality (HRM), only two native-planted green roofs including both floral hosts were identified (one at the Nova Scotia Community College (NSCC green roof), the other at Saint Mary's University (Atrium green roof)), and urban ground-level sites containing >5 individuals of either focal host species were also difficult to locate. Two urban ground level sites (Pine Hill and Point Pleasant Park) were found to contain *Sibbaldia tridentata*, but only one site in urban HRM (Pine Hill) contained >5 individuals of *Solidago bicolor*. Bees were also collected at three coastal barren sites, Chebucto Head, Herring Cove, and Prospect (Table 1, Figure 1). These habitats are exposed to high winds and solar radiation, due to their proximity to the ocean and near absence (> 25%) of forest cover; weather conditions in these exposed coastal locations can fluctuate significantly within a day (NSDNR 2006). While *Sibbaldia tridentata* occurred at all three barren sites, *Solidago bicolor* was located only at Chebucto Head and Herring Cove. Accordingly, Chebucto Head and Prospect were sampled in the early (June) collection period, while Chebucto Head and Herring Cove were sampled during August.

Visual pedestrian surveys were completed to develop a list of flowering plant species present at each collection location (Supplement Tables 1-6), and to provide an

**Figure 1.** Map of bee collection locations and land use classification in Halifax County; land use data from NS DNR (2015), base map from Hijmans et al. (2015).



estimate of floral diversity available to bees and to identify possible sources of pollen. These surveys included plants flowering within 250 m of the bee collection areas and were conducted before, during, and after the bee sampling periods to ensure that both early and late blooming species were identified. Plant species were identified using Nova Scotia Plants (Munro et al. 2014) and Roland's Flora of Nova Scotia (Roland and Zinck 1998) and nativity was determined using these texts and the conservation status ranks produced by the Atlantic Canada Conservation Data Centre (ACDC 2014).

### Pollen and bee collection

A synoptic pollen collection was developed to facilitate pollen identification. Samples were collected from all plant species flowering within 50 m of each plot, except for Pine Hill where nearby private residences reduced the collection area available. Pollen was collected in the field on fuchsin-stained glycerin jelly; reference pollen slides were mounted and sealed on the day of pollen collection or frozen until mounting could be completed. Images of representative pollen grains for all reference species were taken at 40x or 63x magnification, depending on grain size. These images constitute the visual pollen library that was used during pollen identification.

Bee collection effort was standardized by area, sampling duration, collector effort, and collection day. Based on the footprint of the smallest green roof sampled (NSCC), a single 9.7 m x 7.7 m permanent plot was established at all sampling locations. Following a thorough pedestrian survey of each site, the plots were positioned to include

the focal plant species. The number of flowers of the target plant species (*Sibbaldia tridentata*) or the number of target plants (*Solidago bicolor*) present at the sites was recorded on each sampling day. Timed aerial netting of wild bees was conducted between 10am and 4pm. Each day, two collectors monitored concurrent sampling locations for one hour and netted all observed bees that landed within the plot. The same two collectors were used throughout the season, and visited sampling plots at the same time during each visit. The plant species (or non-floral feature) on which the bee alighted prior to capture was recorded; if the plant species was not known, the plant was photographed or tagged and later identified. Netted bees were transferred to individual cleaned vials to reduce pollen contamination and were frozen on the day of capture. Bees were stored in a commercial freezer prior to preparation and pinning and were returned thereafter.

### Data Analysis

Data analyses were performed using RStudio version 0.98.1102 (R Core Team 2014) unless stated. Only data from days on which all site types received equal sampling effort were included in analyses of bee abundance, species richness, and community composition. Means and 95% confidence intervals were calculated for bee abundance and bee species richness in June ( $n = 2$  sites, over 3 sampling days, for 3 site types) and August ( $n = 2$  sites (except 1 urban ground level site), over 3 sampling days, for 3 site types). To assess bee inventory completeness and species richness across all site types, sample-based species accumulation curves ( $n = 2$  sites, for 8 sampling days, for 3 site types) with estimated richness (100 runs without replacement) were generated using EstimateS 9.1.0 (Colwell 2005). Abundance and species richness of the three most common genera (*Andrena* Fabricius (Hymenoptera: Andrenidae), *Bombus*, and *Lasioglossum* Curtis (Hymenoptera: Halictidae)) were compared among the three site types by calculating site type means and their corresponding 95% confidence intervals for June ( $n = 2$  sites, over 3 sampling days, for 3 site types) and August ( $n = 2$  sites (1 site for urban ground level), over 3 sampling days, for 3 site types).

Non-metric multidimensional scaling (NMDS) was performed to visualize variation in bee community composition across site types. Bee abundance data (from each site on each sampling day) was transformed using the Wisconsin double standardization technique; Bray-Curtis dissimilarity coefficients were generated from these data, with singletons removed (2 dimensions, stress = 0.16), and the bee communities were ordinated via NMDS using the

vegan package in R (Oksanen et al. 2007). Plots of weighted averages were centered on the mean of the axes; ellipses representing 95% confidence regions were displayed 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 sites, permutational multivariate non-parametric ANOVA (PERMANOVA) of differences (*adonis* function in the *vegan* package in R, 1000 permutations) was conducted on combined bee abundance data from both sampling periods. In addition, bee community similarity across sites was assessed via an analysis of similarities (ANOSIM; 999 permutations) conducted on Bray-Curtis dissimilarity indices generated from square-root transformed bee abundance data in PRIMER v.7 (Clarke and Gorley 2015; Clarke and Warwick 1994). Key bee species contributing to within-site similarity and between-site dissimilarity in bee communities were identified by calculating similarity percentages via SIMPER analysis in PRIMER.

To assess the attractiveness of focal flowers present within sampling plots at each site type, the proportion of visits to the focal species, *Sibbaldia tridentata* and *Solidago bicolor*, was calculated for each day at each site according to the formula:

Where:  $P_{target}$  = Proportion of bees captured on both focal species on a given day;  $N_{Sibbaldia}$  = Number of bees captured on *Sibbaldia tridentata* per collection site on a given day;  $N_{Solidago}$  = Number of bees captured on *Solidago bicolor* per collection site on a given day;  $N_{total}$  = Number of bees captured per collection site on a given day.

Means and 95% confidence intervals were calculated to statistically compare daily focal flower attractiveness

$$P_{target} = \frac{N_{Sibbaldia} + N_{Solidago}}{N_{total}}$$

among site types. Linear regression was used to assess the relationship between visiting bee species richness and the number of flowering species visited at each site type.

To determine whether the pollen morphospecies richness of bumble bee-collected corbicular pollen loads differed significantly among the habitats studied, daily means for each site type ( $n = 2$  green roofs for 3 days,  $n = 1$  urban ground level site for 6 days,  $n = 2$  coastal barrens for 3 days) and their corresponding 95% confidence intervals were calculated. To visualize whether different bumble bees species collected specific pollen morphotypes, pollen morphotype abundance data were ordinated via NMDS, with data treatment identical to that of the bee community NMDS procedure (2 dimensions, stress = 0.14). *Sedum* L.

