At-risk and common bumble bees (*Bombus* spp.) forage differently in protected areas where they co-occur

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Abstract

Bumble bees are important pollinators in wild and managed ecosystems. In recent decades, some species of bumble bees have declined globally, including across North America. Declines have been reported in certain species of bumble bees historically present in southern Ontario, including: Yellow bumble bee (*B. fervidus*) (Fabricus, 1798), American bumble bee (*B. pensylvanicus*) (DeGeer, 1773), and Yellow-banded bumble bee (*B. terricola*) (Kirby, 1837). Various threats contributing to bumble bee population declines include: land-use changes, habitat loss, climate change, pathogen spillover from managed bumble bee colonies, and pesticide use. A general response to the need for action on pollinator preservation in North America has been to encourage planting "bee-friendly" plants. Previous studies show differences in common and at-risk bumble bee foraging; however, similar data are unavailable for Ontario. Our main research questions are: 1. Is there a difference in at-risk and common bumble bee (*Bombus* spp.) floral use in protected areas in southern Ontario? 2. Do at-risk and common bumble bees exhibit differences in pollen and nectar collection? We hypothesize that common and at-risk species forage differently, predicting that at-risk species forage on a limited selection of host plants. The results of a redundancy analysis show a difference in foraging between common and at-risk bumblebee species. This would have implications for the planting of appropriate forage as a conservation strategy for at-risk bumble bees in Ontario.

Foreword

The three main tenets of my Area of Concentration from my Plan of Study include: biodiversity and conservation management, sustainable agriculture, and environmental law and policy. Through my Major Research Proposal, I intended to build a project that would engage with all three of these tenets. Some North American bumble bee species have been found to have declining population trends, some of which are confirmed to be at-risk or threatened. A main response to this is the development of pollinator action plans and strategies that aims to help bee populations. Unfortunately, there is little data available about the specific foraging requirements of each pollinator species, let alone each bumble bee species. It became clear by working on this project that managing biodiversity requires species-specific approaches and research programs. This is part of how I designed my field research, which assessed foraging behaviour of at-risk and common bumble bee species. The second tenet of my research, sustainable agriculture, interacts heavily with pollinator conservation for two reasons. One is that agriculture is often the culprit of potential bee declines (for example, heavy pesticide use). The second reason is that moving forward, farmers and farmer agencies are working towards designing agricultural practices and programs that cause less harm to pollinators. The problem is that these programs, for example the Ontario Pollinator Health Action Plan, are often quite general, and do not deal with biodiversity on a species level. The specific requirements of various pollinator species will be overlooked by taking this approach in the long term. Lastly, environmental law and policy is intertwined with how we manage biodiversity. The policymakers don't necessarily have all of the correct information, but they do have the responsibility to respond when the public has a concern. Recently public concern over pollinators has been at a peak, triggering policymakers to respond. Without the appropriate species-level ecological information, responses are often generic to pollinators, which is problematic. Overall my Major Paper is intended to fill a knowledge gap about the species-level foraging requirements of some of Ontario's most abundant pollinators. This information can then be used in conservation management, in designing and implementing sustainable agriculture practices, and also in designing appropriate environmental law and policy to address the issue.

Introduction

Bumble bee (*Bombus* spp.) populations of particular species have declined globally in recent decades (Williams, 1986, Kearns et al. 1998, Steffan-Dewenter et al. 2005, Colla and Packer, 2008, Potts et al. 2010, 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 Dumesh, 2010, Colla et al. 2012). Threats to healthy North American 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 (Rathcke and Jules 1993, Buchmann and Nabhan 1996, 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, rather than at a generic or species level, which can cause oversight of important 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 (Buchmann and Nabhan 1996, Berenbaum et al. 2007, CSPNA, 2007, Colla and Packer, 2008, Grixti et al. 2009).

In the relatively young field of conservation biology, a variety of strategies have been designed, recommended, and implemented upon various wildlife populations (Ebenhard et al. 1995, Primack, 2008, Dicks et al. 2010, 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 continued monitoring and assessments into the future. 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, 1979, 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, Lye, and Darvill, 2008). Differences in proboscis length amongst bumblebee species supports resource partitioning within a community (Ranta and Lundberg, 1980). Bumblebee species with long tongue lengths forage on plants with a long corolla length, while species with short 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 found 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, his research found 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. Nevertheless, data on floral usage for Ontario’s at-risk and common bumble bee species are necessary to make informed conservation decisions. 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. Limited understanding of foraging resource use by bumble bee species prevents effective at-risk bumble bee conservation and management.

The three at-risk bumble bee species studied here are *B. fervidus* (Fabricus, 1798), *pensylvanicus* (DeGeer, 1773), and *B. 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. 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 & Dumesh 2010). More details are needed about the specific foraging requirements and behaviour of this species of Special Concern in Ontario as *B. terricola* is an important species to the natural and agroecosystems in which it lives, as it provides valuable pollination services to wild plants and various agricultural crops such as cranberry and blueberry (Mackenzie and Averill 1995, Javorek et al. 2002, Ascher and Pickering 2013). Two other at-risk bumble bees studied here are the Yellow bumble bee (*B. fervidus*), and the American bumble bee (*B. pensylvanicus*). These two species have been assessed by the International Union for the Conservation of Nature (IUCN) to be Vulnerable (as with *B. terricola*) (Hatfield et al. 2015). The IUCN Red List has listed *B. fervidus* and *B. pensylvanicus* as Vulnerable based on information from documented population declines (Colla and Packer, 2008, Colla et al. 2012, Hatfield et al. 2015). 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 and grassland for *B. fervidus* and *B. pensylvanicus* (Hatfield et al. 2015).

There is a lack of data available about 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 behaviour in southern Ontario, Canada. Our main research questions are: 1. Is there a difference in at-risk and common bumble bee (*Bombus* spp.) floral usage in southern Ontario? 2. Do at-risk and common bumble bee species show differences in pollen and nectar usage? We will assess differences in foraging behaviour between common and at-risk bumble bees by observing foraging bumble bees across southern Ontario. Results from this study will be important for managing floral resources for bumble bees in eastern North America.

