

# Conservation Conundrum: At-risk Bumble Bees (*Bombus* spp.) Show Preference for Invasive Tufted Vetch (*Vicia cracca*) While Foraging in Protected Areas

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## Abstract

In recent decades, some bumble bee species have declined, including in North America. Declines have been reported in species of bumble bees historically present in Ontario, including: yellow bumble bee (*Bombus fervidus*) (Fabricius, 1798), American bumble bee (*Bombus pensylvanicus*) (DeGeer, 1773), and yellow-banded bumble bee (*Bombus terricola*) (Kirby, 1837). Threats contributing to bumble bee population declines include: land-use changes, habitat loss, climate change, pathogen spillover, and pesticide use. A response to the need for action on pollinator preservation in North America has been to encourage 'bee-friendly' plantings. Previous studies show differences in common and at-risk bumble bee foraging; however, similar data are unavailable for Ontario. Our research question is whether there is a difference in co-occurring at-risk and common bumble bee (*Bombus* spp.) floral use (including nectar and pollen collection) in protected areas in southern Ontario. We hypothesize that common and at-risk species forage differently, predicting that at-risk species forage on a limited selection of host plants. We conducted a field survey of sites in southern Ontario, using observational methods to determine bumble bee foraging by species. The results of a redundancy analysis show a difference in foraging between common and at-risk bumblebee species. At-risk bumble bee species show a preference for foraging on invasive, naturalized *Vicia cracca* (tufted vetch). This finding raises the question of how to preserve or provide forage for at-risk bumble bees, when they show an association with an invasive species often subject to control in protected areas.

**Key words:** Plant-pollinator Interactions, Conservation, Restoration, Habitat Management, Pollination

Bumble bee (*Bombus* spp.) Latreille populations of particular species have declined globally in recent decades (Williams 1986, Kearns et al. 1998, Colla and Packer 2008, Bartomeus et al. 2013, Beckham and Atkinson 2017). A portion of North American bumble bee species have been found to be in decline (Grixti et al. 2009, Bartomeus et al. 2013, Beckham and Atkinson 2017), including species once abundant in southern Ontario, Canada (Colla and Packer 2008, Colla and Dumes 2010, Colla et al. 2012). Threats to bumble bee populations include habitat loss and land-use changes, climate change, pathogen spillover from managed bees, and pesticide use (Thorp and Shepherd 2005, Colla 2006, Grixti et al. 2009, Szabo et al. 2012, Colla 2016). A global sense of urgency over the conservation of pollinators has manifested, due to their importance primarily in agricultural systems (CSPNA 2007, Colla 2016). Recently, there has been increased pressure on policymakers, who are faced with addressing growing concerns over pollinators quickly and effectively (CSPNA 2007, Colla 2016). Most often, however, policies and programs react to the problem of pollinator declines as a whole, which

can cause oversight of important species-specific ecological requirements (Colla 2016). This is in part due to the documented lack of data available about wild pollinator species, including bumble bees in Ontario and globally (Berenbaum et al. 2007, CSPNA 2007, Colla and Packer 2008, Grixti et al. 2009).

In the field of conservation biology, a variety of strategies have been designed, recommended, and implemented upon various wild-life populations (Ebenhard et al. 1995, Primack 2008, Winfree 2010), with a focus on habitat establishment and maintenance (Cameron et al. 2011, IUCN 2016, Beckham and Atkinson 2017). Primack (2008) argues that for protected areas management to be successful it must be adaptive to the results of ongoing research. This is described as adaptive management, characterized by managers adjusting their guiding plans based on ever-changing ecological data from both inside and outside of the protected area (Primack 2008). Monitoring involves biodiversity data collection, and habitat maintenance involves management to ensure the persistence of the native/natural biodiversity (Primack 2008). Using data from within

the protected areas can also provide information about historical features of local ecosystems for restoration purposes outside of the protected area. For example, key features of a natural ecosystem, such as at-risk species forage availability, may be observed in the protected area and then used elsewhere if appropriate.