(Crassulaceae) abundance (1 pollen load) was removed from the data set to relieve overplotting of all other pollen taxa. Statistical differences ( $\alpha = 0.05$ ) in pollen collection were determined by conducting a PERMANOVA (1000 permutations) on pollen morphotype abundance data, with bumble bee species and site included as factors. Plots of weighted averages were centered on the axes mean; ellipses representing 95% confidence regions were displayed for each bumble bee species and site type. In addition, pollen load compositional similarity across site types was assessed via ANOSIM (999 permutations) conducted on Bray-Curtis dissimilarity indices generated from square-root transformed pollen taxa abundance data in PRIMER. Identities of pollen taxa contributing to within-site type similarity and between-site type dissimilarity in bee-collected pollen loads were determined by calculating similarity percentages via SIMPER analysis in PRIMER.

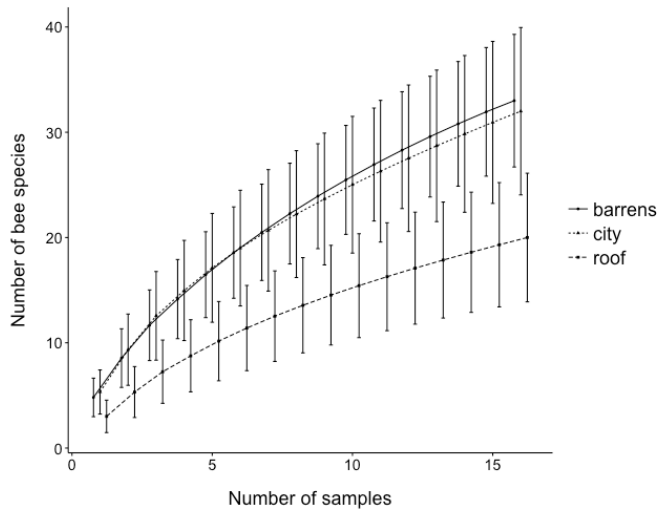
## RESULTS

### Wild bee communities

A total of 480 bees, comprising of 12 genera, and 54 species (including 8 *Lasioglossum*, 2 *Andrena*, and 1 *Sphcodes* Latreille (Hymenoptera: Halictidae) morphospecies) were collected across all sites and both collection periods; 204 bees were collected in June and 276 in August. An additional 50 bees were collected at green roof sites, increasing the total to 530, but were not included in analyses to ensure sampling effort was equal across sites and habitats. Sample-based species accumulation curves indicated that sites differ in total species richness, with coastal barrens sites exhibiting a faster rate of species discovery and a greater final mean ( $\pm$  SE) species count ( $33 \pm 3.2$ ) than green roof sites ( $20 \pm 3.1$ ) sampled; and slightly higher than urban ground level sites ( $32 \pm 4.1$ ). Species accumulation curves failed to level off for all locations sampled (Figure 2).

The abundance of bees at coastal barren sites, urban ground level sites, and green roof sites did not differ when sampling periods were pooled; however, distinct trends emerged when the two collection periods were considered separately. In June, daily capture rates did not differ among sites, with an average of 4.3 – 8.6 bees captured per sampling location per day; in August, bees were more abundant at coastal barrens sites ( $22.3 \pm 2.8$ ) relative to green roof sites ( $7.8 \pm 1.3$ ), while urban ground level sites displayed intermediate daily abundances ( $15.8 \pm 3.8$ ) (Figure 3). The three most common genera collected across all site types were *Andrena*, *Bombus*, and *Lasioglossum* (Figure 3). Other genera common to all site types included *Apis* L. (Hymenoptera: Apidae), *Halictus* Latreille (Hymenoptera:

**Figure 2.** Sample-based species accumulation curves generated for each site type (n = 2 sites, over 8 sampling days, for 3 site types) across sampling periods. Richness estimates were generated using EstimateS v.9.1.0 (Colwell 2005). Bars represent 95% confidence intervals.

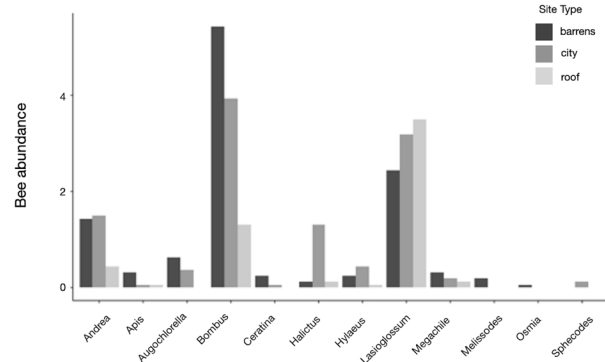


Halictidae), *Hylaeus* Fabricius (Hymenoptera: Colletidae), and *Megachile* Latreille (Hymenoptera: Megachilidae). *Augochlorella* Sandhouse (Hymenoptera: Halictidae) and *Ceratina* Latreille (Hymenoptera: Apidae) were only collected at ground level sites, occurring in both coastal barrens and the city. *Melissodes* Latreille (Hymenoptera: Apidae) and *Osmia* Panzer (Hymenoptera: Megachilidae) were collected only at coastal barren sampling locations, while *Sphecodes* was only collected at an urban ground level site (Pine Hill). *Hylaeus affinis* was collected in the Prospect barren, a new provincial record for this species.

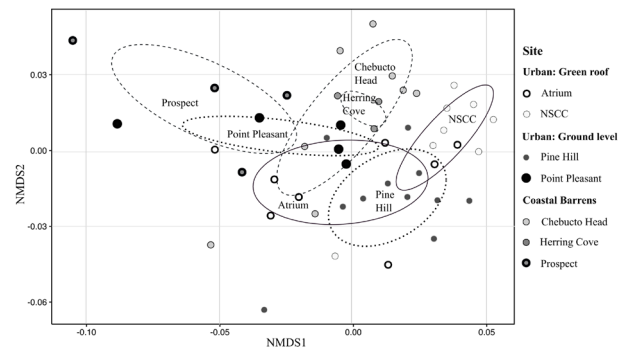
PERMANOVA indicated that bee community composition differed significantly ( $p = 0.001$ ) among the sites sampled based on species abundances (Figure 4). Similarly, analysis of similarity (ANOSIM) indicated that bee communities at individual sites did contain dissimilar constituent bee species ( $p = 0.001$ ,  $R = 0.35$ ). Similarity percentages indicated that the bee community with the greatest self-similarity (54.7% mean within-site sample similarity) occurred in the Herring Cove barrens; two urban locations, the Atrium green roof and Pine Hill ground level sites, displayed the lowest self-similarity (20.6 and 21.2, respectively), though two barren locations, at Prospect and Chebucto Head, showed comparably low self-similarity (21.4 and 22.4, respectively).