Methods

Site Selection/ Transect Design

Twenty-five sites were selected for surveying across southern Ontario (Table 1) (Figure 1). These sites were selected as they had a recent (between 2001-2016) record of *Bombus terricola* and/or *Bombus 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 included national and provincial parks, private land, and conservation areas. 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 0-360°. Each site was to be surveyed three times in 2017 (spring, summer, and late-summer). The spring surveys took place between April 24 – May 26, the summer surveys between June 19-July 7, and the late-summer surveys were between August 7- 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 and each bumble bee present along the transect foraging on a flower within 2 meters 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 by observing bees grooming pollen towards their corbiculae, 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 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. In most cases, a voucher worker specimen was collected for each bumble bee species recorded and identified using Williams et al. (2014). 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. Species identification was verified by Dr. Colla and Victoria MacPhail, York University.

Statistical Analysis

A species accumulation curve was used using the specaccum function (*vegan* package) to determine the number of host plant species found for a particular number of sites sampled (e.g. Williams et al 2009). The number of resampling events at each site was 999. A redundancy analysis (RDA) was used to determine whether there is a difference in common and at-risk bumble bee species foraging in southern Ontario. Any outliers and collinear variables were removed prior to analysis. Outliers were identified using dot charts and boxplots and collinear variables were identified using the vifcor function (*usdm* package) (Figure 2). The following variables were removed as there were too few observations to be included in analysis: Queen Anne's lace, Alfalfa, Apple, Bergamot, Birds eye speedwell, Bladder campion, Chicory, Bunchberry, Hydrangea, Lobelia, Milkweed, Pink pea, Strawberry, Swamp milkweed, Sweet white clover, Tansy, White clover, Wild basil, Wintergreen, Yellow trout lily, *Asclepiadaceae, Hydrangeaceae*, and collinear variables were Hosta, Sumac, and *Fabaceae.* The following variables were retained for analysis: Bearberry, Birds foot trefoil, Brown knapweed, Bull thistle, Crown vetch, Currant, Dandelion, Honeysuckle, Hosta, Knapweed, Mint, Nightshade, Ornamental mint, Purple loosestrife, Red clover, Round headed bush clover, Self-heal, Spotted Joe-pye weed, Spotted knapweed, St. John's Wort, Sumac, Thoroughwort, Tufted vetch, Twinning honeysuckle, Vipers bugloss, Wild rose, *Apiacea, Asteraceae, Boraginaceae,* *Campanulaceae, Caprifoliaceae, Caryophyllacea, Cornaceae, Ericaceae*. A redundancy analysis was performed using the rda and enfit functions (*vegan* package) using the covariance matrix and scaling set to sites. All statistical analyses were performed using R (version 3.4.3. 2017).

Results

A total of 25 sites were visited, almost always three times during the season. There were five *B. fervidus*, two *B. pensylvanicus* and thirteen *B. terricola* recorded foraging during this survey, and a total of 454 individuals of other, not at-risk bumble bees (Table 2). The results of the species accumulation curve show that further sampling would have increased the number of host plant species both common and at-risk bumble bees were found foraging on (Figure 3). The plant Tufted vetch (*Vicia cracca*) was highly positively correlated with at-risk bumble bee foraging in the RDA (Figure 4). Common bumble bee species did not show an association with any plant species or family but were highly negatively correlated with Tufted vetch (*V. cracca*) (Figure 4).

Common and at-risk bumble bees foraged differently on plant species and for nectar and pollen. In the Early season, common bumble bee species were found foraging on seven plant families, primarily *Ericaceae* (Figure 5). There were no at-risk bumble bee species recorded during the Early survey season (Figure 5). In the Mid season, common bumble bee species were found foraging on ten plant families, most often recorded on *Asteraceae* (Figure 6). At-risk bumble bee species were recorded foraging during the Mid season on *Fabaceae, Grossulariaceae,* and *Asteraceae* (Figure 6). During the Late season, common bumble bee species were recorded on 14 plant families, most commonly on *Asteraceae* (Figure 7). At-risk bumble bee species were recorded foraging on *Fabaceae* and *Rosaceae* during the Late season (Figure 7). A total of 194 bumble bees were recorded foraging for pollen, and 269 for nectar (some undetermined) (Figure 8). Common bumble bee species fed for both pollen and nectar primarily on three plant species, *Asteraceae, Fabaceae*, and *Lamiaceae* (Figure 8). At-risk bumble bee species *Fabaceae* and *Rosaceae* for pollen, and *Asteraceae, Fabaceae,* and *Grossulariaceae* for nectar (Figure 8).

Discussion

The objective of this study was to determine whether there are differences among at-risk and common bumble bee foragers in southern Ontario. Understanding differences between species is key to the success of bumble bee conservation management through habitat restoration and pollinator forage planting. In effect, the lack of species-level data on foraging limits the ability for conservation biologists and land managers to properly manage Ontario's at-risk bumble bee species. There are some shortcomings in this study which may restrict its application, however, this work does give 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 mentioned in previous relevant studies (Goulson and Darvill, 2004, Williams et al. 2009). The results of our research do provide important information which may be used in efforts to restore and conserve bumble bee habitat in Ontario (e.g. influencing decisions on forage plants used in restoration projects). 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*, which the at-risk bumble bees recorded almost always used for pollen collection (except for one *B. fervidus* Queen which collected only nectar from *Fabaceae* forage plant).

The *Fabaceae* or "pea" or "bean" family is a large family of flowering plants, many of which are economically important in North America (APG, 2009). This family also goes by the name *Leguminosae*, interchangeably (IAPT, 2012). Economically important species of *Fabaceae* in North America include alfalfa and the common bean (APG, 2009). 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 Tufted vetch (*Vicia cracca*), which is classified as "exotic" in Ontario, and throughout most of Canada (NatureServe, 2016). In our study, at-risk bumble bees were positively correlated with *V. cracc*a, most often documented collecting pollen on this plant. *V. cracca* blooms May-July (NatureServe, 2016), which includes most of our study season (late April to late August). Plant families with different bloom times, or bloom times between our three field sessions, would not have been included in our survey, and therefore foraging also could not be recorded on these plant families/species.