Bumble bee habitat includes nesting resources, overwintering sites, mating sites, and access to appropriate floral resources for nectar and pollen collection (Brian 1957, Goulson 2009, Colla 2016). Habitat requirements are likely to vary by species (Colla 2016), but little is known about patterns in variation (Brian 1957, Cock 1978, Colla 2016). For example, studies from Europe show that floral use has previously been found to differ at the species-level, especially in uncommon bumble bee species (Goulson and Darvill 2004, Goulson et al. 2005). These species-specific differences in habitat requirements have important implications for conservation and management efforts as potential differences in resource preferences would need to be considered (Lye et al. 2012, Jha et al. 2013, Saifuddin and Jha 2014). Differences in proboscis length among bumblebee species support resource partitioning within a community (Heinrich 1976, Ranta and Lundberg 1980). Bumblebee species with longer tongue lengths forage on plants with a long corolla length, while species with shorter tongues forage on plants with a short corolla (Ranta and Lundberg 1980). In Europe, bumble bees with long tongues that forage on deep-corolla flowers have been asserted to be most in decline (Goulson et al. 2005). Long-tongued species have been suggested to have narrower diets; therefore, populations are impacted more by habitat destruction and fragmentation (Goulson et al. 2005). The methods for determining evidence for the ‘food-plant specialization hypothesis’, studied by Goulson and Darvill (2004), have been challenged by colleagues in the field (Williams 2005). Williams highlights that rather than floral specialization, there is a correlation between climatic and habitat specialization and niche breadth (and thus decline). It is possible that dietary breadth is misinterpreted as being the main cause of decline in a species, when in fact there is a more complex explanation, such as climatic specialization or some related factor. Nevertheless, data on floral usage for Ontario’s at-risk and common bumble bee species can inform conservation decisions. This can be done by determining if there are species or plant families that at-risk bumble bees preferentially forage on and ensure these species and/or families are abundant or even promoted in management efforts. As bumble bees are both an intrinsically valuable species and critically important to natural and agricultural ecosystems, it is important that their populations are preserved.

The three at-risk bumble bee species studied here are *Bombus fervidus* (Fabricius, 1798), *Bombus pensylvanicus* (DeGeer, 1773), and *Bombus terricola* (Kirby, 1837). *Bombus terricola* is of the subgenus *Bombus* sensu stricto, and *B. fervidus* and *B. pensylvanicus* are of the subgenus *Thoracobombus* (Koch 2011, Williams et al. 2014). The yellow-banded bumble bee (*B. terricola*) was assessed as a species of Special Concern in Canada by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in May (2015) and listed as Special Concern in Ontario in 2016 and was listed as Vulnerable by the International Union for the Conservation of Nature (IUCN) (Hatfield et al. 2015a). Studies have documented a decline of *B. terricola* abundance in areas of southern Canada where it was once very common (Colla and Packer 2008). COSEWIC (2015) lists various potential threats to *B. terricola* populations and causes for decline, including interaction with pesticides, land-use changes, and pathogen spillover from managed bumble bee colonies (see Colla 2006). This bumble bee species generally has a short face and a short tongue length (Williams et al. 2014). While limited research from Ontario has found that bees with short tongues tend to have access

to a smaller diversity of flowers than bees with long tongues (Harder 1985), *B. terricola* has been found foraging on a diversity of plant genera (Colla and Dumesh 2010). More details are needed about the specific foraging requirements and behavior of this species of Special Concern in Ontario as *B. terricola* is an important species to the natural and agroecosystems in which it lives. This species is known to provide valuable pollination services to wild plants and various agricultural crops such as cranberry (*Vaccinium macrocarpon*) and blueberry (*Vaccinium corymbosum*) (Mackenzie and Averill 1995, Javorek et al. 2002). Two other at-risk bumble bees included here are the yellow bumble bee (*B. fervidus*), and the American bumble bee (*B. pensylvanicus*). These two species have been assessed by the IUCN to be Vulnerable (Hatfield et al. 2015b, c) based on information from documented population declines (Colla and Packer 2008, Colla et al. 2012). Further, Colla et al. (2012) found *B. pensylvanicus* to be one of eastern North America’s most sharply declining species. One major conservation action recommended by IUCN involves the creation, protection, and restoration of habitat for *B. fervidus* and *B. pensylvanicus* (Hatfield et al. 2015b, c).

There is a lack of forage resource data available for at-risk bumble bee species, hindering their conservation management in Ontario and abroad. Continued planning for conservation actions and programs without this information could potentially lead to harmful effects on at-risk bumble bee populations. Given the importance of forage in the creation and restoration of habitat, this study aims to investigate whether there is a difference between common and at-risk bumble bee foraging behavior in southern Ontario, Canada. Our main research question is whether there is a difference in at-risk and common bumble bee (*Bombus* spp.) floral usage (including nectar and pollen collection) in southern Ontario. We examine this research question using associations between bumble bee species and plant forage species and families using redundancy analysis, and by comparing the abundance of foraging at-risk and common bumble bee species on the plant families used for nectar or pollen collection.