Dissimilarity percentages indicated that key species at each site frequently contributed to between site dissimilarity (Table 2). *Lasioglossum* morphospecies 2

**Figure 3.** Mean daily abundance of bee genera at each site type (June: n = 2 sites, over 3 sampling days, for 3 site types; August: n = 2 sites (1 site for urban ground level), over 3 sampling days, for 3 site types).



**Figure 4.** NMDS ordination of bee species abundances across sampling periods by site; June (n = 2 sites, over 3 sampling days, for 3 site types) and August (n = 2 sites (1 site at urban ground level), over 3 sampling days, for 3 site types) data combined. Ellipses represent 95% confidence regions; data centered on axes means, singletons removed.



provided the greatest source of community dissimilarity for the Atrium green roof relative to other sites. The Atrium bee community was not significantly different from those found in the Herring Cove barrens ( $p = 0.13$ ,  $R = 0.18$ ) or at the ground level urban site in Point Pleasant Park ( $p = 0.19$ ,  $R = 0.10$ ). The bee community present on the green roof at NSCC was differentiated from all other sites due to the abundance of *Lasioglossum* morphospecies 1. Within Point Pleasant Park, an urban ground level bee community, the greatest source of dissimilarity to other site types was contributed by *Lasioglossum* morphospecies 2 and *Andrena carlini* (Cockerell). The

**Table 2.** Correlation matrix showing site dissimilarity percentages ca for bee species contributing to greatest similarity (per comparator site) between site pairs. First comparisons are boldface, with the second directly below. Acarol = *Andrena carolina*; Acarlin = *Andrena carlini*; Aaurat = *Augochlorella aurata*; Bimpat = *Bombus impatiens*; Bvagan = *Bombus vagans*; Bterna = *Bombus ternarius*; Lasi01 = *Lasioglossum* morphospecies 1; Lasi02 = *Lasioglossum* morphospecies 2.

Sites	Comparator					
	Chebucto Head (%)	Herring Cove (%)	NSCC (%)	Pine Hill (%)	Point Pleasant (%)	Prospect (%)
Atrium	<b>Lasi02 (11.3)</b>					
Atrium	Bvagan (15.94)	<b>Lasi02 (5.8)</b>				
Atrium		Bterna (13.2)	<b>Lasi02 (15.3)</b>			
Atrium			Lasi01 (17.65)	<b>Lasi02 (10.5)</b>		
Atrium				Bimpat (14.4)	<b>Lasi01 (11.9)</b>	
Atrium					Lasi02 (13.23)	<b>Lasi02 (14.4)</b>
Atrium						Acarol (15.21)
Chebucto Head		<b>None<sup>1</sup></b>				
Chebucto Head		Aaurat (11.01)				
Chebucto Head			<b>Bvagan (17.8)</b>			
Chebucto Head			Lasi01 (14.15)	<b>Bvagan (12)</b>		
Chebucto Head				Bimpat (12.51)	<b>Bvagan (15.4)</b>	
Chebucto Head					Lasi02 (10.43)	<b>Acarol (13.25)</b>
Chebucto Head						Bvagan (17.2)
Herring Cove			<b>Bterna (13.4)</b>			
Herring Cove			<b>None<sup>1</sup></b>	<b>Bterna (10.8)</b>		
Herring Cove				Aaurat (9.61)	<b>Bterna (13.7)</b>	
Herring Cove					Lasi02 (5.72)	<b>Aaurat (11)</b>
Herring Cove						Acarol (6.71)
NSCC				<b>Lasi1 (12.3)</b>		
NSCC				Bimpat (15.08)	<b>Lasi01 (12.3)</b>	
NSCC					Lasi02 (13.31)	<b>Lasi01 (19.2)</b>
NSCC						Acarol (15.65)
Pine Hill					<b>Bimpat (12.8)</b>	
Pine Hill					Lasi02 (9.57)	<b>Bimpat (14.4)</b>
Pine Hill						Acarol (11.22)
Point Pleasant						<b>Acarli (14.3)</b>
Point Pleasant						Acarol (15.03)

Note: <sup>1</sup> Site did not contain any key species with greater abundance than the comparator site.

Pine Hill urban ground level site contained several species at abundances that increased dissimilarity to other sites, including *Lasioglossum* morphospecies 1 and 2, *Bombus ternarius* (Say), *Bombus vagans* (Smith), and *Bombus impatiens* (Cresson). At Chebucto Head, the bee species contributing the greatest dissimilarity to other sites was *Bombus vagans*. The bee community in the Chebucto Head barrens was similar to that present in the Herring Cove barrens ( $p = 0.58$ ,  $R = -0.11$ ), though Herring Cove contained greater mean abundances of shared bee species and was more species rich. The bee community in the Herring Cove barrens was primarily differentiated from other bee communities due to the abundance of *Bombus ternarius* and *Augochlorella aurata* (Smith); it did not appear distinct from the bee community sampled in the Prospect barrens ( $p = 0.7$ ,  $R = 0.45$ ). *Andrena carolina* was the primary driver of dissimilarity between the Prospect

barrens' bee community and those at all other sites.

### Pollen loads

Floral communities at all sites contained both native and exotic co-flowering species (Supplement Tables 1-6). Across sites, flowering abundance trends were similar: few exotic species flowered May to mid-June ( $4.6 \pm 0.7$  species) while many flowered from mid-June to August ( $20 \pm 2.6$ ) and August – September ( $21 \pm 2.9$ ), though richness of native plant species in flower was similar across the entire summer (13.1 – 18 species). Although the availability of receptive flowers for each target plant species (*Sibbaldia tridentata* and *Solidago bicolor*) varied considerably among plots ( $627.6 \pm 127.3$  *Sibbaldia tridentata* flowers,  $24.3 \pm 1.4$  *Solidago bicolor* individuals in bloom), the proportion of bee captures on focal species did not differ across site types (41 – 65% of bees captured).

Thirty-seven unique pollen morphotypes were identified in 128 bumble bee pollen loads (Table 3). For each bumble bee, both the identity of the flower on which it was captured, and the contents of its pollen load were characterized. The flower genera on which the most bumble bees were captured within sampling plots included *Solidago* (56), *Centaurea* L. (Asteraceae) (24), *Scorzoneroideis* Moench (Asteraceae) (12), *Campanula* L. (Campanulaceae) (10), *Trifolium* L. (Fabaceae) (7), and *Rosa* L. (Rosaceae) (4). The frequency with which each plant species also occurred in a bee's pollen load varied; *Rosa* pollen appeared as the dominant grain type in 100% of the pollen loads collected by bees captured on *Rosa*. However, while *Centaurea* pollen occurred in 100% of the pollen loads of bees that were captured on *Centaurea*, only 45.7% of those pollen loads featured *Centaurea* as a dominant (> 100 grains) grain type. Of the most commonly contacted plant species, *Campanula* occurred the least frequently (40%) as a dominant grain in the pollen loads of bees that were captured on that species. The degree of pollen mixing by bumble bees differed among the three site types sampled in this study.