This warrants further research on persistence of at-risk bumble bees at our study sites, and also in terms of habitat restoration and monitoring. Perhaps *Fabaceae* is more visually attractive to at-risk bumble bees and thus they might show a preference for those. Perhaps at-risk bumble bee populations at our sites have been influenced by the nectar or pollen quality of these preferred plants, as pollen quality is known to differ by plant species (Rouston et al. 2000, Forcone et al. 2010). *Fabaceae* may provide important food sources in degraded bumble bee habitat. While bumble bees were mostly found foraging on non-native species of *Fabaceae*, there are many native species within the family that might be used for habitat restoration purposes. Bumble bees are important pollinators in their natural ecosystems and for many agricultural crops, and this research prompts more questions into the natural history and its role in designing effective conservation strategies for common and at-risk bumble bee species in Ontario.

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 behaviour for common and at-risk bumble bee species in various protected areas in Ontario, Canada. Common species were found foraging on a wide variety of plants for both pollen and nectar, while 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.

Conclusions

The results of this study show an association between declining bumble bee species in Ontario, Canada, and the plant species *V. cracca.* Common bumble bees did not show an association with a particular plant family. Our research highlights the need for continued species-level study of Ontario’s at-risk bumble bee species. Conservation planning efforts targeted at Ontario’s pollinator species may consider these results. Future research might aim to determine diet breadth and forage plant preference in Ontario’s bumble bees.

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Table 1. The site name and GPS location (latitude, longitude) of the 25 sites surveyed during 2017 sampling. 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.

Site Name	**latitude**	**longitude**	**Bumble bee (*Bombus* sp.) species**	**# of surveys**	**Site description**
Arrowhead Provincial Park	45.3917	-79.1978	*B. terricola*	3	Forest, hilled
Awenda Provincial Park	44.84871	-80.0194	*B. terricola*	3	Forest, beach, near open water
Backus Woods	42.68102	-80.4739	*B. pensylvanicus*	2	Forest and grassland, sandy soil, surrounded by agriculture
Bass Lake Provincial Park	44.60251	-79.4867	*B. terricola*	3	Forest, beach, near open water, marshy
Bayview Park	44.38811	-79.6869	Both	3	Urban park, lawn and maintained gardens, near open water
Beausoleil Island	44.84754	-79.8605	*B. terricola*	1	Forested with some built-up recreational areas, near open water
Black Creek Provincial Park	44.96836	-81.3625	*B. terricola*	3	Dense forest, near open water, beach
Bruce Peninsula National Park	45.2128	-81.4895	*B. terricola*	3	Dense forest
Bruce Trail Caledon	43.8015	-79.99	*B. terricola*	3	Forest, exposed rock, steep rockface
Central Big Creek Block	42.64919	-80.5604	*B. pensylvanicus*	3	Forest and grassland, sandy soil, surrounded by agriculture
Forks of the Credit Provincial Park	43.8249	-80.004	Both	3	Grassland and sloping hills few wooded areas
Guelph Lake Conservation Area	43.596	-80.252	*B. terricola*	3	Campground surrounded by forest, pollinator garden within a grassland

Harris Park	42.983	-81.25	*B. pensylvanicus*	3	Urban park, lawn, few scattered trees
Inverhuron Provincial Park	44.2987	-81.5944	*B. terricola*	3	Dense forest, few forest clearings, near open water
MacNaughton Trail	43.35	-81.483	*B. pensylvanicus*	3	Forest, surrounded by agriculture, marsh
Mara Provincial Park	44.58661	-79.3571	*B. terricola*	3	Forest, beach, near open water, marsh
Matchedash Bay	44.75084	-79.646	*B. terricola*	3	Wetland and forest, surrounded by agriculture
Pinery Provincial Park	43.2734	-81.8183	*B. pensylvanicus*	2	Forest, dunes, beach, near open water
Pollinators Park	43.57776	-80.2331	Both	3	Grassland, surrounded by development
Scotsdale Farm	43.69024	-80.0051	*B. terricola*	3	Forest and rangeland, surrounded by agriculture, marsh
Singing Sands	45.1912	-81.5776	*B. terricola*	3	Beach, dunes, near open water, dense forest
Sulphur Springs Conservation Area	44.11729	-81.0035	*B. terricola*	3	Forest and marsh, surrounded by agriculture
Turkey Point Provincial Park	42.7279	-80.3369	*B. pensylvanicus*	3	Forest, some forest clearings
University of Guelph Arboretum	43.54205	-80.2115	*B. terricola*	3	Maintained gardens, scattered trees, forest
Waubaushene Beaches	44.75054	-79.7209	*B. terricola*	3	Shrubland meadow, scattered trees, sandy soil

Table 2. Count of each bumble bee species (*Bombus* spp.) collected during opportunistic sampling along transects in southern Ontario between April and August 2017. Species marked with * are at-risk in our study based on declining and vulnerable population trends as assessed by the IUCN Red List.