## Methods

### Site Selection/Transect Design

Twenty-five sites were selected for surveying across southern Ontario (Table 1) (Fig. 1). These sites were selected as they had a recent (between 2001 and 2016) record of *B. terricola* and/or *B. pensylvanicus* and we were successful in gaining access. We obtained a ‘Research Authorization for Provincial Parks and Conservation Reserves’ permit to conduct research in Ontario’s protected areas. The selected sites include national and provincial parks, private land, and conservation areas. These sites had mixed landscape types including forests, grasslands, dunes, and urban areas (Table 1). We chose to focus on *B. terricola* and *B. pensylvanicus* records in determining the sites, as these species represent two different subgenera that are in decline, but still present, in southern Ontario. These two species have distinct habitat requirements with *B. terricola* described as a woodland species and *B. pensylvanicus* as a grassland species (Colla and Dumesh 2010). Sampling areas were designated using the QGIS buffer function at a distance of 1 km away from the location the recent occurrence record. Two 250-m transects were randomly placed using the QGIS random point function within each buffer. The direction of each transect was determined using a random number generator between 0 and 360°. Each site was to be surveyed three times in 2017 (spring/early, mid-summer, and late-summer). The spring surveys took place between April 24 and May 26, the summer surveys between June 19

Table 1. A description of the 25 sites surveyed during 2017 sampling

Site name	Latitude	Longitude	At-risk recent occurrence	Shannon diversity	Bumble bee species surveyed	Site description
Arrowhead Provincial Park (3)	45.3917	-79.1978	<i>B. terricola</i>	1.63	<i>B. bimaculatus</i> <i>B. griseocolis</i> <i>B. impatiens</i> <i>B. perplexus</i> <i>B. ternarius</i> <i>B. vagans</i>	Densely forested, hills, beach.
Awenda Provincial Park (3)	44.84871	-80.0194	<i>B. terricola</i>	1.66	<i>B. bimaculatus</i> <i>B. griseocolis</i> <i>B. impatiens</i> <i>B. perplexus</i> <i>B. terricola</i> *	Densely forested, beach, near open water
Backus Woods (2)	42.68102	-80.4739	<i>B. pensylvanicus</i>	1.49	<i>B. vagans</i> <i>B. bimaculatus</i> <i>B. griseocolis</i> <i>B. impatiens</i> <i>B. perplexus</i> <i>B. terricola</i> *	Forest and grassland patches sandy soil, surrounded by agriculture
Bass Lake Provincial Park (3) Bayview Park (3)	44.60251 44.38811	-79.4867 -79.6869	<i>B. terricola</i> Both	0 0.61	<i>B. vagans</i> <i>B. borealis</i> <i>B. bimaculatus</i> <i>B. impatiens</i>	Forest, beach, near open water, marshy Urban park, lawn and maintained gardens, near open water, scattered trees, urban landscape Forested with some built-up recreational areas, near open water
Beausoleil Island (1)	44.84754	-79.8605	<i>B. terricola</i>	1.04	<i>B. bimaculatus</i> <i>B. impatiens</i>	Dense forest, near open water, beach
Black Creek Provincial Park (3)	44.96836	-81.3625	<i>B. terricola</i>	1.52	<i>B. griseocolis</i> <i>B. bimaculatus</i> <i>B. borealis</i> <i>B. griseocolis</i> <i>B. impatiens</i> <i>B. ternarius</i>	Dense forest, wet soil
Bruce Peninsula National Park (3)	45.2128	-81.4895	<i>B. terricola</i>	1.33	<i>B. bimaculatus</i> <i>B. griseocolis</i> <i>B. impatiens</i> <i>B. vagans</i>	Forest, exposed rock, steep rockface Forest and grassland patches, sandy soil, surrounded by agriculture
Bruce Trail Caledon (3) Central Big Creek Block (3)	43.8015 42.64919	-79.99 -80.5604	<i>B. terricola</i> <i>B. pensylvanicus</i>	0 1.54	<i>B. bimaculatus</i> <i>B. fervidus</i> * <i>B. griseocolis</i> <i>B. impatiens</i> <i>B. terricola</i> *	Forest, exposed rock, steep rockface Forest and grassland patches, sandy soil, surrounded by agriculture
Forks of the Credit Provincial Park (3)	43.8249	-80.004	Both	1.41	<i>B. bimaculatus</i> <i>B. borealis</i> <i>B. griseocolis</i> <i>B. impatiens</i> <i>B. pensylvanicus</i> * <i>B. vagans</i>	Grassland and sloping hills some wooded areas