The combination of pollen morphotypes constituting individual bumble bee pollen loads differed depending on the species of bumble bee collecting the pollen (ANOSIM:  $p = 0.004$ ,  $R = 0.17$ ; PERMANOVA:  $p = 0.001$ ) and the sites at which pollen was collected (ANOSIM:  $p = 0.01$ ,  $R = 0.18$ ; PERMANOVA:  $p = 0.001$ ). Across bumble bee species, *Bombus rufocinctus* (Cresson) demonstrated the lowest within-species pollen collection variability, with a mean pollen load similarity of 39.8% among *Bombus rufocinctus* foragers and a high abundance of *Campanula* and *Trifolium* pollen. Comparable levels of within-species similarity were displayed by *Bombus ternarius* (36.7%) and *Bombus vagans* (35.7%), both species favouring *Centaurea*, *Taraxacum* Wigg (Asteraceae), and *Spiraea* L. (Rosaceae) pollen; and *Bombus impatiens* (34.8%), primarily collecting *Solidago* and *Taraxacum*-type pollen. *Hydrangea* L. (Hydrangeaceae) pollen accounted for 100% of the within-species similarity of *Bombus bimaculatus* (Cresson), the bumble bee species exhibiting the greatest within-species pollen load composition variability (10.1%) (Figure 5).

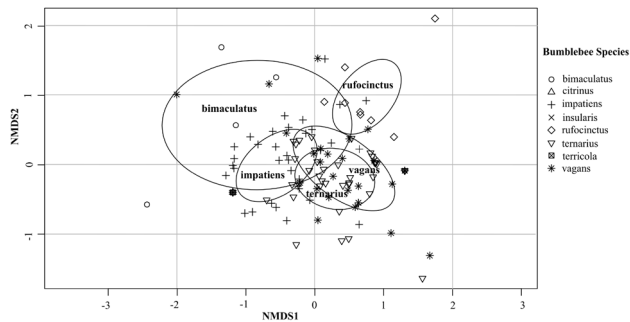
Bumble bees foraging at sites in different habitats appeared to focus on distinct pollen morphotypes during this study (Supplement Figure 1). Within-site similarity of bumble bee-collected pollen loads gathered at green roof sites (45.5% within-site similarity) were defined by abundance of *Solidago* (58.4%) and *Campanula* (20.4%). Bumble bees at urban ground level sites displayed the lowest within-site

**Table 3.** Pollen taxa identities and grain dominance frequency in August-collected bumble bee pollen loads.

Pollen morphotype	Frequency		
	10-49 grains	50-99 grains	100+ grains
<i>Achillea</i>	2	1	1
<i>Borago</i>	1	1	1
<i>Campanula</i>	9	7	5
<i>Centaurea</i>	65	43	29
<i>Cerastium</i>	1	1	1
<i>Chamerion</i>	1	1	1
<i>Cirsium</i>	4	0	0
<i>Daucus</i>	8	2	1
<i>Diervilla</i>	1	0	0
Ericaceae-type	1	1	1
<i>Erigeron</i>	2	1	1
<i>Euphrasia</i>	1	1	1
<i>Galium</i>	1	0	0
<i>Gaultheria</i>	11	6	4
<i>Hosta</i>	9	2	2
<i>Hydrangea</i>	13	10	10
<i>Hypericum</i>	4	2	2
<i>Impatiens</i>	2	1	1
Liliaceae-type	1	1	1
<i>Mentha</i> -type	11	9	7
Onagraceae-type	1	0	0
<i>Plantago</i>	2	2	2
<i>Prunella</i>	1	1	1
<i>Rosa</i>	17	14	12
<i>Rubus</i>	14	13	13
<i>Sedum</i>	2	1	1
<i>Sibbaldiopsis</i>	2	2	2
<i>Solanum</i>	4	3	3
<i>Solidago</i>	68	54	40
<i>Spiraea</i>	45	38	34
<i>Taraxacum</i> -type	60	38	30
<i>Trifolium</i>	37	29	27
<i>Urtica</i> -type	1	1	1
<i>Viburnum</i>	12	5	5
<i>Vicia</i>	4	1	1
Unknown1	1	0	0
Unknown2	1	0	0

similarity (32.8%), driven by the contributions of *Solidago* (61.1%) and *Taraxacum*-type pollen (10.4%). *Centaurea* (44%), *Taraxacum*-type (22.7%), and *Spiraea* (14.8%) grains were the primary determinants of coastal barrens within-site similarity (36.6%). Pollen loads collected at green roof sites contained pollen taxa similar to ground level urban (67.3% similar) and coastal barren sites (59.2% similar); however, pollen load compositions from coastal barren sites differed significantly ( $p = 0.029$ ,  $R = 0.186$ ) from those collected at urban ground level sites (mean dissimilarity = 73.8%). At urban ground level sites, *Solidago* (11.2%), *Hypericum* L. (Hypericaceae) (4.8%), and *Hydrangea* (4.6%)

**Figure 5.** NMDS ordination of pollen taxa contained in bumble bee collected pollen loads across sampling periods and sites (n = 2 green roofs for 3 days, n = 1 urban ground level site for 6 days, n = 2 coastal barrens for 3 days). Ellipses represent 95% confidence regions for each bumble bee species mean; data centered on axes means, singletons removed.



contributed to pollen load dissimilarity, while *Centaurea* (12.8%), *Taraxacum*-type (10.3%), *Trifolium* (10.1%), *Rubus* (L. (Rosaceae) (5.3%), and *Rosa* (4%) represented the sources of greatest dissimilarity at coastal barren sites.

## DISCUSSION

### Wild bee communities

Bees frequently visited all habitats monitored in this study. The slope of species accumulation indicated that all sites sampled, contained substantial undocumented bee richness. Our observation of lower abundance and total richness in bee communities at green roof sites relative to those located in natural habitat must be interpreted cautiously due to low site type replication and fairly restricted sampling periods. However, these results correspond with findings from Tonietto et al. (2011), who compared bee communities on green roofs to those found in urban parks and natural prairie habitat in Chicago. Green roofs in Toronto also appeared to host less species rich and less abundant bee communities relative to ground level sites (Colla et al. 2009).

