DEPARTMENT OF TRANSPORTATION

# Monitoring and Habitat Assessment of Declining Bumble Bees in Roadsides in the Twin Cities Metro Area of Minnesota

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16. Abstract (Limit: 250 words)

Several bumble bee species have declined dramatically, including the endangered rusty-patched bumble bee, *Bombus affinis*. Roadsides offer a unique opportunity to increase habitat for these declining species. The objectives of this study are to: (1) characterize the bumble bee community and floral availability within roadsides in the Minneapolis and Saint Paul, Minnesota, metro area, (2) estimate detection probabilities and occupancy for bumble bees using occupancy modeling, (3) determine the effort needed to detect rusty-patched bumble bees, and (4) examine the relationship of the bumble bee community to the surrounding landscape. We use rapid and broad-scale sampling at randomly selected locations. Despite overall low floral abundance, many bumble bee species, including rare and declining species, use roadsides. Occupancy models predict rusty-patched bumble bees occupy 4% of sites, with a 30% chance of detection if it is at the site. We recommend performing nine surveys in a single season to be 95% sure that *B. affinis* is detected if it is there. Bumble bee abundances and species numbers increase with more wooded area and floral cover. Crops are negatively associated with bee abundance, species numbers, and the presence of rare bumble bees. Our management recommendations for roadsides to support rare and declining bumble bees are: (1) incorporate additional bumble bee forage, (2) when weed control requires elimination of flowering plants, replace with bumble bee forage, (3) use our estimates for occupancy and abundance as a baseline to assess conservation efforts for bumble bees within roadsides in the metropolitan area of Minneapolis and Saint Paul.

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# Monitoring and Habitat Assessment of Declining Bumble Bees in Roadsides in the Twin Cities Metro Area of Minnesota

## FINAL REPORT

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# EXECUTIVE SUMMARY

Roadsides have conservation potential for wildlife including bumble bees, important pollinators in both crops and natural systems. Roughly one in four bumble bee species are in decline. The rusty-patched bumble bee, *Bombus affinis*, is no longer found in more than 95% of its original range and was listed as a federally endangered species in 2017. The metropolitan area around Saint Paul and Minneapolis in Minnesota is one of the few areas in which this species persists, though at a highly reduced abundance than in the past. Accurate distribution and population estimates are needed to best manage the endangered rusty-patched bumble bee, but there is currently a lack of rigorous, monitoring efforts for this and other declining pollinators. Our objectives in this study are to (1) characterize the bumble bee community and floral availability within roadsides in the Saint Paul and Minneapolis metropolitan area, (2) estimate detection probabilities and true occupancy for the rusty-patched bumble bee and other bumble bee species, (3) determine how many surveys must be performed to be reasonably certain that the rusty-patched bumble bee is absent, and (4) examine the relationship of the bumble bee community to surrounding landscape factors. These findings can form the basis of sound management practices to protect populations of endangered and declining bumble bees.

We met these goals using the following methods. 1) Bumble bees were surveyed along transects at 94 sites that were selected based on randomly generated points along major roads and highways in seven counties around the Saint Paul and Minneapolis metropolitan area. Sites with uncommon bees were surveyed more frequently to improve estimates for these species. Each site was sampled three to fifteen (average six) times throughout the season. We surveyed vegetation along the same transects. 2) We used single-season occupancy modeling to estimate true occupancy and detection probabilities for bumble bee species. We also used N-mixture models to estimate abundance per site for each bumble bee species. 3) We calculated p-star to determine the number of surveys needed for detection of the rusty-patched bumble bee based on our estimate of detection probability. 4) We examined the impact of surrounding land use on total bumble bee abundance, species richness, and the presence of rare species with linear regression models.

We observed a total of 5,304 bumble bees representing twelve different species or species groups. Some species are indistinguishable in the field and we therefore used species groups. Highly trained observers conducted all surveys. The species or species groups were *Bombus affinis* (rusty-patched), *B. auricomus/pensylvanicus* (black and gold/American), *B. bimaculatus* (two-spotted), *B. citrinus* (lemon cuckoo), *B. fervidus/borealis* (yellow/northern amber), *B. griseocollis* (brown-belted), *B. impatiens* (common eastern), *B. perplexus* (confusing), *B. rufocinctus* (red-belted), *B. ternarius* (tri-colored), *B. terricola* (yellow-banded), and *B. vagans/sandersoni* (half black/Sanderson's). The most common species was the common eastern bumble bee, *Bombus impatiens*, representing 51% of individuals and present at 77% of sites. The endangered rusty-patched bumble bee, *B. affinis*, represented 0.5% of individuals and was found at 3% of sites. Another bumble bee species that is currently being considered for listing with the U.S. Fish and Wildlife Service (USFWS), the yellow-banded bumble bee, *B. terricola*, represented 0.02% of individuals and was found at 1% of sites. Although common species dominated the community, rare bees were present in roadside areas, including bumble bees of conservation

concern. The presence of a species-rich assemblage of bumble bees foraging in roadside areas indicates the potential for roadside areas to support bumble bees, but increased floral abundance and diversity in roadsides is recommended to increase overall bee diversity.

Floral availability within roadsides varied, with most sites having either low or moderate floral abundance. Few sites had high abundance of blooming flowers. Some sites had no blooming flowers during a particular survey but had blooming flowers during other surveys due to variability in bloom phenology. More than 158 plant species were identified along survey transects. Sites varied in plant species richness from 5 to 27 blooming flowering plants present over all rounds. Several blooming flower species were found at the majority of sites: Canada thistle (*Cirsium arvense*)*,* birdsfoot trefoil (*Lotus corniculatus*), sweet clover (*Melilotus alba*), Canada goldenrod (*Solidago canadensis*), perennial sow thistle (*Sonchus arvensis*), and black medic (*Medicago lupulina*). The most common native blooming plants at survey sites were Canada goldenrod (*Solidago canadensis*)*,* annual fleabane (*Erigeron annuus*)*,* and common milkweed (*Asclepias syriaca*)*.* These results show that many roadsides could increase floral availability, and that currently most flowers available in roadsides are non-native. Many of these non-native blooming flowers are known to be used by native bumble bees. Control of non-native plant species, such as Canada thistle and spotted knapweed, may be required by some management plans. To best support bumble bees, plans for elimination of flowering plants should be accompanied by plans to replace these plants with floral resources that are preferred by bumble bees. Where management for supporting the rusty-patched bumble bee is a priority, plants preferred by the rusty-patched bumble bee can be added. See plant list here: https://www.fws.gov/midwest/endangered/insects/rpbb/plants.html (accessed May 26, 2019).

Occupancy modeling is used to estimate the probability of the presence of a species at a site. Occupancy modeling can also be used to estimate detection probabilities, that is, the probability that a species will be observed if present. The key advantages over standard counts are that it explicitly models imperfect detection, provides an estimate of the variability around site occupancy, and provides a probability of finding the species if it is present. As expected, occupancy, the proportion of sites estimated to be used by each bumble bee species, differed greatly by species. Occupancy across species ranged from 0.03-0.82, with a mean of 0.49. The rusty-patched bumble bee is predicted to be present at 4% of sites. Since we have no means to accurately predict which sites will be occupied by rusty-patched bumble bees, it is important to provide broad protection across habitats used by bumble bees. Detection probability, the probability of a species being observed at a site if it is present, ranged from 0.14-0.57, with a mean of 0.33. We predict that the rusty-patched bumble bee has a 30% probability of being observed at a site if present. This detection probability shows that rusty-patched bumble bees are about as likely to be found if present as other bumble bee species, despite their rarity.