Table 1. Continued

Site name	Latitude	Longitude	At-risk recent occurrence	Shannon diversity	Bumble bee species surveyed	Site description
Guelph Lake Conservation Area (3)	43.596	-80.252	<i>B. terricola</i>	1.32	<i>B. bimaculatus</i> <i>B. griseocolis</i> <i>B. impatiens</i> <i>B. pennsylvanicus</i> * <i>B. vagans</i>	Campground surrounded by forest, pollinator garden within a grassland
Harris Park (3)	42.983	-81.25	<i>B. pennsylvanicus</i>	1.48	<i>B. bimaculatus</i> <i>B. griseocolis</i> <i>B. impatiens</i> <i>B. rufocinctus</i> <i>B. ternarius</i> <i>B. vagans</i>	Urban park, lawn, few scattered trees, urban landscape
Inverhuron Provincial Park (3)	44.2987	-81.5944	<i>B. terricola</i>	1.52	<i>B. bimaculatus</i> <i>B. borealis</i> <i>B. griseocolis</i> <i>B. impatiens</i> <i>B. terricola</i> *	Dense forest, few forest clearings, near open water
MacNaughton Trail (3)	43.35	-81.483	<i>B. pennsylvanicus</i>	1.04	<i>B. griseocolis</i> <i>B. impatiens</i>	Forest, surrounded by agriculture, marsh and residential development
Mara Provincial Park (3)	44.58661	-79.3571	<i>B. terricola</i>	0.97	<i>B. vagans</i> <i>B. borealis</i> <i>B. impatiens</i>	Forest, beach, near open water, marsh
Matchedash Bay (3)	44.75084	-79.646	<i>B. terricola</i>	1.41	<i>B. vagans</i> <i>B. bimaculatus</i> <i>B. borealis</i> <i>B. citrinus</i> <i>B. impatiens</i> <i>B. perplexus</i> <i>B. rufocinctus</i>	Wetland and forest, surrounded by agriculture
Pinery Provincial Park (2)	43.2734	-81.8183	<i>B. pennsylvanicus</i>	1.49	<i>B. bimaculatus</i> <i>B. citrinus</i> <i>B. griseocolis</i> <i>B. impatiens</i> <i>B. vagans</i>	Forest, dunes, beach, near open water
Pollinators Park (3)	43.57776	-80.2331	Both	1.82	<i>B. bimaculatus</i> <i>B. borealis</i> <i>B. fervidus</i> * <i>B. griseocolis</i> <i>B. impatiens</i> <i>B. rufocinctus</i> <i>B. terricola</i> *	Grassland, surrounded by development
Scotsdale Farm (3)	43.69024	-80.0051	<i>B. terricola</i>	1.22	<i>B. vagans</i> <i>B. bimaculatus</i> <i>B. borealis</i> <i>B. griseocolis</i> <i>B. impatiens</i>	Forest and rangeland, surrounded by agriculture, marsh

Table 1. Continued

Site name	Latitude	Longitude	At-risk recent occurrence	Shannon diversity	Bumble bee species surveyed	Site description
Singing Sands (3)	45.1912	-81.5776	<i>B. terricola</i>	1.04	<i>B. bimaculatus</i> <i>B. borealis</i>	Beach, dunes, near open water, dense forest
Sulfur Springs Conservation Area (3)	44.11729	-81.0035	<i>B. terricola</i>	1.1	<i>B. fervidus</i> * <i>B. bimaculatus</i> <i>B. impatiens</i>	Forest and marsh, surrounded by agriculture
Turkey Point Provincial Park (3)	42.7279	-80.3369	<i>B. pennsylvanicus</i>	0.69	<i>B. perplexus</i> <i>B. impatiens</i> <i>B. vagans</i>	Densely forested, some forest clearings
University of Guelph Arboretum (3)	43.54205	-80.2115	<i>B. terricola</i>	1.07	<i>B. bimaculatus</i> <i>B. griseocollis</i> <i>B. impatiens</i> <i>B. vagans</i>	Maintained gardens, scattered trees, forest, arboretum
Waubaushene Beaches (3)	44.75054	-79.7209	<i>B. terricola</i>	1.04	<i>B. bimaculatus</i> <i>B. impatiens</i> <i>B. vagans</i>	Shrubland meadow, scattered trees, sandy soil

The number of times the site was surveyed is given in bracket. The at-risk bumble bee species that was recently observed at each site is given as 'at-risk recent occurrence'. The at-risk bumble bee species that was recently (past ten years) observed at each site and a general description of the site are also given. The Shannon diversity estimate for each site is listed as well as all bumble bee species found during sampling (\* denotes at-risk species).