The absence of *Augochlorella* and *Ceratina* at green roof sites sampled in our study, is consistent with other green roof studies; in North America (Colla et al. 2009; MacIvor et al. 2015; Tonietto et al. 2011). *Ceratina* nest in pithy stems (e.g., *Rubus*) (Packer et al. 2007), and lack of these nesting resources may dissuade these small bees from visiting green roofs. *Augochlorella* are eusocial, ground-nesting halictids, and foundresses produce workers, males, and queens over the course of the summer (Packer et al. 2007). As colonies increase in size, their resource

requirements grow. Thus, the floral resources of a small green roof may not adequately support large, in situ colonies of *Augochlorella*, and, as with *Ceratina*, their small body size may prohibit continued visits of green roofs for pollen or nectar. Furthermore, drought conditions, which occur frequently on green roofs, can reduce the productivity of *Augochlorella* colonies (Packer 1990), which may also reduce the likelihood of *Augochlorella* colony establishment on extensive green roofs.

*Lasioglossum* are commonly found a part of green roof bee communities (Colla et al. 2009; Tonietto et al. 2011), and this was also found in our study. While *Lasioglossum* are abundant in the urban environment (Colla and Packer 2008), their size precludes extended foraging flights (Greenleaf et al. 2007), suggesting that these small sweat bees might nest directly on green roofs, with foragers relying entirely on green roof floral resources to provide both pollen and nectar (Tonietto et al. 2011).

However, MacIvor et al. (2015) found that bee communities on green roofs in Toronto featured more large and medium-bodied bees, such as *Bombus* and *Apis*; however, the roofs they sampled contained large populations of *Sedum*, a mass flowering plant that is known to be attractive to these genera (Ishii 2006). Green roofs in this study however, featured low densities of mixed flowering species. While the large body size and crop volume of bumble bees allow them to forage over long (>1 km) distances (Cresswell et al. 2000), increased body size also intensifies energy expenditure during flight (Heinrich 2004). It is unlikely that bumble bees would nest on extensive green roofs, as they prefer abandoned rodent burrows and tree cavities (Packer et al. 2007); therefore, each trip by a forager to a green roof involves energetic costs during vertical flight and foraging on the roof. Longer foraging distances have been shown to negatively affect bumblebee colony growth (Cresswell et al. 2000), so sparse green roof floral resources or flowers with low nectar carbohydrate content (or volume) may create uneconomic foraging conditions for bumble bees when ground level resources are abundant.

Three of the most abundant bumble bees collected in this study, *Bombus impatiens*, *Bombus rufocinctus*, and *Bombus ternarius*, appear to be experiencing population increases in eastern North America (Colla and Packer 2008). Despite documented decline of *Bombus vagans* in Canada (Colla and Packer 2008), we found that *Bombus vagans* was frequently found at ground level sites and displayed a high abundance in coastal barrens. Two *Bombus terricola* were collected on the Atrium green roof, and another at the Pine Hill urban site. It appears



that some *Bombus terricola* were attracted to resources present within urban habitat in Halifax, and though none were collected during timed aerial netting, many *Bombus terricola* were observed foraging on *Spiraea alba* (Du Roy) and *Centaurea nigra* (L.) in the Chebucto Head coastal barren. Andrenid presence at all sites in June and frequent visits to *Sibbaldia tridentata* on green roofs suggests that *Sibbaldia tridentata* may represent attractive forage for these spring flying bees. Surveys of urban bees indicate that ground nesting *Andrena* are rare in the urban environment (Hernandez et al. 2009), so provision of attractive, early-blooming forage in the city, including on green roofs, may improve establishment of these highly effective pollinators (Javorek et al. 2002) in cities.

The urban residential site at Pine Hill contained a diverse bee community, including a parasitic genus, *Sphecodes*, which was not collected at any other site. As a parasite of other halictids (Packer et al. 2007), *Sphecodes* at this site were likely targeting abundant *Halictus rubicundus* (Christ). Similar to the Atrium green roof, correspondence between the urban bee community at Pine Hill and that in the Herring Cove barren centered on similarities in *Bombus impatiens* abundance. The Pine Hill site contained shrubs (e.g., *Morella* Lour. (Myricaceae), *Ilex* Mill. (Fagaceae), *Aronia* Medik. (Rosaceae), *Vaccinium* L. (Ericaceae)) common to the Herring Cove barren but sparse elsewhere in the city. *Osmia simillima* (Smith), a cavity-nesting bee, was not found at the urban Pine Hill location but was present at Herring Cove. Proximity to a forest edge provided much woody debris at Herring Cove, with many logs exhibiting signs of beetle activity. These features would contribute nesting sites for cavity-nesting *Osmia* at Herring Cove (Packer et al. 2007). As the area planted with native species increases in urban gardens, abundance of native bees, especially bumble bees, appears to also increase (Fukase and Simons 2016). The residential yard sampled at Pine Hill features an atypical diversity of native plants relative to neighbouring properties, which may attract urban bumble bees like *Bombus impatiens*.

Among the barrens, Chebucto Head and Herring Cove featured similar bee communities, with both sites hosting similar abundances of *Bombus vagans*. However, Herring Cove was more species rich than Chebucto Head. Proximity to a forest edge has been shown to increase bee richness in blueberry fields (Cutler et al. 2015) and the forested boundary of the Herring Cove barren may produce greater environmental heterogeneity, and thus nesting opportunities, at that site relative to the other, more extensive barrens sampled. The bee community present

in the Prospect barren was distinct from all sites except the community in the Herring Cove barren, with which it shared a large population of *Bombus vagans*. The andrenid *Andrena carolina* (Viereck), collected in abundance at Prospect, was absent at all other sites. *Andrena carolina* specializes on Ericaceae, and work by Tuell et al. (2009) indicated that *Andrena carolina* collected pollen exclusively from *Vaccinium* when lowbush blueberry was in bloom. Barrens are characterized by predominantly ericaceous, shrubby plant communities and *Vaccinium* was present at all barren sites sampled in this study; thus, certain coastal barrens may represent high quality habitat for this species. Sellars and Hicks (2015) also found *Andrena carolina* to be highly abundant in open woodland in Newfoundland. One male *Hylaeus affinis* was collected in the coastal barren at Prospect, representing a new provincial record for this species. Together, undocumented species richness, indicated by species accumulation curves, presence of *Vaccinium* specialists, and a new provincial record of *Hylaeus affinis* suggest that further sampling of bee communities in coastal barren environments is warranted.

### Pollen load composition

Pollen load analysis revealed that bumble bees in urban and coastal barren environments capitalized on both native and non-native pollen. Bumble bee foraging fidelity was lower in urban ground level and coastal barren environments relative to green roofs. None of the ground level sites featured large monocultures of any flowering species, though green roofs contained the fewest species – with only *Solidago* and *Campanula* in bloom in large quantities. This may explain the greater pollen collection constancy observed on green roofs relative to ground level sites.