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

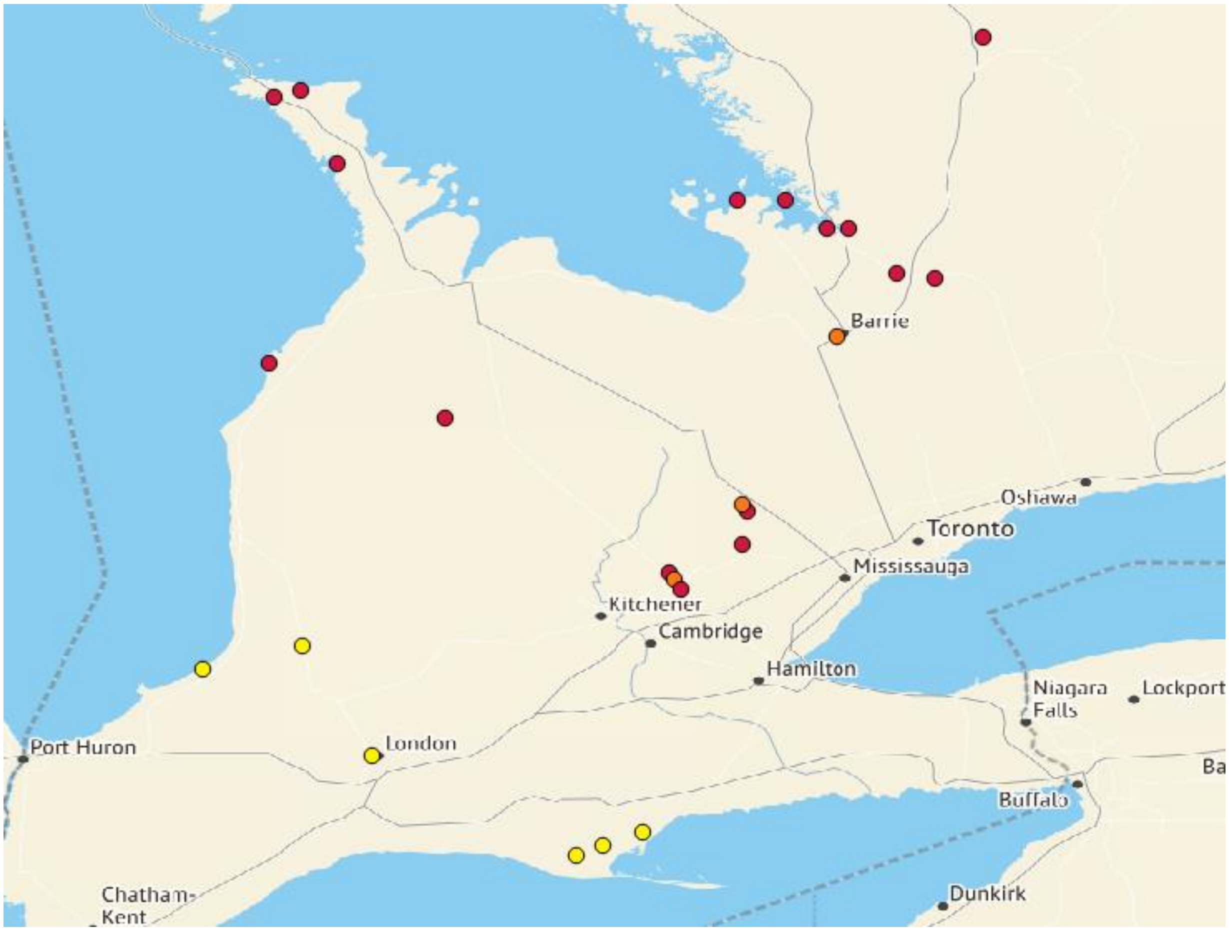

Figure 1. Map of survey site locations for sampling declining bumblebees in southern Ontario. Site locations were based on historical data of presence of at-risk species: red = *B. terricola*, yellow = *B. pensylvanicus*, orange = both. Each site was surveyed 3 times during 2017 sampling.