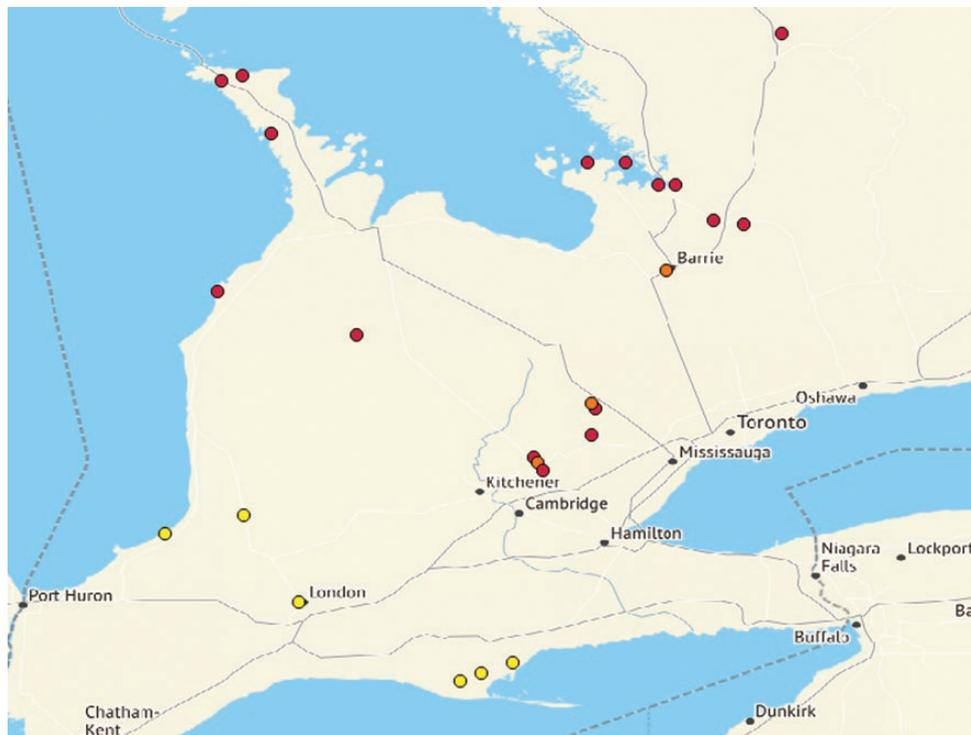
and July 7, and the late-summer surveys were between August 7 and August 24. Not every site was surveyed in each time-period due to inability to gain access or flooding in the survey area due to a very wet spring season (Table 1), but each site was surveyed at least once.

## Survey Methods

Observational survey methods were used to collect bumble bees for this study. Transects were walked once a day at each site and each bumble bee present along the transect foraging on a flower within 2 m on either side was recorded. Foraging bees were collected using a sweep net or by vial collection on the flower (Kearns and Inouye 1993). Determination between nectar and pollen foraging was made using a combination of observing bees grooming pollen toward their corbiculae, while on the flower, and presence of pollen sacs, prior to net collection (Goulson and Darvill 2004). Bees otherwise on the flower were recorded as collecting nectar. The date, site, time, and host plant (i.e., the forage species) were recorded on the vial for each of the bumble bees, which were then placed inside a small lunch cooler containing freezer packs. The freezer packs help to cool the bumble bees down to the appropriate temperature required for them to stop moving which allows for identification in the field. While the bumble bees were chilled, photos were taken to verify the species-level identification of each bumble bee collected during the study. Photos were also taken of each plant for identification purposes. In most cases, a voucher worker specimen was collected for each bumble bee species recorded and identified using Williams et al. (2014). The majority of bees were released after identification. Only a small number of bees were collected for identification later in the lab. A table was used to record the count and status of bumble bees collected during this survey (Table 2). Voucher specimens and specimens difficult to identify in the field were collected. Collected specimens were frozen in the vial. Each bee was pinned to the right of the center of the thorax using size II BioQuip Insect Pins (Kearns and Inouye 1993). This collection is being held in Dr. Colla's laboratory at York University, Toronto, Ontario, Canada. Bumble bees were identified according to Bumble Bees of North America (Williams et al. 2014). Plants bumble bees were observed foraging on were identified according to Plants of Southern Ontario (Dickinson and Royer 2014). Plants were identified to species level when possible and were otherwise identified to family level. Species identification was verified by Dr. Colla and Victoria MacPhail, York University.

## Statistical Analysis

The number of host plant species found for a particular number of sites sampled was determined with a species accumulation curve using the *specaccum* function (Oksanen et al. 2018) (e.g., Williams et al. 2009). The number of resampling events at each site was 999. Redundancy analysis (RDA) was used to determine whether common and at-risk bumble bee species forage on different plant species for mid and late-summer combined, and mid and late-summer analyzed separately. The variables that were included were the forage species and family and the bumble bee species that were observed foraging on these species. The early season was not included in either RDA as we did not find any at-risk species during spring sampling. Collinear variables were identified using variance inflation factors (*vifcor* function in package *usdm*) and all identified collinear variables ( $R = >0.90$ ) were removed as they would introduce redundancy into the model. The list of collinear variables is given in Supplementary Appendix Table 1. Redundancy analysis was performed using the *rda* and *enfit* functions (*vegan* package) using the covariance matrix and scaling set to sites (Naimi et al. 2014, Oksanen et al. 2018). A redundancy



**Fig. 1.** Map of survey site locations for sampling declining bumblebees in southern Ontario. Site locations were based on historical data of presence of at-risk species: red = *B. terricola*, yellow = *B. pensylvanicus*, orange = both. Twenty-two sites were surveyed three times, two sites were surveyed twice, and one site was surveyed once.