The estimates of occupancy and detection probability for individual bumble bee species inform survey efforts focused on particular species, such as those aimed at determining the presence or absence of the endangered rusty-patched bumble bee. If a species is not recorded at a site, it may in fact not be present, or it may be present but might not have been observed. As the abundance of rusty-patched bumble bee was low, we cannot predict where this species would be present without conducting surveys. We recommend performing nine surveys in a single season during the time of higher worker activity (mid-June through August) to achieve 95% probability of detection of the rusty-patched bumble bee at sites in our study area. The estimates we present for occupancy and abundance can also be used as a baseline to assess conservation efforts for bumble bee species in the Twin Cities metro area of Minnesota. With habitat improvements, an increase in occupancy and estimated abundances could indicate a positive effect of these improvements on rusty-patched bumble bee populations. Although the estimate of occupancy for the endangered rusty-patched bumble bee is low (4%), this does not mean that its potential presence should be dismissed. Since this species is completely absent in most (~95%) of its former range, each location harboring this species is of vital importance to its recovery.

While we counted all bumble bees along our survey transects, our raw counts do not account for detection probability. Therefore, we used N-mixture modeling to predict species abundance per site because it accounts for detection. Predicted species abundance differed between species, ranging from 1.9-40.0 individual bees using a site, with a mean of 17.24 bees per site. An abundance estimate of 1.9 rusty-patched bumble bees does not mean that we predict there are two rusty-patched bumble bee individuals at each site, but rather that we would expect to find two rusty-patched bumble bees at sites at which they are present. Occupancy and abundance estimates work together when telling the story of roadside bumble bee communities.

Effects of surrounding land use on bumble bee communities were examined using linear regression models. Land uses were summarized within a 2 km buffer using data from the National Land Cover Database. Bumble bee communities at each site were summarized as the total abundance over all surveys, the number of species, and the presence of uncommon species. We used total bumble bee abundance to assess landscape effects rather than predicted abundances from N-mixture models as we do not have the power to look at single-species responses due to the small sample sizes for some bumble bee species. Sites with more wooded areas within 2 km and greater average floral area had increased bumble bee abundances and numbers of bumble bee species. Developed areas were associated with increased bumble bee abundances. Crops (primarily corn and soybeans) were negatively associated with all bee metrics, including the presence of uncommon bumble bee species, indicating that increasing floral availability and wooded areas in areas dominated by crops could help to expand suitable habitat areas for bees of conservation concern.

Overall, roadsides are found to harbor many bumble bee species, including several bumble bee species of conservation concern. Floral resources are often in low abundance. As floral abundance is seen to have a positive impact on both the abundance and species richness of bumble bees, increasing floral abundance in roadside areas would likely increase the abundance and diversity of bumble bees using roadside areas. Since we have no means to accurately predict which sites will be occupied by rusty-patched bumble bees, it is important to provide broad protection across habitats used by bumble bees. We recommend performing nine surveys during the time of higher worker activity to achieve 95% probability of detection at sites in our study area. The estimates we have presented for occupancy and abundance can also be used as a baseline to assess the impact of conservation efforts for bumble bee species in the Twin Cities metro area. If there are habitat improvements, an increase in the occupancy and estimated abundances could indicate a positive effect of these improvements on rusty-patched bumble bee populations.

# CHAPTER 1: INTRODUCTION

## 1.1 BACKGROUND

Declines in bumble bees have been observed worldwide (Cameron et al., 2011; Colla and Packer, 2008; Grixti et al., 2009; Morales et al., 2016; Williams et al., 2009; Williams and Osborne, 2009) and have been attributed to agricultural intensification, habitat loss, pesticides, fungicides, pathogen spillover from commercial bees and disease (Colla and Packer, 2008; Evans et al., 2008; Potts et al., 2010; Williams and Osborne, 2009). Approximately 25% of bumble bee species globally are considered vulnerable, endangered, or critically endangered by the International Union for Conservation of Nature (Hatfield et al., 2015). In 2017, the rusty-patched bumble bee, *Bombus affinis* Cresson, was the first bumble bee to be listed as federally endangered in the United States and more listings for other species could follow. *B. affinis*, once common, has been nearly extirpated from Canada and the eastern portion of its range in the United States since 2000 (Colla and Packer, 2008; Evans et al., 2008), with some surviving populations in the Midwestern United States and a few scattered populations in the Eastern United States (e.g., southeast -Virginia, WV) (Cameron et al., 2011; Grixti et al., 2009). With so many species in decline, it is vital that efficient, non-lethal monitoring programs are implemented to track the success of conservation efforts.

As one of the few places in North America where the rusty-patched bumble bee is still regularly found, the Minneapolis and Saint Paul metro area in Minnesota is poised to play an important role in its conservation and recovery. The total study area is approximately 7700 $km^2$ (Yuan et al., 2005) encompassing Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington counties. The seven counties combined have a population of approximately 3.033 million people; 1.773 million of which reside in Hennepin and Ramsey counties alone, according to the 2016 census published by the Metropolitan Council (https://metrocouncil.org/News-Events/Communities/News-Articles/Population-growth-in-the-7-county-metro-remains-st.aspx). The study area includes a metropolitan center consisting of high-density residential and industrial areas surrounded by suburban and rural areas consisting of lower-density residential and industrial areas, as well as crops, forests, and wetlands. Historically, this area was dominated by floodplain forests, maple-basswood forests, and oak brush land interspersed with prairie wetlands (Wendt and Coffin, 1988).

Across North America, roadsides are being examined for their potential role in pollinator conservation. Roadside habitats have been shown to provide important resources for bees (Hopwood, 2008). The designation of the rusty-patched bumble bee as an endangered species increases the need to understand their use of roadsides so roadside management can support federal level recovery goals. In addition, a better understanding of the distribution and detectability of the rusty-patched bumble bee and other declining bumble bee species is needed to inform monitoring plans. Absence from a site during a survey could be due to a low rate of detection rather than true absence. Estimates of detection can be used to determine a recommended survey effort.

## 1.2 RESEARCH GOALS

Roadsides have conservation potential for bumble bees and represent an important subset of land that serves as potential wildlife habitat. Our objectives are to (1) characterize the bumble bee community and floral availability within roadsides, (2) estimate detection probabilities and true occupancy for *B. affinis* and other species across the Twin Cities metro area in Minnesota, (3) determine how many surveys must be performed to be reasonably certain that *B. affinis* is absent, and (4) examine the relationship of the bumble bee community to surrounding landscape factors. These findings can form the basis of sound management practices to protect populations of endangered and declining bumble bees in managed lands.

# CHAPTER 2: BUMBLE BEE COMMUNITY

## 2.1 INTRODUCTION

A number of bumble bee species have recently experienced dramatic declines. For example, once relatively common in Minnesota, the rusty-patched bumble bee (*Bombus affinis*) is now listed as Critically Endangered by the IUCN and Endangered under the Endangered Species Act (82 FR 3186). Similar losses have also been documented in other Minnesota species including the yellow-banded (*B. terricola*) and American bumble bee (*B. pensylvanicus*). These declines have been attributed to a combination of factors such as disease, pesticides, climate change, and habitat loss - including reductions in floral resources and nesting sites. While all three of these species have been recently recorded in the Twin Cities metro area surrounding Minneapolis and Saint Paul, reliable population estimates and rigorous assessments of habitat associations are lacking. Roadsides offer a unique opportunity to increase habitat for these declining species. However, little is known about whether the rusty-patched bumble bee and other declining bees use roadsides. Our goal was to characterize the bumble bee community and floral resources available within roadside habitats in the Twin Cities metro area to inform how these habitats may serve bees of conservation concern.