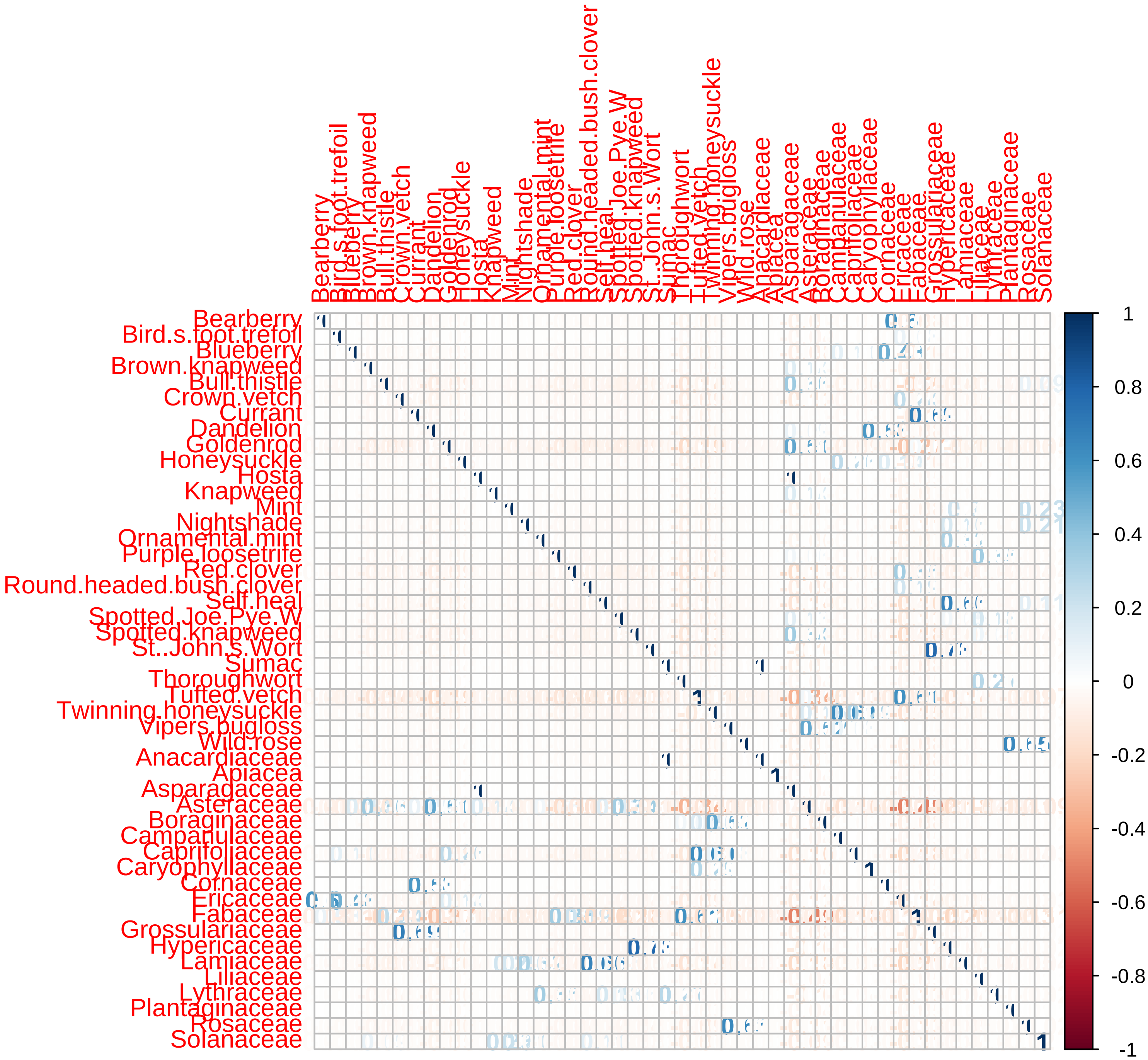

Figure 2. Correlation matrix showing the dependence between multiple variables (plant families). The matrix is displaying the correlation between plant families bumble bees were observed foraging on in southern Ontario between April and August 2017.

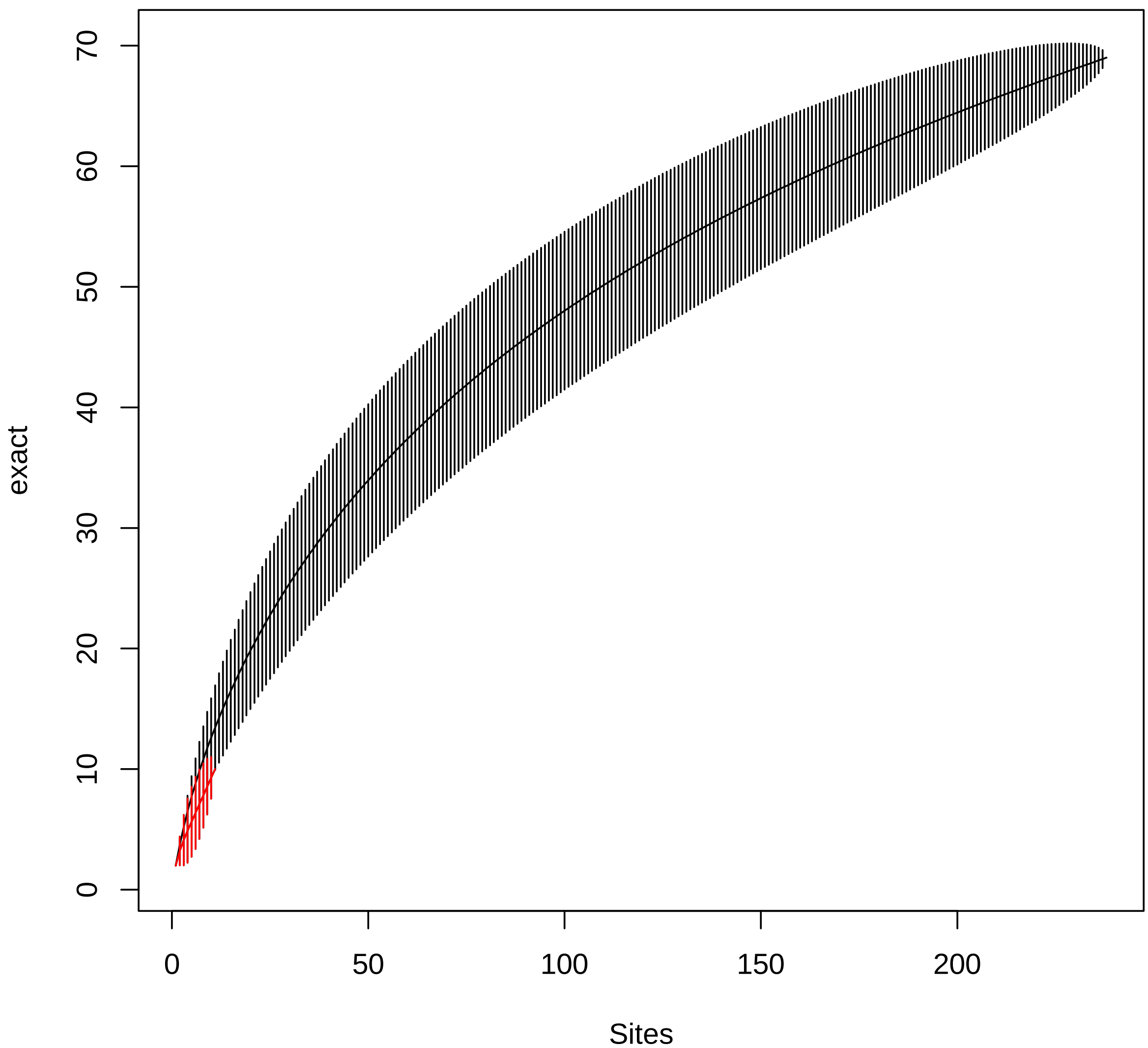

Figure 3. Species accumulation curve displaying number of plants foraged on by common (black) and at-risk (red) bumble bee species (*Bombus* spp.) surveyed in protected areas of southern Ontario between April and August 2017.