**Table 2.** Count of each bumble bee species (*Bombus* spp.) collected during opportunistic sampling along transects in southern Ontario between April and August 2017

Bumble bee ( <i>Bombus</i> sp.) species	Count
<i>B. bimaculatus</i>	98
<i>B. borealis</i>	13
<i>B. citrinus</i>	2
<i>B. fervidus</i> *	5
<i>B. griseocollis</i>	75
<i>B. impatiens</i>	179
<i>B. pensylvanicus</i> *	2
<i>B. perplexus</i>	10
<i>B. rufocinctus</i>	14
<i>B. ternarius</i>	10
<i>B. terricola</i> *	13
<i>B. vagans</i>	48

Species marked with \* are at-risk in our study based on declining and vulnerable population trends as assessed by the IUCN Red List.

analysis was used as our data are multivariate data and contain both response and explanatory variables (i.e., bumble bee species and forage species/families). The Hellinger transformation was applied to the data prior to running the RDA as the data contained many zeros and to avoid the double-zero effect (Zuur et al. 2007). Shannon diversity was calculated for the bumble bee species found foraging at all sites using the *diversity* function (*vegan* package). All statistical analyses were performed using R (version 3.4.3. 2017) (R Core Development Team 2017, R Documents 2018).

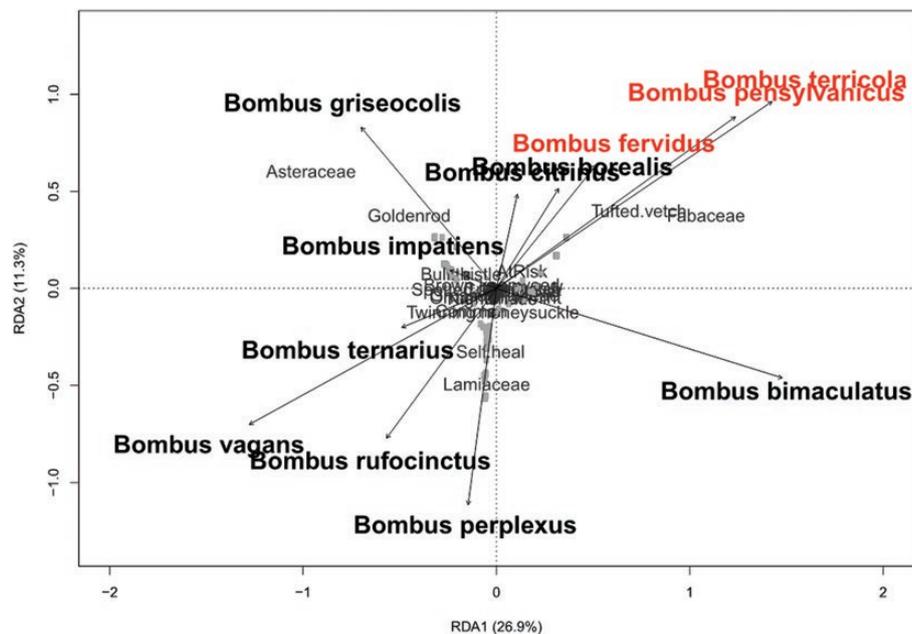
## Results

At-risk species were observed at eight of our study sites (Table 1) (Fig. 1). The sites surveyed ranged in richness from zero to eight

bumble bee species and had a Shannon diversity value between 0 and 1.82 (Table 1). There were 5 *B. fervidus*, 2 *B. pensylvanicus*, and 13 *B. terricola* individuals recorded foraging during this survey, and a total of 454 individuals of other, not at-risk bumble bees (Table 2). The results of a species accumulation curve showed that increased sampling would have increased the number of host plant species for both common and at-risk species (see Supplementary Appendix Fig. 1).

At-risk bumble bee species foraged on different plant families/species than common bee species (Fig. 2). All three at-risk bumble bee species (*B. fervidus*, *B. pensylvanicus*, and *B. terricola*) foraged on similar plant species/families when forage data was summarized across the mid and late season (Fig. 2) or only in late season when each season was analyzed separately (Fig. 3). In mid-season, two of three species foraged on similar plants (Fig. 3). The at-risk bumble bee species were consistently associated with the invasive plant species *V. cracca* Linnaeus (tufted vetch) and *Fabaceae* Linnaeus (legumes) in late-summer (Figs. 2 and 3). In mid-summer, *B. terricola* was more positively correlated with the family *Fabaceae* than *V. cracca* and was weakly correlated with the other at-risk species *B. fervidus* or *B. pensylvanicus*. In mid-summer, *B. fervidus* and *B. pensylvanicus* had a strong positive correlation with *V. cracca*, and a weaker but still positive correlation with *Fabaceae*. *B. terricola* was positively correlated with *Trifolium pratense* Fabales: Fabaceae, Linnaeus (red clover) and *Securigera varia* Fabales: Fabaceae, Lassen (crown vetch) (Fig. 3). The at-risk species *B. fervidus* and *B. pensylvanicus* were positively correlated with *V. cracca* for forage in mid-summer. In late-summer, all three at-risk bumble bee species were positively correlated with *Fabaceae*, *V. cracca*, *T. pratense* (red clover), and *Lespedeza capitata* Fabales: Fabaceae, Michaux (round bush clover) (Fig. 3).