In Halifax, *Solidago* appeared to be an important source of pollen for bumble bees, especially in the urban environment. The pollen loads collected by bumble bees on green roofs were similar to those collected at our urban ground level and coastal barren sites. However, bumble bees collected distinct pollen loads at coastal barren sites relative to urban ground level sites. Though bumble bees at both locations relied on native pollen sources, like *Spiraea*, and exotic pollen sources, like *Hieracium* or *Scorzoneroideis*, bumble bees at urban ground level sites collected more pollen from *Solidago*, while coastal barren foragers collected *Centaurea* and *Trifolium* pollen and relied less on *Solidago*. Both *Solidago* and *Spiraea* are known to be attractive to pollinators despite minimal nectar rewards due to their ease of handling, as bees can crawl across inflorescences and contact multiple flowers

with minimal energy expenditure (Robson 2008). For bumble bees, pollen handling requires more time to learn than does nectar handling (Raine and Chittka 2007), which may explain the high frequency of *Solidago* grains in bee pollen loads despite low nectar reward. The protein-rich pollen offered by *Trifolium* frequently attracts bumble bees foraging in urban environments (Larson et al. 2014). In Britain where it is native, *Centaurea nigra* is a highly valuable forage resource for bumble bees (Carvell et al. 2006).

As generalists, bumble bees may benefit from the added floral resources offered by exotic plant species (Jha and Kremen 2013). Hinners and Hjelmroos-koski (2009) found that bees collected large amounts (45%) of exotic pollen taxa in urban grasslands, and in disturbed habitat, bees foraged on exotic plant species when availability of native flowers was limited (Williams et al. 2011). However, a high frequency of pollen collection from exotic species has the potential to reduce bumble bee interactions with native barren plant species. Grass et al. (2013) reported that an increase in abundance of exotic plants promoted generalist pollinators and generalist pollination strategies. Several studies have indicated that coastal barren communities host rare plant species and plant communities differing from other environments in Nova Scotia (Cameron and Bondrup-Nielsen 2013; Oberndorfer and Lundholm 2009; Porter 2013). The relationships between rare plants and their pollinators in Nova Scotia coastal barrens remain poorly understood. Bee-pollinated plant species with patchy, low-density distributions (e.g., *Agalinis* Raf. (Orobanchaceae), *Saxifraga* Tourn. (Saxifragaceae), and *Silene* L. (Caryophyllaceae)) may be vulnerable to pollen limitation if these plants must compete for pollinators with large aggregations of highly attractive exotics (Geslin et al. 2014). Understanding the impact of exotic invaders on plant-pollinator relationships in coastal barrens in Nova Scotia could benefit efforts to conserve some rare plant species.

## CONCLUSION

Results from this study indicate that native-planted green roofs can serve as habitat for a number of urban bee taxa; however, the suitability of green roof habitat depends on the species of bee. Our findings also demonstrated that some native-planted green roofs can host bee communities similar to those found at ground level and coastal barren sites, though further sampling at additional sites and for a greater portion of the summer is needed to confirm these patterns. Common, urban-adapted species linked roof communities to urban ground level and proximal coastal barren sites; however, larger, more geographically

distant coastal barrens did not host bee communities similar to native planted green roofs. Despite differences in bumble bee pollen collection habits between urban ground level and coastal barrens sites detected in this study, bumble bees on native-planted green roofs showed pollen collection habits intermediate between the two ground level environments – indicating that foraging options on our native-planted green roofs diversified the pollen taxa available to and used by urban bees in Halifax. Two native plant species, *Sibbaldia tridentata* and *Solidago bicolor* are attractive forage options for bee species, with *Solidago bicolor* contributing significantly to the pollen load content of bumble bee foragers.

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## SUPPLEMENTAL MATERIALS

### Detailed site descriptions

Two green roofs containing the focal plant species were sampled over all collection periods. The Atrium green roof is located on Saint Mary's University campus in Halifax, NS. This green roof consists of a 216 m<sup>2</sup> rectangular vegetated area on the fifth story of the Atrium building; it was installed in 2010 and has since been covered primarily by *Sibbaldia tridentata*, *Solidago bicolor*, *Danthonia spicata*, L. (Poaceae), mosses, and lichens; other forbs and grasses have dispersed into the vegetated area from adjacent modular experiments. Weeds have been periodically removed, though this maintenance activity ceased during the study period. The roof receives uneven shade from surrounding buildings. The second green roof included in this study is located at the NSCC waterfront campus in Dartmouth, NS, over the Centre for the Built Environment, and features a vegetated area of 75 m<sup>2</sup> approximately eight meters above ground level, installed June 2013. The NSCC green roof plant community is composed of ten species of *Sedum* and mixed plantings of native species (*Solidago bicolor*, *Campanula rotundifolia* L. (Campanulaceae), *Sagina procumbens* L. (Sagina), *Rhodiola rosea* L. (Crassulaceae), *Luzula multiflora* (Ehrh.) Lej. (Juncaceae), *Plantago maritima* L. (Plantaginaceae), *Danthonia spicata* (L.) P.Beauv., *Deschampsia flexuosa* (L.) Trin. (Poaceae), *Festuca rubra* L. (Poaceae), and *Sibbaldia tridentata*). Installation details are described by Appleby-Jones (2014). One quarter of the roof area is planted exclusively with *Sedum*, while the remaining roof area contains a patchwork of *Sedum* plots and native species plots. Twenty modules containing *Solidago bicolor* in flower were transported to the site in late July to facilitate bee collection in August, as few *Solidago bicolor* individuals were present within the vegetated area. A smaller green roof was located one level above this study roof, and the plant species present on this smaller roof were included in the site floral survey.

Two urban ground level sites were included in this study, both occurring on the Halifax peninsula. One site (Pine Hill) was located in a residential area of Halifax on Pine Hill Drive and was sampled during the bloom period of both focal host plant species. This site features plants common to coastal barrens, including *Empetrum* L. (Ericaceae), *Aronia*, *Ilex*, *Morella*, and *Vaccinium*, as well as common city weeds, such as *Hieracium* L. (Asteraceae) and *Vicia* L. (Fabaceae). Surrounding properties contained garden ornamentals, herbs, and weeds. An additional ground level urban site was located in Point Pleasant Park. This approximately 75-hectare park (Jotcham et al. 1992) hosts

popular walking trails and a mixed forest community, which experienced significant disturbance in the form of blowdown damage in September 2003 as a result of Hurricane Juan (Burley et al. 2008). Surveys of park vegetation (Burley et al. 2008; Neily et al. 2004) revealed a diverse plant community within the park, including many understory species atypical of the urbanized peninsula. Both urban sites featured numerous weedy plant species. Only the site at Pine Hill contained both *Sibbaldia tridentata* and *Solidago bicolor*; therefore, Point Pleasant was not sampled in the later (August) collection period. Rather, the site at Pine Hill was sampled for three additional days (August 6–8, 2014) during which no other sites were sampled.