## 2.2 METHODS

### 2.2.1 Site selection

Sites were selected using randomly generated points. A large number of sites was necessary to get more accurate estimations of detection probability of rare species using occupancy modeling (see Chapter 3) (MacKenzie et al., 2002a). We aimed for 100 random sites to increase our chances of including sites with rare species. The random points used for site selection were generated using ArcGIS (ESRI 2011) to place random points along major roads and highways by using the Functional Class Roads data layer produced by the Metropolitan Council (Metropolitan Council and NCompass Technologies 2018).

Initially, we generated 300 random points within the target study area so that unsuitable sites could be removed while still having close to 100 usable sites. Next, sites that were within 2 km of each other were eliminated using code written by U-Spatial (University of MN GIS help desk) to minimize the chance of observing the same *Bombus* individual at more than one site (Redhead et al., 2015). We were provided with ten sets of random sites with ≥200 sites. We chose one of the ten sets of random points by overlaying a 10 $km^2$ grid and counting the number of grid cells that contained no random points. We selected the set with the least number of empty grid cells because that indicated the greatest geographic spread across the study area. We selectively removed unsuitable habitats, defined as sites with no suitable foraging habitat along the roadway within 500 m of the random point, using examination of aerial imagery from ArcGIS. These included roadsides that consisted of sidewalks, homeowner's lawns, and business properties. Additional sites were removed by the Minnesota Department of Transportation (MNDOT) due to current or future construction or development to take place within the survey period. We also removed sites along roads that were not county or state/federal highways except local roadways within Minneapolis and Saint Paul. Including local roadways in urban centers helped to compensate for fewer roadsides with suitable foraging habitat compared to suburban and rural areas. After submitting sites to MNDOT for approval, we still had 190 sites. Additional sites were removed by generating random numbers and removing corresponding sites. Sites were not removed if there were two or fewer sites in the grid square. We ended up with 98 sites at the start of our surveys, however four more sites were eliminated following ground truthing due to construction, leaving us with 94 total sites (Figure 2.1). We overlaid site point locations with shapefiles that were generated by USFWS (http://www.fws.gov/midwest/Endangered/insects/rpbb/rpbbmap.html, updated on March 25, 2019 and accessed April 30, 2019), which are modeled to estimate the likelihood of rusty patched bumble bee presence based on foraging distances and dispersal (https://www.fws.gov/midwest/Endangered/insects/rpbb/pdf/HabitatConnectivityModelRPBB.pdf).

Most of the sites were within a “high potential zone” for rusty-patched bumble bee, as modeled by USFWS. Of the 94 sites, 50 were in what USFWS considers “primary dispersal zones” and 13 were in the high potential zones (highest potential for the species to occur) of presence.  Surveys took place within 400 m of a random point along the roadway, starting approximately 4.5 m inward from the road edge to reduce the chance of surveying along frequently mown areas.

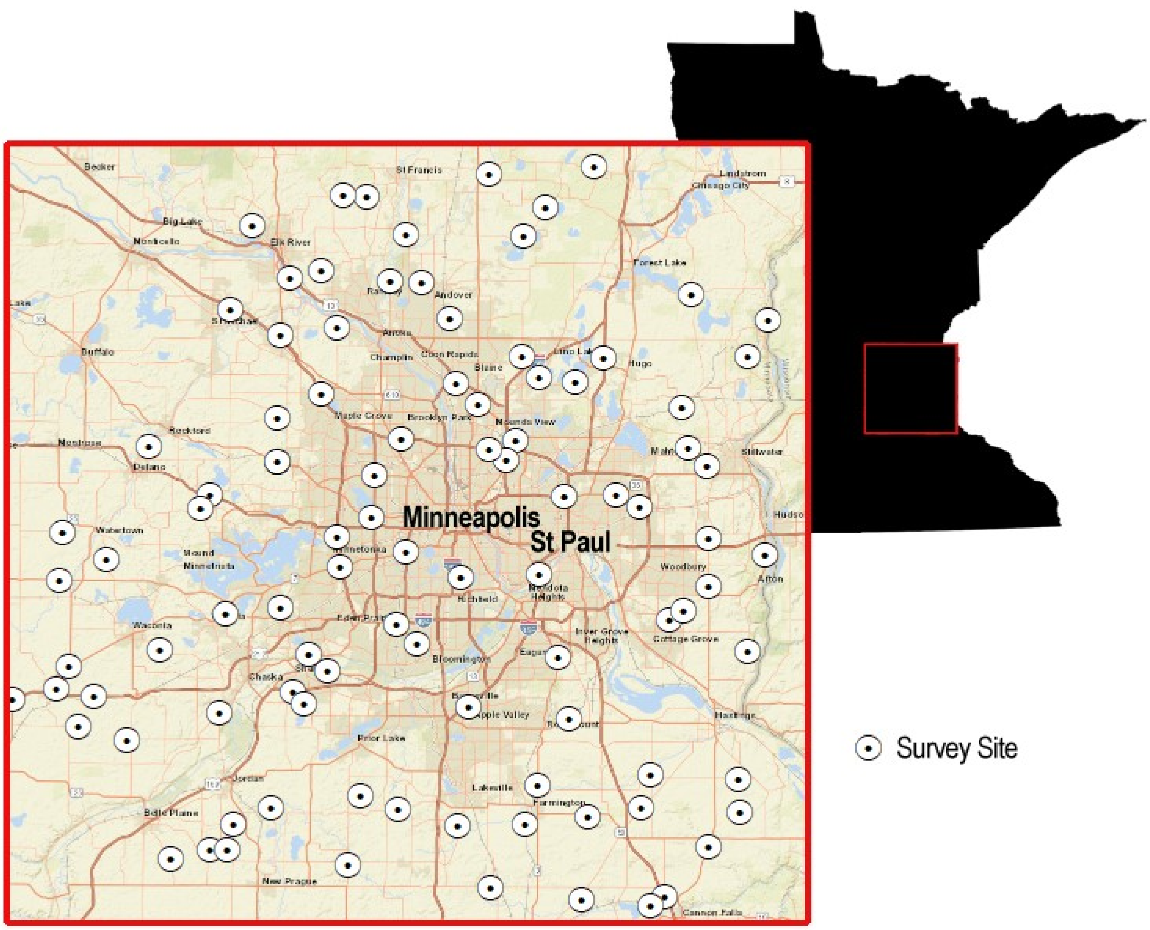


**Figure 2-1 Map of survey sites across the seven county metro area of Saint Paul and Minneapolis in Minnesota**

### 2.2.2 Bumble Bee Surveys

We surveyed bumble bees along a 250 m transect running parallel to the road. Meandering transects allowed us to survey flowering plants that were not located directly on a straight transect lines (Droege et al., 2016), increasing the chance of detecting bumble bees at our sites. Surveys lasted 18 minutes on average and surveyors were trained to walk at a consistent pace along the transect. Observers trained extensively to visually identify bumble bee to species or species group level by practicing using photographs, specimens, and trial surveys. Most species could be reliably identified; however, the following were identified to the level of species group: *B. auricomus/ pensylvanicus*, *B. fervidus/ borealis*, and *B. vagans/ sandersoni*. During surveys, we recorded the species (or species group) and sex of all bumble bee individuals observed within 1 m of the transect. For each survey, we caught one individual of each species that we detected and took a photograph for species verification from bumble bee expert, Elaine Evans. Photographs were also used to quantify observer error and to improve observer accuracy by pointing out identification errors. For uncommon species, which included *B. affinis, B. terricola, B. fervidus/B. borealis*, and *B. rufocinctus*, we netted and photographed all individuals detected for species verification. All surveys were non-lethal as we were surveying in an area known to be occupied by the federally endangered *B. affinis*. We obtained a scientific recovery permit from the USFWS (TE30471C-0) to allow handling of bumble bees.