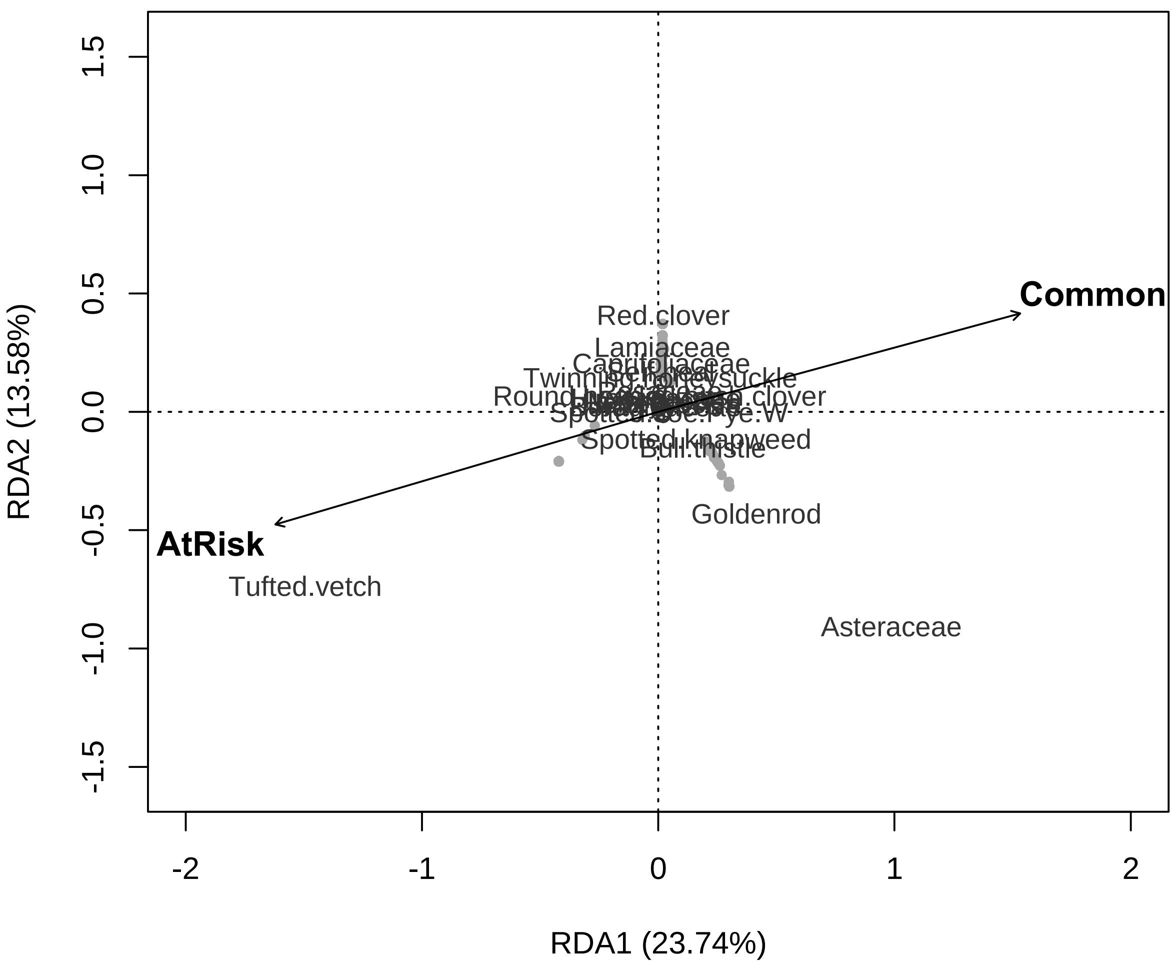

Figure 4. Redundancy analysis (RDA) showing association between at-risk and common bumble bee (*Bombus* spp.) species and host plant for Early, Mid, and Late season foraging in southern Ontario between April and August 2017.

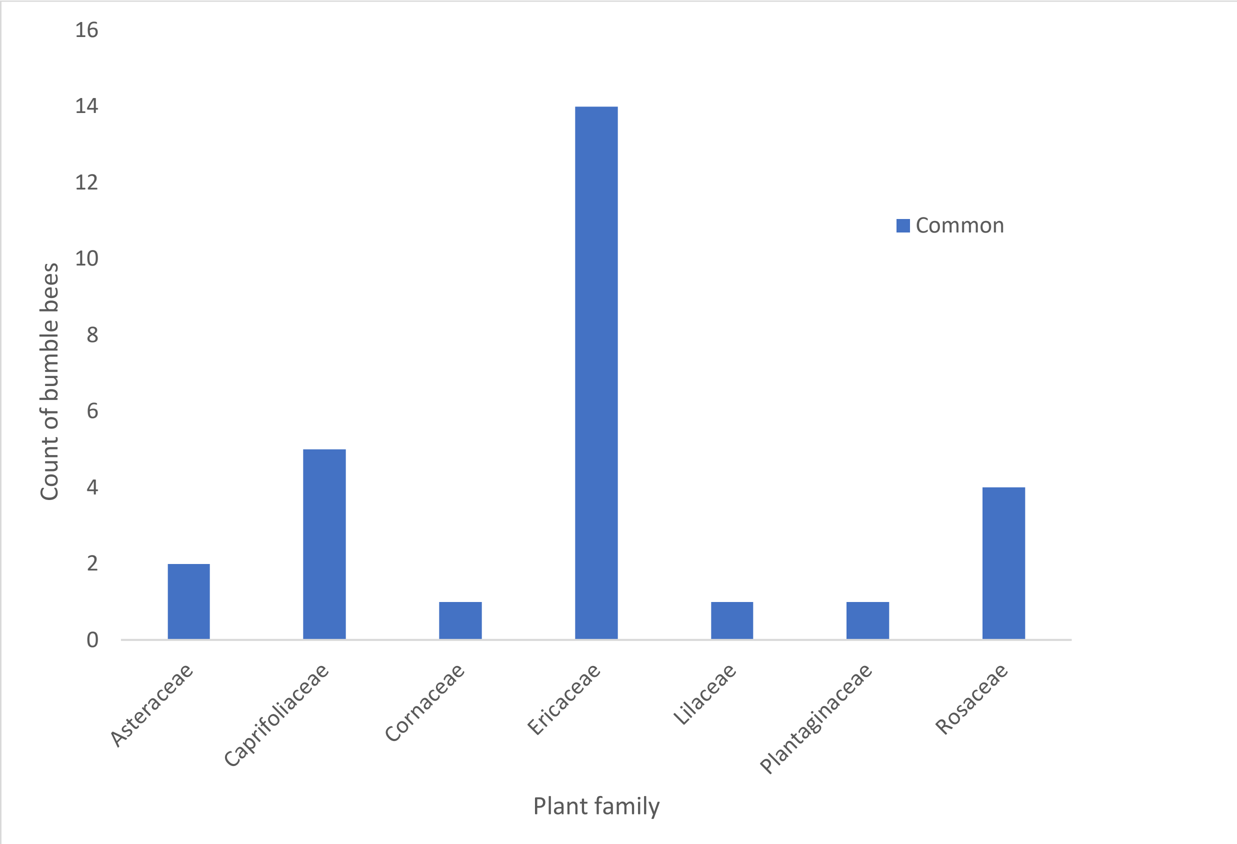

Figure 5. Count of common bumble bees (*Bombus* spp.) found foraging on each plant family during opportunistic field surveys in various protected areas in southern Ontario during the Early sampling season, early April to May 2017. No at-risk bumble bees were recorded during the Early sampling season.