Bees were collected at three coastal barrens sites, Chebucto Head, Herring Cove, and Prospect. These habitats are exposed to high winds and solar radiation, due to their proximity to the ocean and near absence (> 25%) of forest cover; weather conditions in these exposed coastal locations can fluctuate significantly within a day (NSDNR 2006). Coastal barrens, or coastal heathlands, are characterized by low-growing and shrubby plant communities dominated by ericaceous species, such as *Empetrum nigrum* (L.), *Kalmia angustifolia* L. (Ericaceae), *Morella pensylvanica* ((Mirb.) Kartesz), and *Vaccinium angustifolium* (Aiton), though plant community composition can vary significantly among sites (Cameron and Bondrup-Nielsen 2013; Oberndorfer and Lundholm 2009; Porter 2013). While *Sibbaldia tridentata* occurs at all three barrens sites, *Solidago bicolor* was located only at Chebucto Head and Herring Cove. Accordingly, Chebucto Head and Prospect were sampled in the early (June) collection period, while Chebucto Head and Herring Cove were sampled during August. The coastal barrens at Herring Cove are spread thinly between a rocky coastline and a forested inland border that abuts a coastal road, whereas the barrens at Chebucto Head and Prospect are comparatively open (Figure 1). Paved areas interrupt the Herring Cove and Chebucto Head barrens; exotic plants (*Centaurea*, *Trifolium*) often populate the margins of these features along with more typical barrens taxa.

### SUPPLEMENTAL REFERENCES

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**Table S1.** Native plant species in bloom from May to mid-June by site type. Presence of “x” indicates observation of >5 individuals within 250 m of sampling plots at that site.

Native Genus	May to mid-June						
	Green roof		Urban ground level		Coastal barrens		
	Atrium	NSCC	Pine Hill	Point Pleasant	Chebucto Head	Prospect	Herring Cove
<i>Acer</i>	x	x	x	x	x		x
<i>Alnus</i>				x	x	x	x
<i>Amelanchier</i>	x			x	x	x	x
<i>Aralia</i>				x	x	x	x
<i>Arctostaphylos</i>					x	x	
<i>Arethusa</i>					x	x	
<i>Argentina</i>						x	
<i>Aronia</i>			x		x	x	x
<i>Chamaedaphne</i>					x	x	
<i>Clintonia</i>				x			
<i>Convallaria</i>				x			
<i>Corema</i>					x	x	
<i>Cornus</i>	x		x	x	x	x	x
<i>Empetrum</i>			x		x	x	x
<i>Epigaea</i>				x			x
<i>Fragaria</i>	x	x	x	x	x	x	x
<i>Gaylussacia</i>					x	x	x
<i>Houstonia</i>	x	x		x			
<i>Hudsonia</i>	x				x		
<i>Ilex</i>			x		x	x	x
<i>Ledum</i>					x	x	
<i>Lonicera</i>						x	
<i>Maianthemum</i>	x			x	x	x	x
<i>Morella</i>		x	x	x	x	x	x
<i>Prunus</i>					x		
<i>Salix</i>			x		x		
<i>Rhodiola</i>	x	x	x		x	x	
<i>Rhododendron</i>			x		x	x	
<i>Sarracenia</i>					x	x	
<i>Trientalis</i>				x	x	x	x
<i>Vaccinium</i>			x	x	x	x	x
<b>Total</b>	<b>8</b>	<b>5</b>	<b>11</b>	<b>14</b>	<b>25</b>	<b>23</b>	<b>15</b>

**Table S2.** Exotic plant species in bloom from May to mid-June. Presence of “x” indicates observation of >5 individuals within 250 m of sampling plots at that site.

Exotic Genus	May to mid-June						
	Green roof		Urban ground level		Coastal barrens		
	Atrium	NSCC	Pine Hill	Point Pleasant	Chebucto Head	Prospect	Herring Cove
<i>Aesculus</i>				x			
<i>Aquilegia</i>	x						
<i>Cerastium</i>	x	x	x	x	x	x	x
<i>Ilex</i>	x						
<i>Malus</i>	x		x				
<i>Magnolia</i>	x						
<i>Oxalis</i>	x	x	x	x			x
<i>Ranunculus</i>	x	x	x	x	x	x	x
<i>Tussilago</i>	x	x	x	x	x		x
<i>Typha</i>		x					
<b>Total</b>	<b>8</b>	<b>5</b>	<b>5</b>	<b>5</b>	<b>3</b>	<b>2</b>	<b>4</b>

**Table S3.** Native plant species in bloom from mid-June to August. Presence of "x" indicates observation of >5 individuals within 250 m of sampling plots at that site.

Native Genus	mid-June to August						
	Green roof		Urban ground level		Coastal barrens		
	Atrium	NSCC	Pine Hill	Point Pleasant	Chebucto Head	Prospect	Herring Cove
<i>Achillea</i>	x	x	x	x	x	x	x
<i>Angelica</i>						x	x
<i>Argentina</i>						x	
<i>Aronia</i>			x	x	x	x	x
<i>Campanula</i>	x	x	x		x	x	x
<i>Cornus</i>	x		x	x	x	x	x
<i>Cypripedium</i>							x
<i>Diervilla</i>			x	x	x		
<i>Erigeron</i>	x	x	x				
<i>Euphrasia</i>					x		x
<i>Fragaria</i>	x	x	x	x	x	x	x
<i>Galium</i>	x	x					
<i>Gaultheria</i>				x	x	x	x
<i>Hudsonia</i>	x				x		
<i>Ilex</i>			x		x	x	x
<i>Iris</i>		x				x	x
<i>Kalmia</i>				x	x	x	
<i>Lathyrus</i>				x		x	x
<i>Mitchella</i>				x			
<i>Plantago</i>	x	x	x	x	x	x	x
<i>Potentilla</i>		x	x	x	x		x
<i>Prunella</i>	x	x	x	x			
<i>Rhodiola</i>	x	x	x		x	x	
<i>Rhus</i>				x	x		
<i>Rubus</i>		x	x	x	x	x	x
<i>Sarracenia</i>				x	x		
<i>Sibbaldiopsis</i>	x	x	x	x	x	x	x
<i>Sisyrinchium</i>			x		x	x	x
<i>Sorbus</i>					x	x	x
<i>Trientalis</i>				x	x	x	x
<i>Vaccinium</i>			x	x	x	x	x
<i>Viburnum</i>	x	x	x	x	x	x	x
<b>Total</b>	12	13	17	18	23	22	21

**Table S4.** Exotic plant species in bloom from mid-June to August. Presence of "x" indicates observation of >5 individuals within 250 m of sampling plots at that site.