We conducted surveys from June 15 to August 31, 2018 between 8:30-16:30 h when there was no rain, temperatures were 15 C or above, and wind was below 25 mph. We surveyed five to seven days per week, weather permitting. We used a modified conditional design for occupancy modeling as proposed by Specht et al. (2017) where surveys are initially performed at all sites, while replicate surveys are only performed at sites where the species of interest is detected. We performed a total of six survey rounds, with a survey round being defined as a complete and consecutive set of all survey sites being visited at least once. For rounds 1-3, we surveyed all 94 sites. We revisited sites at which we found uncommon species (*B. affinis, B. terricola, B. fervidus/B. borealis, and B. rufocinctus,*) within 36 hours of the initial visit to for an additional bee survey. We defined “uncommon” species using bumble bee species prevalence data from previous surveys in the area (Evans, unpublished data). For survey rounds four and five, we dropped all sites at which no bumble bees were observed in the first three rounds, leaving 78 sites. We continued to revisit sites at which uncommon species were found. For round six, we only visited sites at which “rare” species had been observed. Rare species were defined as those that were found at less than 30% of sites throughout the first five rounds. These were *B. affinis, B. terricola, B. fervidus/B. borealis, B. rufocinctus,* and *B. auricomus/ B. pensylvanicus,*. Some species that were observed at fewer than 30% of sites were not included in this definition because our survey sites included the edges of their range, so we did not think that these species could potentially have been found in all areas of our study region. These species were *B. perplexus* and *B. ternarius*. We also did not include *B. citrinus* as they are social parasites and do not produce workers. For round six, this left us with 45 sites. We continued to revisit sites within 36 hours if a rare species was detected.

### 2.2.3 Vegetation Surveys

In conjunction with bee surveys, we surveyed vegetation along the same transects once during each round. We walked the same 250 m meandering transect as the bee observer, stopping every 25 m to survey a 1 $m^2$ quadrat, alternating which side of the transect to drop the quadrat every time. We surveyed 10 quadrats at each site. For each quadrat, we counted the number of floral units of each blooming plant species observed. For each plant species, we predefined the definition of a single “floral unit”. For example, for a common dandelion, *Taraxacum officinale*, a floral unit was one blooming flower head consisting of multiple individual florets. For a species such as Canada goldenrod, *Solidago canadensis*, a floral unit was a panicle consisting of multiple branches with flower heads. For a list of floral units for each observed plant species, see Appendix A. At each site, we also recorded a subjective measurement of overall blooming flower abundance by categorizing bloom coverage as none (0-25%), few (26-50%), moderate (51-75%), or high (76-100%).

We estimated the total area of blooming flowers at each site on each survey date using our counts of blooming floral units in each quadrat. To get a mean area of each floral unit for every plant species, we either measured ten floral units in the field and calculated the mean, or we searched online at MN Wildflowers, an online field guide to the flora of MN, for an average floral diameter (https://www.minnesotawildflowers.info/). We used the following equation to estimate the total area of blooming flowers per 250 m transect:

$$[\sum_{10}^{1}(area\ of\ each\ floral\ unit) * (number\ of\ floral\ units\ for\ each\ species\ recorded\ per\ quadrat)] * 25$$

We multiplied the area of each floral unit by the number of floral units of each species recorded within the quadrat and added together the total area of blooming flowers in the 10 quadrats from each site. For each site, we then extrapolated the data from the ten quadrats to estimate total area of blooming flowers for the entire 250 $m^2$ transect by multiplying the floral area from the 10 $m^2$ of quadrat surveys by 25. We used this estimate of total area of blooming flowers.

## 2.3 RESULTS

### 2.3.1 Bumble bee community composition

We observed a total of 5,304 bumble bees representing twelve different species or species groups. The species were *Bombus affinis*, *B. auricomus/pensylvanicus*, *B. bimaculatus*, *B. citrinus*, *B. fervidus/borealis*, *B. griseocollis*, *B. impatiens*, *B. perplexus*, *B. rufocinctus*, *B. ternarius*, *B. terricola*, and *B. vagans/sandersoni.* The three species groups each included two species that were not possible to identify to species level in the field without close examination. Individuals examined by photographs indicated that most *B. auricomus/pensylvanicus* represented *B. auricomus*, most *B. fervidus/borealis* represented *B. fervidus*, and most *B. vagans/sandersoni* represented *B. vagans*. A small proportion of individuals (40 out of 5,304) were categorized as unknown due to inability to identify in the field. The twelve species or species groups we found represent at least 52% of Minnesota bumble bee species, with many of the species not recorded being more northern in distribution or being rare social parasites.

The total number of individuals found at each site over six sampling rounds ranged from 0 to 813, with a mean of 56.43 +/- 111.66 bees per site over all rounds. The most common species was *Bombus B. impatiens*, representing 51% of individuals and present at 77% of sites (Table 2.1). The endangered rusty-patched bumble bee, *B. affinis*, represented 0.5% of individuals and was present at 3% of sites. Another bumble bee species that is currently being considered for listing with the USFWS, the yellow-banded bumble bee, *B. terricola*, represented 0.02% of individuals and was present at 1% of sites. Details of collection events for *B. affinis* and *B. terricola* are reported in Table 2.2. See Appendix B for a summary of bee abundance, species richness, and the presence of rare species over all sites.

**Table 2-1 Bumble bees found during roadside surveys.**

*The total abundance of each bumble bee species or species group includes bees for all sites and sampling rounds. The relative abundance is the proportion of the total number of bumble bees observed comprised by each bumble bee species or species group. The endangered bumble bee, Bombus affinis, a focal species for this study, is indicated by bold font. Although a few species dominated the community, a wide range of species was found within roadside habitat.*

| ***Bombus* species** | **Abundance** | **Relative abundance** | **Bees per 100 m$^2$** | **Proportion of sites** |
|---|---|---|---|---|
| *impatiens* | 2731 | 0.51 | 1.93 | 0.77 |
| *bimaculatus* | 805 | 0.15 | 0.569 | 0.66 |
| *griseocollis* | 775 | 0.15 | 0.548 | 0.62 |
| *vagans/sandersoni* | 511 | 0.10 | 0.361 | 0.53 |
| *rufocinctus* | 189 | 0.04 | 0.134 | 0.30 |
| *fervidus/borealis* | 115 | 0.02 | 0.081 | 0.22 |
| *auricomus/pensylvanicus* | 89 | 0.02 | 0.063 | 0.18 |
| ***affinis*** | **28** | **0.005** | **0.020** | **0.03** |
| *citrinus* | 11 | 0.002 | 0.008 | 0.07 |
| *ternarius* | 7 | 0.001 | 0.005 | 0.05 |
| *perplexus* | 2 | 0.0004 | 0.002 | 0.01 |
| *terricola* | 1 | 0.0002 | 0.001 | 0.01 |
| unknown | 40 | 0.008 | | |