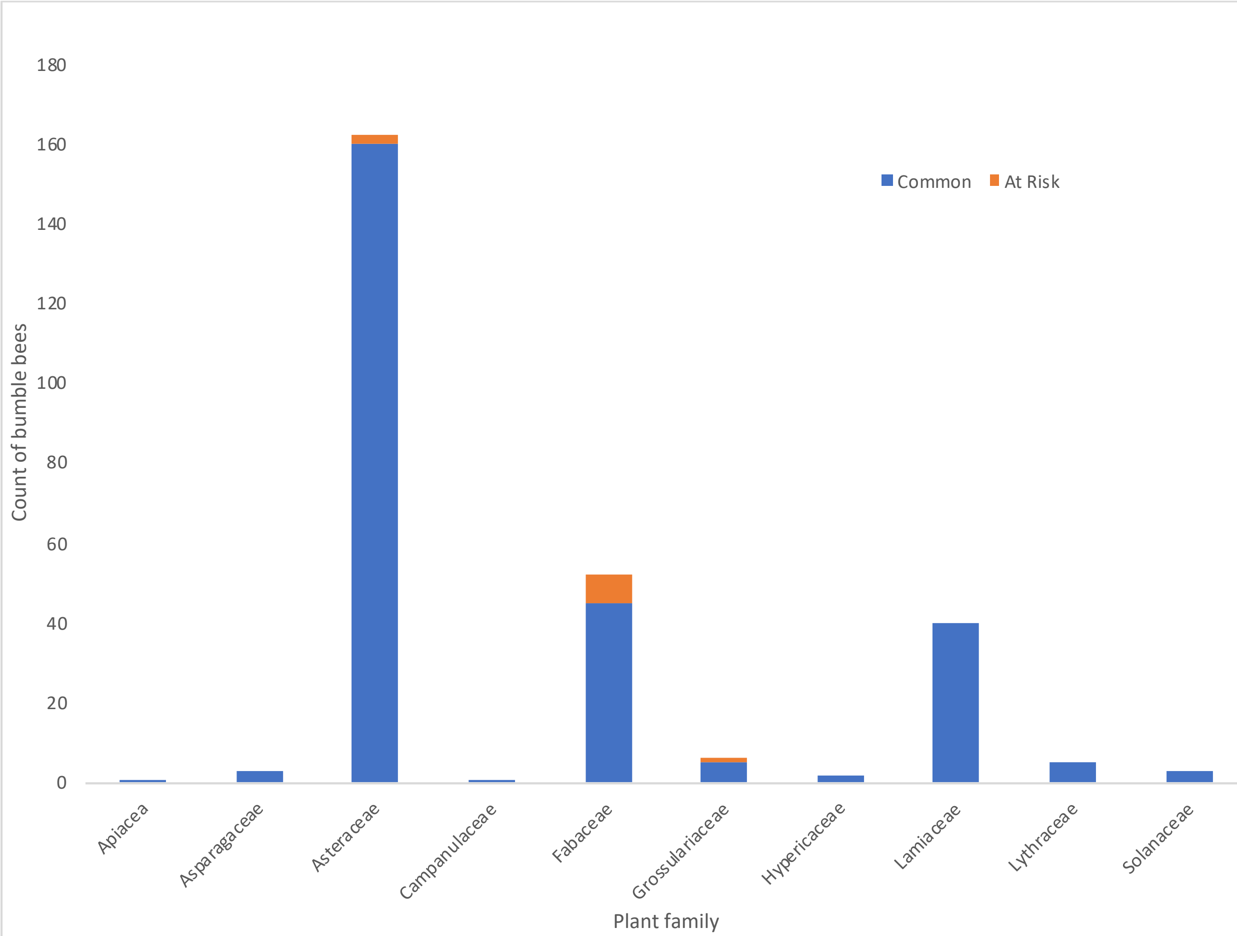

Figure 6. Count of common and at-risk bumble bees (*Bombus* spp.) found foraging on each plant family during opportunistic field surveys in various protected areas in southern Ontario during the Mid sampling season, June to mid-July 2017.