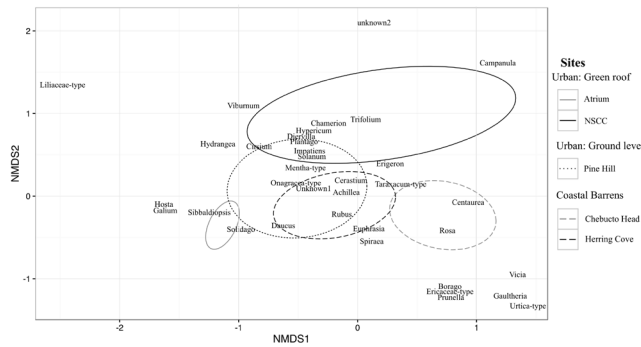
Exotic Genus	mid-June to August						
	Green roof		Urban ground level		Coastal barrens		
	Atrium	NSCC	Pine Hill	Point Pleasant	Chebucto Head	Prospect	Herring Cove
<i>Allium</i>	x	x			x		
<i>Cerastium</i>	x	x	x	x	x	x	x
<i>Daucus</i>	x	x	x	x	x	x	x
<i>Epiobium</i>	x	x					
<i>Erysimum</i>		x					
<i>Glechoma</i>						x	
<i>Hemerocallis</i>	x	x	x				
<i>Hieracium</i>	x	x	x	x	x	x	x
<i>Hosta</i>	x	x	x				
<i>Hypericum</i>		x	x	x	x		
<i>Ilex</i>	x						
<i>Impatiens</i>		x					
<i>Leontodon</i>				x	x		x
<i>Leucanthemum</i>		x	x	x			
<i>Liatris</i>			x				
<i>Linaria</i>				x			
<i>Lotus</i>		x					
<i>Lupinus</i>		x				x	x
<i>Malva</i>		x					
<i>Matricaria</i>			x	x			x
<i>Medicago</i>	x	x	x	x	x		
<i>Melilotus</i>		x	x				
<i>Oxalis</i>	x	x	x	x			x
<i>Paeonia</i>			x				
<i>Plantago</i>	x	x	x	x	x	x	x
<i>Polygonum</i>	x	x	x	x		x	x
<i>Ranunculus</i>	x	x	x	x	x	x	x
<i>Raphanus</i>		x					x
<i>Rhinanthus</i>					x	x	
<i>Rorippa</i>	x						
<i>Sagina</i>	x						
<i>Sedum</i>	x	x	x				
<i>Senecio</i>	x	x	x	x			
<i>Solanum</i>			x	x			
<i>Sorbus</i>			x	x			
<i>Stellaria</i>	x	x	x	x	x	x	x
<i>Taraxacum</i>	x	x	x	x	x	x	x
<i>Thymus</i>			x				
<i>Trifolium</i>	x	x	x	x	x	x	x
<i>Veronica</i>	x	x	x	x			
<i>Viburnum</i>		x					
<i>Vicia</i>	x	x	x	x	x	x	x
<b>Total</b>	22	31	25	21	15	12	14



**Table S5.** Native plant species in bloom from August to September. Presence of “x” indicates observation of >5 individuals within 250 m of sampling plots at that site.

Native Genus	August to September						
	Green roof		Urban ground level		Coastal barrens		
	Atrium	NSCC	Pine Hill	Point Pleasant	Chebucto Head	Prospect	Herring Cove
<i>Achillea</i>	x	x	x	x	x	x	x
<i>Anaphalis</i>	x			x	x		
<i>Campanula</i>	x	x	x		x	x	x
<i>Conyza</i>	x	x					
<i>Doellingeria</i>				x	x	x	x
<i>Erigeron</i>	x	x		x			
<i>Euphrasia</i>					x		
<i>Euthamia</i>			x	x	x	x	x
<i>Gaultheria</i>				x	x	x	x
<i>Oclemena</i>					x		
<i>Oenothera</i>		x		x	x		
<i>Plantago</i>	x	x		x	x	x	x
<i>Prenanthes</i>				x	x	x	x
<i>Prunella</i>	x	x	x	x	x		
<i>Rosa</i>			x	x	x	x	x
<i>Rubus</i>		x	x	x	x	x	x
<i>Sibbaldiopsis</i>	x	x	x	x	x	x	x
<i>Solidago</i>	x	x	x	x	x	x	x
<i>Spiraea</i>			x	x	x	x	x
<i>Symphotrichum</i>	x	x	x	x	x	x	x
<i>Thalictrum</i>						x	
<b>Total</b>	<b>10</b>	<b>11</b>	<b>10</b>	<b>16</b>	<b>18</b>	<b>14</b>	<b>13</b>

**Figure S1-** NMDS ordination of pollen taxa contained in bumble bee collected pollen loads across sampling periods and sites (n = 2 green roofs for 3 days, n = 1 urban ground level site for 6 days, n = 2 coastal barrens for 3 days). Ellipses represent 95% confidence regions for each site mean; data centered on axes means, singletons removed.



**Table S6.** Exotic plant species in bloom from August to September. Presence of “x” indicates observation of >5 individuals within 250 m of sampling plots at that site.

Exotic Genus	August - September						
	Green roof		Urban ground level		Coastal barrens		
	Atrium	NSCC	Pine Hill	Point Pleasant	Chebucto Head	Prospect	Herring Cove
<i>Allium</i>		x		x	x		
<i>Bidens</i>			x	x			
<i>Centaurea</i>		x		x	x		x
<i>Cerastium</i>	x	x	x	x	x	x	x
<i>Daucus</i>	x	x	x	x	x	x	x
<i>Epilobium</i>	x	x					
<i>Hemerocallis</i>	x	x	x				
<i>Hieracium</i>	x	x	x	x	x	x	x
<i>Hosta</i>	x	x	x				
<i>Hydrangea</i>	x		x				
<i>Hypericum</i>		x	x	x	x		
<i>Impatiens</i>		x					
<i>Leontodon</i>	x	x		x	x	x	x
<i>Leucanthemum</i>		x	x	x	x		
<i>Linaria</i>				x			
<i>Lotus</i>		x					
<i>Lupinus</i>		x			x		x
<i>Matricaria</i>	x	x	x	x			x
<i>Medicago</i>	x	x	x	x	x		
<i>Melilotus</i>		x	x				
<i>Oxalis</i>	x	x	x	x			x
<i>Plantago</i>	x	x	x	x	x		x
<i>Polygonum</i>	x	x				x	
<i>Ranunculus</i>	x	x	x	x	x	x	x
<i>Raphanus</i>		x					
<i>Rhisanthus</i>					x	x	
<i>Rudbeckia</i>		x					
<i>Sagina</i>	x						
<i>Sedum</i>	x	x	x				
<i>Senecio</i>	x	x	x	x	x		
<i>Solanum</i>			x	x			
<i>Sonchus</i>		x	x		x		x
<i>Spiraea</i>	x	x	x				
<i>Stellaria</i>	x	x	x	x	x	x	x
<i>Tanacetum</i>	x						
<i>Taraxacum</i>	x	x	x	x	x		x
<i>Thymus</i>			x				
<i>Trifolium</i>	x	x	x	x	x		x
<i>Veronica</i>	x	x	x	x			
<i>Vicia</i>	x	x	x	x	x		x
<b>Total</b>	<b>24</b>	<b>32</b>	<b>26</b>	<b>22</b>	<b>19</b>	<b>8</b>	<b>16</b>