**Table 2-2 Details for collection events of threatened or endangered bumble bee species during the 2018 field season.**

*Female=total number of females collected on that date Male=total number of males collected on that date*

| Date | County | Latitude | Longitude | *Bombus* | Female | Male | Forage plant |
|---|---|---|---|---|---|---|---|
| 27-July | Scott | 44.76122 | -93.51179 | *affinis* | 6 | 0 | *Trifolium pratense* |
| 27-July | Scott | 44.76122 | -93.51179 | *affinis* | 8 | 0 | *Melilotus officinalis* |
| 3-August | Scott | 44.76122 | -93.51179 | *affinis* | 2 | 2 | *Monarda fistulosa* |
| 3-August | Scott | 44.76122 | -93.51179 | *affinis* | 3 | 0 | *Melilotus officinalis* |
| 10-August | Scott | 44.76122 | -93.51179 | *affinis* | 1 | 0 | *Melilotus officinalis* |
| 19-July | Hennepin | 44.85603 | -93.36294 | *affinis* | 1 | 0 | *Monarda fistulosa* |
| 21-July | Hennepin | 44.85603 | -93.36294 | *affinis* | 2 | 0 | *Centaurea stoebe* |
| 2-August | Hennepin | 44.85603 | -93.36294 | *affinis* | 1 | 0 | *Monarda fistulosa* |
| 2-August | Hennepin | 44.85603 | -93.36294 | *affinis* | 1 | 0 | *Monarda fistulosa* |
| 18-July | Washington | 45.24933 | -92.88995 | *affinis* | 1 | 0 | *Centaurea stoebe* |
| 5-July | Washington | 45.11599 | -92.90510 | *terricola* | 1 | 0 | *Centaurea stoebe* |

### 2.3.2 Floral presence at survey sites

Over 158 plant species were identified along transects. Sites varied in plant species richness from 5 to 27 blooming flowering plants present over all rounds. Several blooming flower species were found at the majority of sites (Table 2.3): Canada thistle (*Cirsium arvense*), birdsfoot trefoil (*Lotus corniculatus*), sweet clover (*Melilotus alba*), Canada goldenrod (*Solidago canadensis*), perennial sow thistle (*Sonchus arvensis*), and black medic (*Medicago lupulina*). The most common native blooming plants at survey sites were Canada goldenrod (*Solidago canadensis*), annual fleabane (*Erigeron annuus*), and common milkweed (*Asclepias syriaca*) (Table 2.4). The abundance of blooming flowers at sites varied, with most sites having either low or moderate abundance (Figure 2.2). Few sites had high abundance of blooming flowers. Some sites had no blooming flowers during a particular survey but had blooming flowers during other surveys due to variability in bloom phenology.

**Table 2-3 The ten most commonly found blooming flower species based on presence at survey sites.**

* plant of native origin. Most of the commonly found blooming flowers in roadsides were of non-native origin.

| Flower species | Proportion of sites |
|---|---|
| Canada thistle *Cirsium arvense* | 0.79 |
| Birdsfoot trefoil *Lotus corniculatus* | 0.64 |
| Sweet clover *Melilotus alba* | 0.62 |
| Canada goldenrod *Solidago canadensis** | 0.56 |
| Perennial sow thistle *Sonchus arvensis* | 0.53 |
| Black medic *Medicago lupulina* | 0.52 |
| Hoary alyssum *Berteroa incana* | 0.48 |
| Annual fleabane *Erigeron annuus** | 0.46 |
| White clover *Trifolium pratense* | 0.41 |
| Alfalfa *Medicago sativa* | 0.38 |

**Table 2-4 Common native plants at survey sites.**

*The ten most commonly found blooming native flower species based on presence at survey sites. Many native flowering plants are widely distributed across roadsides sites.*

| Flower species | Proportion of sites |
|---|---|
| Canada goldenrod *Solidago canadensis* | 0.56 |
| Annual fleabane *Erigeron annuus* | 0.46 |
| Common milkweed *Asclepias syriaca* | 0.37 |
| Black-eyed susan *Rudbeckia hirta* | 0.22 |
| Common yarrow *Achillea millefolium* | 0.30 |
| Rough cinquefoil *Potentilla norvegica* | 0.17 |
| Wild bergamot *Monarda fistulosa* | 0.16 |
| Evening primrose *Oenothera biennis* | 0.16 |
| Blue vervain *Verbena hastata* | 0.14 |
| Gray-headed coneflower *Ratibida pinnata* | 0.13 |

## 2.4 MANAGEMENT IMPLICATIONS AND SUGGESTIONS

Our surveys indicated that bumble bees were present at many of the randomly selected roadsides areas despite overall low levels of floral cover across sites. Although common species dominated the community, rare bees were present in roadside areas, including bumble bees of conservation concern. The presence of a species-rich assemblage of bumble bees foraging in roadside areas indicates the potential for roadside areas to support bumble bees. While non-native plant species were widespread across sites, many of these are known to be used by bumble bees. Control of non-natives plant species, such as Canada thistle, may be required by some management plans. To best support bumble bees, plans for elimination of flowering plants should be accompanied by plans to replace these plants with floral resources that are preferred by bumble bees. Where management for supporting the rusty-patched bumble bee is a priority, plants preferred by the rusty-patched bumble bee can be added. See plant list here: https://www.fws.gov/midwest/endangered/insects/rpbb/plants.html (accessed May 26, 2019).

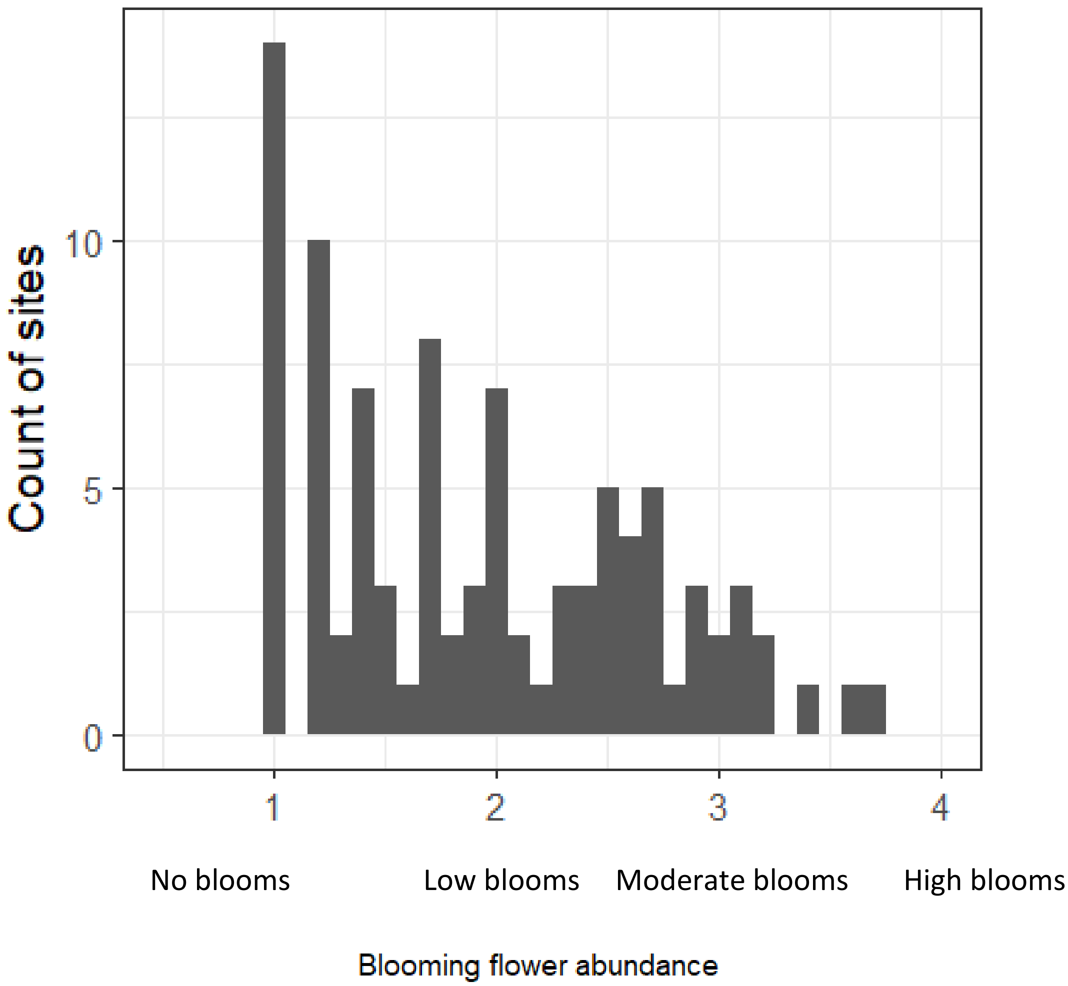


**Figure 2-2 Average estimated abundance of blooming flowers along transects at survey sites over all sampling rounds.**

*Flower abundance along the survey transect was visually estimated during each sampling round as the following categories: 1=No blooming flowers, 2=Low blooming flower abundance, 3=Moderate blooming flower abundance, 4=High blooming flower abundance. These numbers were averaged across all sampling rounds to give an overall blooming flower abundance score for each survey site. Most survey sites had no to low blooming flower abundance.*