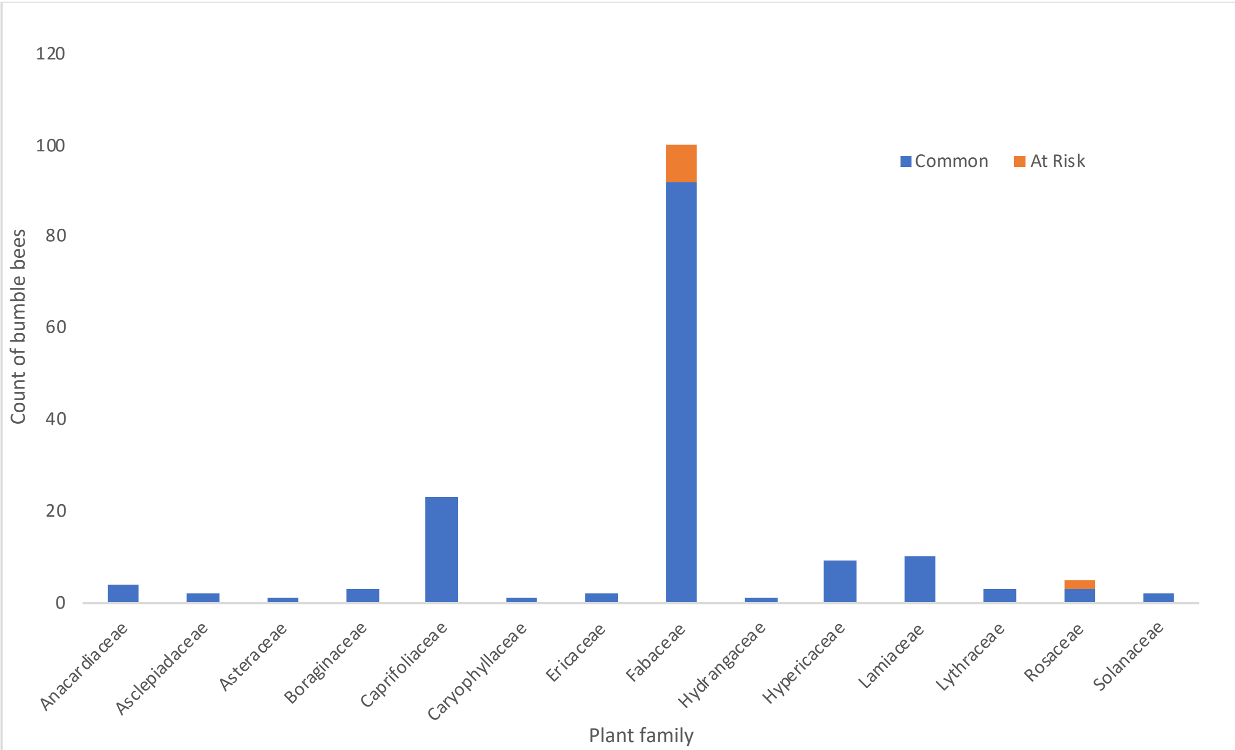

Figure 7. Count of common and at-risk bumble bees (*Bombus* spp.) found foraging on each plant family during opportunistic field surveys in various protected areas in southern Ontario during the Late sampling season, late July to August 2017.

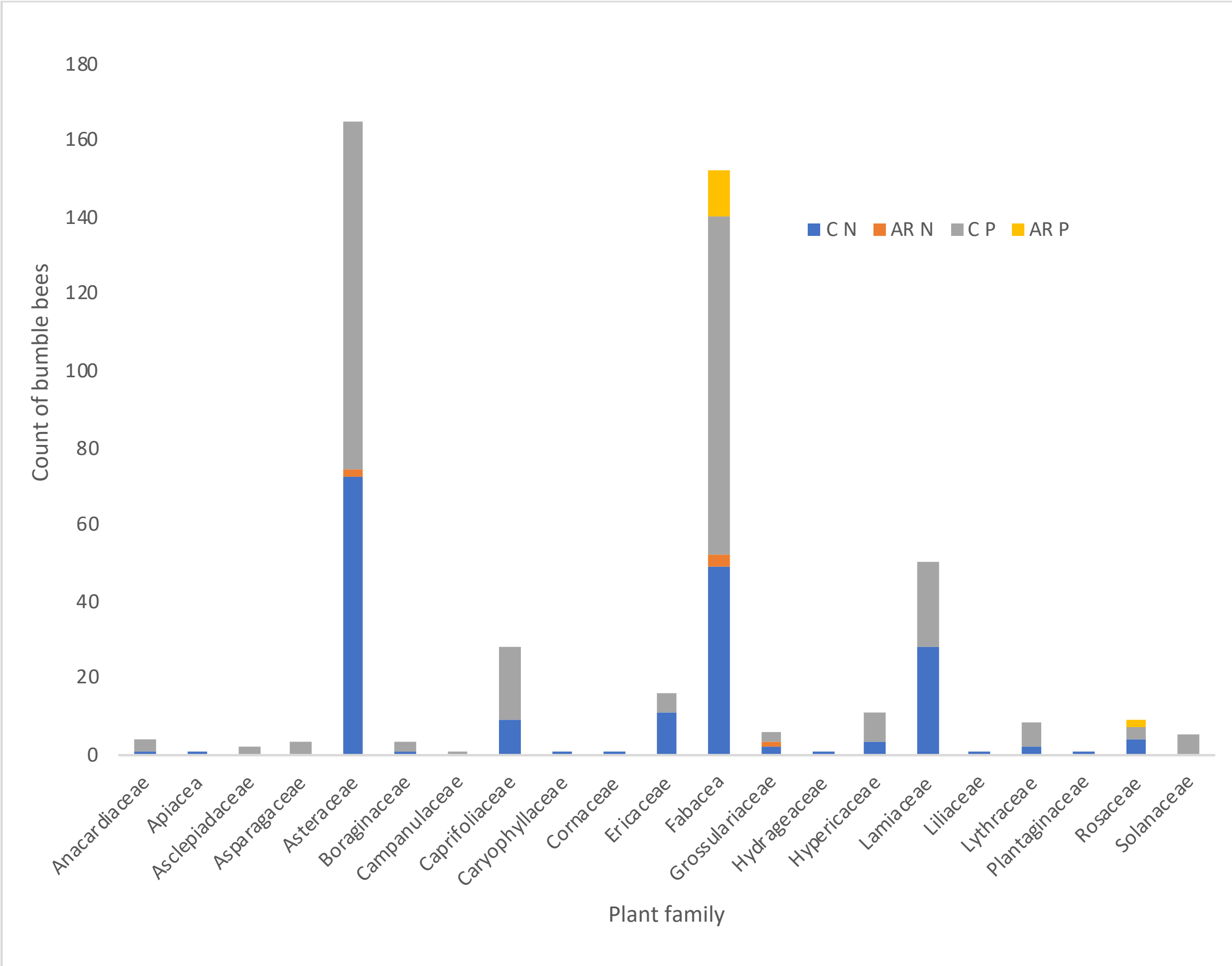

Figure 8. Count of common (C) and at-risk (AR) bumble bees foraging for nectar (N) and pollen (P) on plant families found during opportunistic field surveys in southern Ontario protected areas during the Early, Mid, and Late seasons, between April and August 2017.