Common bee species were found to forage more often on *Asteraceae* (asters), *Solidago* (goldenrod), (*Bombus impatiens*, Cresson, *Bombus griseocollis*, De Geer), *Lamiaceae* (mints), and



**Fig. 2.** Redundancy analysis showing the association between at-risk and common bumble bee (*Bombus* spp.) species and host plant for Mid, and Late season foraging in southern Ontario between April and August 2017. Red text indicates the at-risk bumble bee species. The total variance explained is 38.2%.

*Prunella vulgaris* Lamiales: Lamiales, Linnaeus (self-heal) (*Bombus vagans*, Smith, *Bombus rufocinctus*, Cresson, *Bombus ternarius*, Say, *Bombus perplexus*, Cresson) over the whole season (Fig. 2). In mid-summer, common bumble bee species were positively correlated with *Lonicera dioica* Dipsacales: Caprifoliaceae, Linnaeus (Twinning honeysuckle) (*Bombus bimaculatus*, Cresson, *B. perplexus*, Cresson) (Fig. 3). In late-summer, common bumble bee species were positively correlated with *Asteraceae* and *Solidago*, (*B. griseocollis*, *Bombus citrinus*, Smith, *B. ternarius*), *Lamiaceae*, and *Prunella vulgaris* (*B. rufocinctus*, *B. impatiens*, *B. perplexus*) (Fig. 3). Over the whole season, common bumble bees were correlated with *Asteraceae* and *Solidago* (*B. griseocollis*, *B. impatiens*, *B. citrinus*, and *Bombus borealis*), Kirby, *Lamiaceae* and *Prunella vulgaris* (*B. vagans*, *B. rufocinctus*, *B. ternarius*, *B. perplexus*).

A total of 194 bumble bees were recorded foraging for pollen, and 269 for nectar (some undetermined whether pollen or nectar foraging) (Fig. 4). Common bumble bee species foraged on 21 plant families and foraged for both pollen and nectar primarily on three plant families, *Asteraceae*, *Fabaceae*, and *Lamiaceae* (Fig. 4). At-risk bumble bee species foraged on four plant families, including *Fabaceae* and *Rosaceae* for pollen, and *Asteraceae*, *Fabaceae*, and *Grossulariaceae* for nectar (Fig. 4). The majority of at-risk bumble bee species foraging was on *V. cracca* (see Supplementary Appendix Table 2).