# CHAPTER 3: DETECTION AND OCCUPANCY PROBABILITIES FOR THE RUSTY-PATCHED BUMBLE BEE AND OTHER BUMBLE BEE SPECIES

## 3.1 INTRODUCTION

Efficient monitoring supports conservation programs by allowing us to assess the success of conservation actions, (Caro, 2011; Lovett et al., 2007; Mackenzie et al., 2018; Nichols and Williams, 2006) however there is a lack of standardized sampling in studies of bee decline, with most scientists relying on museum specimens or measures of relative abundance to assess changes in populations over time (Biesmeijer et al., 2006; Cameron et al., 2011; Colla and Packer, 2008; Grixti et al., 2009). Additionally, current bee survey methods (netting and pan trapping) do not account for imperfect detection, thus their abundance estimates may be inaccurate (McNeil et al., 2018). Because of the lack of standardized sampling and the use of methods that do not account for imperfect detection, reliable benchmark data for bumble bees is largely lacking (McNeil et al., 2018; Potts et al., 2010). Thus, we need to set up targeted monitoring programs for declining and stable species, so we can use this information to make informed conservation decisions (Nichols and Williams, 2006).

Occupancy modeling is commonly used in wildlife studies to estimate the probability of site occupancy for a species of interest whose detection probability is < 1 and may vary as a function of site characteristics or environmental variables (MacKenzie et al., 2002a). Occupancy modeling can also be used to estimate detection probabilities, that is, the probability that a species will be observed if it is present. This information is invaluable for monitoring efforts; however, this analytical technique is rarely used in entomology, with some exceptions (see Loffland et al., 2017; M'Gonigle et al., 2015; MacIvor and Packer, 2016; Woodcock et al., 2016). Additional work exploring bumble bee species detection would prove valuable to monitoring regimes aimed at surveying bumble bees (McNeil et al., 2018), as would additional studies that estimate detection probabilities for each bumble bee species. Our study builds on these early bee occupancy modeling studies surveying a large number of sites and completing many replicate visits to sites throughout the season to estimate detection probabilities for individual bumble bee species including the rusty-patched bumble bee. Having many replicate surveys in our study will also provide estimates of occupancy and detection probability with tighter confidence intervals than previous bee studies that used this analytical method. These estimates of occupancy and detection can be used to make specific recommendations for survey effort.

## 3.2 METHODS

We used single-season occupancy modeling (MacKenzie et al., 2002b) to estimate true occupancy ($\psi$) and detection probabilities ($p$) for bumble bee species detected within our survey region. We performed the analysis in R (R Core Team 2017) using the package RPresence (MacKenzie and Hines, 2018) to interface with the statistical software program Presence 2.12.22 (Hines, 2006). We ran separate single-season occupancy models for each *Bombus* spp. For each species, we determined the top four models by comparing AIC values and calculated the model average parameter values for our results. We also calculated p* (p-star) for *B. affinis*. This value is the probability of detecting *B. affinis* at sites at which it is present at least once during the entire season. P* is based on the number of surveys performed. P* is useful for determining how many replicate surveys are needed to reach a desired level of certainty that a species is absent. It is calculated using the following equation: p*= 1-(n*(1-p)), where n is the number of surveys and p is detection probability.

We fit single-season N-mixture models (Royle, 2004) to our bumble bee data to estimate abundance per site for eight species using the R package unmarked (Fiske and Chandler 2011). We set the latent abundance distribution as negative binomial. No site covariates were included in our occupancy models or N-mixture models.

## 3.3 RESULTS

We fit occupancy models and N-mixture models to eight of the twelve species observed to get estimates for occupancy, detection, and abundance. Occupancy addresses the spread of bees across the landscape. It tells us what proportion of roadsides are being used by bumble bees. Knowing where bumble bees are found indicates areas that may be important for conservation. Detection gives us information about the effectiveness of our survey effort. Abundance indicates the density of bees on the landscape. We can infer that a site being visited by a large number of bumble bees has more nectar and pollen resources than one with few or no bees. While occupancy tells us how much of the landscape is used for foraging by bumble bees, abundance can indicate the quality of the habitat.

In general, only species found at 10% or more of our sites were included in analysis. The rusty patched-bumble bee (*Bombus affinis*) was included despite only being found at three sites because we were able to detect it multiple times at the sites at which it was found, so we had enough detection data for *B. affinis* for analysis. Species excluded from analysis due to small sample sizes were *B. citrinus, B. perplexus, B. ternarius,* and *B. terricola*. Occupancy, the proportion of sites estimated to be used by each bumble bee species, differed greatly by species. Occupancy across species ranged from 0.03-0.82, with a mean of 0.49 (Table 3.1). *B. affinis* is estimated to be present at 4% of sites. Detection probability, the probability of a species being observed at a site if it is present, ranged from 0.14-0.57, with a mean of 0.33. We predict that *B. affinis* has a 30% probability of being observed at a site if present. We calculated p* for *B. affinis* for 1-15 surveys and found that 9 surveys are required to be 95% confident that *B. affinis* is absent from a site (Table 3.2).

We also predicted the abundance per site for each bumble bee species. Predicted species abundance differed between species, ranging from 1.9-40.0 individual bees using a site, with a mean of 17.24 bees per site. Take caution when interpreting the results of our abundance predictions. An abundance estimate of 1.9 rusty-patched bumble bee does not mean that we predict there are two rusty-patched bumble bee individuals at each site, but rather that we would expect to find two rusty-patched bumble bees at sites at which they are present. Occupancy and abundance estimates work together when telling the story of roadside bumble bee communities.

**Table 3-1 Estimated occupancy and detection probabilities for bumble bee species**.

*ψ = occupancy. p= detection probability. SE= standard error. CI= confidence interval. Abundance=estimated abundance. While the occupancy of affinis was lower than many other species, the probability of detection was similar; indicating that if affinis is present at a site there is a 30% probability of finding it during each survey event.*

| Species | ψ ± SE | 95% CI (ψ) | p ± SE | 95% CI (p) | Abundance ± SE |
|---|---|---|---|---|---|
| *affinis* | 0.038 ± 0.022 | 0.012-0.114 | 0.298 ± 0.088 | 0.156-0.492 | 1.931 ± 2.915 |
| *auricomus* grp. | 0.317 ± 0.086 | 0.175-0.503 | 0.146 ± 0.037 | 0.088-0.233 | 4.953 ± 1.465 |
| *bimaculatus* | 0.828 ± 0.065 | 0.664-0.921 | 0.284 ± 0.025 | 0.238-0.335 | 25.280 ± 1.195 |
| *fervidus* grp. | 0.261 ± 0.051 | 0.174-0.373 | 0.334 ± 0.039 | 0.262-0.414 | 9.300 ± 1.543 |
| *griseocollis* | 0.755 ± 0.064 | 0.611-0.858 | 0.332 ± 0.026 | 0.283-0.384 | 17.814 ± 1.217 |
| *impatiens* | 0.817 ± 0.046 | 0.709-0.892 | 0.573 ± 0.024 | 0.527-0.619 | 40.045 ± 1.168 |
| *rufocinctus* | 0.370 ± 0.061 | 0.260-0.495 | 0.295 ± 0.033 | 0.234-0.364 | 17.288 ± 1.379 |
| *vagans* grp. | 0.593 ± 0.058 | 0.477-0.700 | 0.415 ± 0.028 | 0.361-0.471 | 21.328 ± 1.240 |

**Table 3-2 Probability of detection of rusty-patched bumble bee (*B. affinis*) based on number of surveys performed throughout the season (p*).**

*n=number of surveys. p=detection probability. p*=probability of detection for an entire season based on number of surveys. These results estimate an 80% probability of detection if present after five surveys, and a 95% probability of detection if present after nine surveys for our study area.*

| n | (1-p) | p* |
|---|---|---|
| 1 | 0.7025 | 0.2975 |
| 2 | 0.7025 | 0.506494 |
| 3 | 0.7025 | 0.653312 |
| 4 | 0.7025 | 0.756452 |
| 5 | 0.7025 | 0.828907 |
| 6 | 0.7025 | 0.879807 |
| 7 | 0.7025 | 0.915565 |
| 8 | 0.7025 | 0.940684 |
| 9 | 0.7025 | 0.958331 |
| 10 | 0.7025 | 0.970727 |
| 11 | 0.7025 | 0.979436 |
| 12 | 0.7025 | 0.985554 |
| 13 | 0.7025 | 0.989851 |
| 14 | 0.7025 | 0.992871 |
| 15 | 0.7025 | 0.994992 |

## 3.4 MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS

The estimates of occupancy and detection probability for individual bumble bee species inform survey efforts focused on particular species, such as those aimed at determining the presence or absence of the endangered rusty-patched bumble bee. Only 4% of sites are expected to harbor rusty-patched bumble bees. This indicates that if the goal is to determine where rusty-patched bumble bees are located, a large number of sites is required. Since we have no means to accurately predict which sites will be occupied by rusty-patched bumble bees, it is important to provide broad protection across habitats used by bumble bees. As an endangered species with requirements for protection, it is important to understand the likelihood of the presence of the rusty-patched bumble bee even when it is not found in surveys. If a species is not recorded at a site, it may in fact not be present or it may be present but might not have been observed. We found a detection probability of 30% for the rusty-patched bumble bee. This detection probability can help in the interpretation of absence data. We recommend performing nine surveys in a single season to achieve 95% probability of detection at a site for our study area. Other areas are likely to have different detection probabilities. The estimates we have presented for occupancy and abundance can also be used as a baseline to assess the impact of conservation efforts for bumble bee species in the Twin Cities metro area. If there are habitat improvements, an increase in the occupancy and estimated abundances could indicate a positive effect of these improvements on rusty-patched bumble bee populations.

# CHAPTER 4: IMPACTS OF LANDSCAPE FACTORS ON THE BUMBLE BEE COMMUNITY

## 4.1 INTRODUCTION

Surrounding land use is known to have an impact on bee communities (Holzschuh et al., 2010; Hopfenmüller et al., 2014; McArt et al., 2017; Westphal et al., 2006; Winfree et al., 2011). When habitat enhancements are considered, it is helpful to consider surrounding landscape to provide the greatest benefit. Our goal was to evaluate the impact of landscape factors, including land use and floral abundance, on the bumble bee community.

## 4.2 METHODS

### 4.2.1 Bumble bee community assessment

See Chapter 2 for details on bumble bee survey methods. Bumble bee community metrics were compiled from surveys conducted at 93 sites. One site of the 94 survey sites had incomplete data collection, so was not included in this analysis. These sites were sampled during rounds 1-3, from June 15$^{th}$ – July 27$^{th}$. We did not include bee counts from later rounds as not all sites were included in these surveys, due to the need to focus sampling efforts on sites with bumble bees. We chose to include all sites, even those where no bumble bees were found, to ensure random site selection.

We measured the impact of landscape factors on bumble bees with three measures: 1) abundance, 2) species richness, and 3) the presence of rare species. Abundance was calculated as the total number of all bumble bees recorded during surveys at each site. We use total bumble bee abundance to assess landscape effects rather than predicted abundances from N-mixture models as we do not have the power to look at single-species responses due to small sample sizes for some bumble bee species. Species richness was calculated as the total number of species or species groups (see Chapter 2 for details of species groups) over survey dates at each site. The presence of rare species was assessed as a 1 or a 0, with a 1 given for any site with a rare species present during rounds 1 to 3. Rare species were defined as those that were found at less than 30% of sites throughout the first five rounds. These were *B. rufocinctus, B. affinis, B. terricola, B. pensylvanicus/B. auricomus* and *B. fervidus/B. borealis*.

### 4.2.2 Land use assessment

To assess land use, we calculated the area occupied by different land uses in a 2 km$^2$ buffer around each site using a 2011 Land Cover layer in ArcGIS (National Land Cover Database) (Homer et al., 2015). A 2 km buffer distance was chosen to encompass the foraging range of bumble bees, which has been documented varying from 700 m to 2500 m (Dramstad, 1996; Hagen et al., 2011; Walther-Hellwig and Frankl, 2000). The land uses and their proportions across all sites are summarized in Table 4.1. In addition, floral area was also included as a covariate. These data were taken from vegetative surveys (see Chapter 2 for details) and are summarized as the average area of floral bloom per survey for each site.

**Table 4-1 Groupings for land use variables**

| Land use groupings | NLCD categories included in groupings | Proportion over all sites |
|---|---|---|
| developed | high, medium, and low intensity developed and developed open space | 0.32 |
| crops | cultivated crops | 0.28 |
| pasture | pasture/hay and grasslands | 0.17 |
| wooded | deciduous forest, evergreen forest, and shrub/scrub | 0.12 |
| wetlands | emergent herbaceous wetlands, woody wetlands, open water | 0.10 |

### 4.2.3 Analysis

Regression models were used to examine the impact of land use factors on bumble bee communities using R with the package MASS (Table 4.2) (Venables & Ripley, 2002). Models were examined to ensure assumptions were met. The land-use variable "crops" was removed from models due to a high variance inflation factor indicating multicolinearity. Due to the high prevalence (28%) and potential importance of this land use, it was included in separate single effect models. A negative binomial model was used for "abundance" due to the high prevalence of zeros in counts of bumble bees. A binomial regression with a logit link was used for "rare" due to the binomial nature of this data set.

**Table 4-2 Models examining impact of landscape factors on bumble bee communities**

| Bee metric | Model |
|---|---|
| richness | lm(richness ~ wooded+pasture+floral_area+developed+wetlands |
| | lm(richness ~ crops) |
| abundance | glm.nb(abundance ~wooded+pasture+floral_area+developed+wetlands) |
| | glm.nb(abundance ~crops) |
| rare | glm(rare~wooded+pasture+floral_area+developed+wetlands, family=binomial) |
| | glm(rare~crops, family=binomial) |

## 4.3 RESULTS

Several land uses were positively associated with increased bumble bee community measures (Figure 4.1, Appendix C). Sites with more wooded areas within 2 km and greater average floral area had increased abundances and species numbers. Developed areas were also associated with increased abundances. There was a trend towards a positive impact of pasture on bumble bee abundance. None of the examined landscape factors positively impacted the presence of rare bumble bee species. Crops were negatively associated with all bee metrics, including the presence of rare bumble bee species.