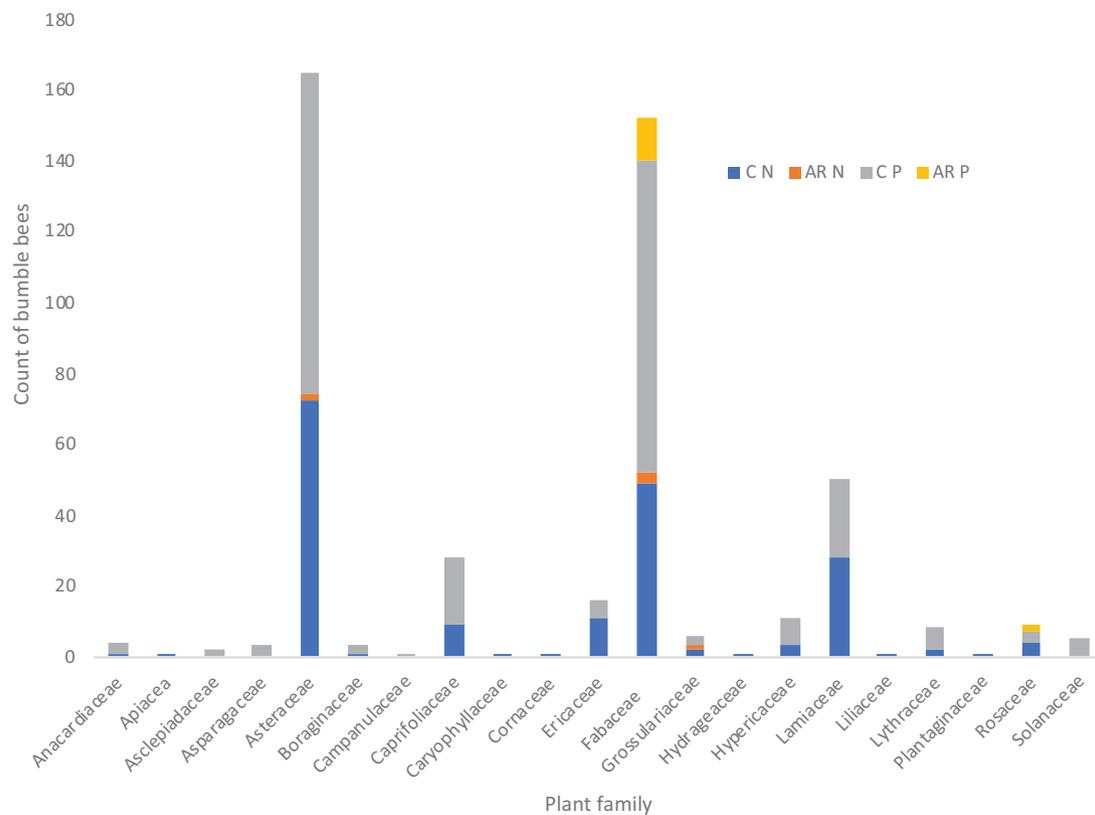
## Discussion

The results of our research provide important information which may be used in efforts to restore and conserve bumble bee habitat in Ontario, particularly by influencing decisions on forage plants used in restoration. Our results indicate at-risk and common species use the same plant community in different ways. In particular, we provide evidence of an association between at-risk bumble bee species and the plant family *Fabaceae*, particularly *V. cracca*, which the at-risk bumble bees recorded used for nectar and pollen collection. Land managers in habitat restoration face the challenge of providing both nectar and pollen sources for at-risk bumble bee species. Common bumble bee species were also commonly recorded visiting *V. cracca*, however were not associated with any particular plant species/family.

There are some shortcomings in this study, which may restrict its application, however, this work does give us a preliminary understanding which can be used to design further research to understand the ecological requirements of at-risk bumble bees in Ontario. The result of our species accumulation curve shows that we did not sample sufficiently to capture all of the potential forage plants being used by either common or at-risk bumble bee species. Our study, therefore, cannot provide data on dietary breadth for the studied bumble bee species, a limitation also mentioned in previous relevant studies (Goulson and Darvill 2004, Williams et al. 2009). Another limitation would be the potential inaccuracy of determining between pollen and nectar collection, which is unlikely to be exactly correct.

In our study, at-risk bumble bees were positively correlated with *V. cracca*, most often documented collecting pollen on this plant (see Supplementary Appendix Table 2). *Vicia cracca* blooms May–July (Aarssen et al. 1986), which includes most of our study season (late April to late August). The *Fabaceae* ‘pea’ or ‘bean’ family (interchangeable with *Leguminosae*) is a large family of flowering plants, many of which are economically important in North America (APG 2009, IAPT 2012). While *Fabaceae* is considered to have worldwide distribution (APG 2009), some species within this family are considered invasive species in Ontario. Included in this category is the species *V. cracca* (tufted vetch), which is classified as exotic, invasive, and naturalized in Ontario, and throughout most of Canada (Aarssen et al. 1986). *Vicia cracca* is considered a weed by the Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA), and warrants the use of pesticides for control in agricultural areas in Ontario (Cowbrough 2005). Pesticides are used to control *V. cracca* mainly in soybean, corn, and winter wheat plantings (Cowbrough 2005). This raises a significant conservation conundrum, where at-risk bumble bees have shown a preference for foraging on an invasive plant species that may face extensive eradication protocols including pesticide application. Research from Europe has associated reduction of legume plantings with decreases in certain bumble bee populations (Goulson et al. 2005). Future research may investigate whether a highly invasive species should be preserved in order to help conserve an at-risk bumble bee species, or perhaps if a similar native plant species could be supplemented for *V. cracca* and used in





**Fig. 4.** Count of common (C) and at-risk (AR) bumble bees foraging for nectar (N) and pollen (P) on plant families found during opportunistic field surveys in southern Ontario protected areas during the Early, Mid, and Late seasons, between April and August 2017.

many native species within the family that might be used for habitat restoration purposes.

Many important features are required to provide high-quality bumble bee habitat, including both nectar and pollen forage resources. Populations of bumble bees found to be influenced by various threats, including *B. fervidus*, *B. pensylvanicus*, and *B. terricola*, will require targeted conservation programs to maintain resilience and avoid population declines. Part of this work includes collecting baseline data to ensure that future conservation programs have species-specific data to work with. Here, we present records of foraging behavior for common and at-risk bumble bee species in various protected areas in Ontario, Canada. Common bumble bees did not show such an association with a particular plant family or species but were found foraging on a broad host of plant families and species. At-risk bumble bees show an association with *Fabaceae*, specifically *V. cracca*. Future conservation research should further consider the role of this plant family as an ecological requirement for at-risk bumble bees.

## Supplementary Data

Supplementary data are available at *Journal of Insect Science* online.

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