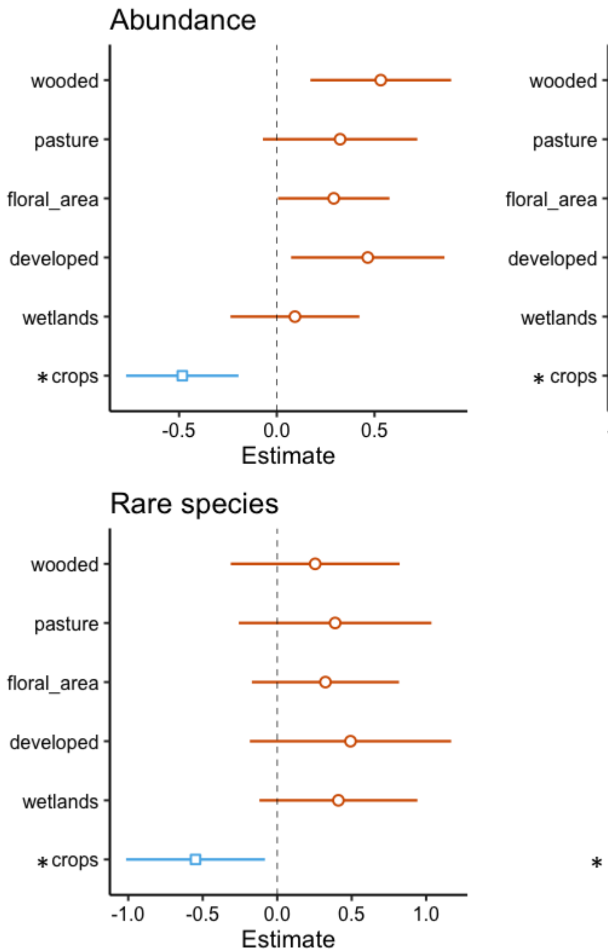


**Figure 4-1 Bumble bee community and landscape factors.**

*Coefficients of variables with 95% confidence intervals (CI) from models with proportion of land use. Effects of land use variables are significant when the 95% CI does not cross zero (e.g. positive impact of wooded and developed areas and floral area on abundance). All models are presented as standardized z- scores. *Separate single-effect models were constructed for crops. Abundance was calculated as the total number of all bumble bees recorded during surveys at each site. Species richness was calculated as the total number of species or species groups over survey dates at each site. The presence of rare species was assessed as a 1 or a 0, with a 1 given for any site with a rare species present during rounds 1 to 3. These were B. rufocinctus, B. affinis, B. terricola, B. pensylvanicus/B. auricomus and B. fervidus/B. borealis. Land uses were obtained from a 2 km² buffer around each site using a 2011 Land Cover layer in ArcGIS (National Land Cover Database.*

## 4.4 MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS

While it is difficult to influence the amount of land dedicated to different land uses in the Twin Cities metro area, our observed associations of bumble bee measures and landscape factors can inform where best to place habitat enhancements. Similar to our findings, floral abundance is often positively associated with measures of bee success due to the importance of flowers as the only food source for most bees (Potts et al., 2003; Roulston and Goodell, 2011). The positive impact of wooded areas on both abundance and species richness may indicate the importance of wooded areas in providing nesting habitat for a variety of bumble bee species. The presence of wooded area within 2 km of proposed habitat assessments could help improve the diversity as well as the abundance of bumble bees. Our finding that crops had a negative impact on all bumble bee metrics could be interpreted as a caution to avoid putting bumble bee habitat near crops, or it could be interpreted as meaning that areas near crops need more support for bumble bees than other areas. Where the goal is to increase the value to existing populations, focusing habitat improvements on areas with wooded areas within 2 km and high floral cover would be most productive. However, if the goal is to expand the current range into areas that were historically occupied, increasing floral availability and wooded areas in areas where the surrounding landscape is dominated by crops could help to expand suitable habitat areas for bees of conservation concern. When management plans require the removal of noxious plant species, such as Canada thistle and spotted knapweed, we recommend replacing them with floral species preferred by bumble bees.

# CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

## 5.1 CONCLUSIONS

Overall, roadsides are found to harbor many bumble bee species, including several bumble bee species of conservation concern. We recorded twelve species or species groups, representing 52% of Minnesota bumble bee species, with many of the species not recorded being more northern in distribution or being rare social parasites. Floral resources are often in low abundance. As floral abundance is seen to have a positive impact on both the abundance and species richness of bumble bees, increasing floral abundance in roadside areas would likely increase the abundance and diversity of bumble bees using roadside areas. Only 4% of sites are expected to harbor rusty-patched bumble bees. Since we have no means to accurately predict which sites will be occupied by rusty-patched bumble bees, it is important to provide broad protection across habitats used by bumble bees. We recommend performing nine surveys in a single season to achieve 95% probability of detection at sites in our study area. The estimates we have presented for occupancy and abundance can also be used as a baseline to assess the impact of conservation efforts for bumble bee species in the Twin Cities metro area. If there are habitat improvements, an increase in the occupancy and estimated abundances could indicate a positive effect of these improvements on rusty-patched bumble bee populations.

## 5.2 RECOMMENDATIONS

### 5.2.1 Roadside habitat management

Our surveys indicated that bumble bees were present at many of the randomly selected roadsides areas despite overall low levels of floral cover across sites. Although common species dominated the community, rare bees were present in roadside areas, including bumble bees of conservation concern. The presence of a species-rich assemblage of bumble bees foraging in roadside areas indicates the potential for roadside areas to support bumble bee populations, but increased floral abundance and diversity in roadsides is recommended to increase overall bee diversity. While non-native plant species were widespread across sites, many of these are known to be used by bumble bees. Control of non-natives plant species, such as Canada thistle, may be required by some management plans. To best support bumble bees, plans for elimination of flowering plants should be accompanied by plans to replace these plants with floral resources that are preferred by bumble bees. Where management for supporting the rusty-patched bumble bee is a priority, plants preferred by the rusty-patched bumble bee can be added. See plant list here:
https://www.fws.gov/midwest/endangered/insects/rpbb/plants.html (accessed May 26, 2019).

While it is difficult to influence the amount of land dedicated to different land uses in the Twin Cities metro area, our observed associations of bumble bee measures and landscape factors can inform where best to place habitat enhancements. The presence of wooded area within 2 km of proposed habitat assessments could help improve the diversity as well as the abundance of bumble bees. Our finding that crops had a negative impact on all bumble bee metrics could be interpreted as a caution to avoid putting bumble bee habitat near crops, or it could be interpreted as meaning that areas near crops need more support for bumble bees than other areas. Where the goal is to increase the value to existing populations, focusing habitat improvements on areas with wooded areas within 2 km and high floral cover would be most productive. However, if the goal is to expand the current rusty-patched bumble bee range into areas that were historically occupied, increasing floral availability near wooded areas where the surrounding landscape is dominated by crops could help to expand suitable habitat areas for bees of conservation concern..

### 5.2.2 Bumble bee survey efforts

The estimates of occupancy and detection probability for individual bumble bee species inform survey efforts focused on particular species, such as those aimed at determining the presence or absence of the endangered rusty-patched bumble bee. Only 4% of sites are expected to harbor rusty-patched bumble bees. This indicates that if the goal is to determine where rusty-patched bumble bees are located, a large number of sites will need to be sampled. As an endangered species with requirements for protection, it is important to understand the likelihood of the presence of the rusty-patched bumble bee even when it is not found in surveys. If a species is not recorded at a site, it might not be present or it may be present but might not have been observed. We found a detection probability of 30% for the rusty-patched bumble bee. This detection probability can help in the interpretation of absence data. We recommend performing nine surveys in a single season of worker activity to achieve 95% probability of detection at a site for our study area. Other areas are likely to have different detection probabilities. The estimates we have presented for occupancy and abundance can also be used as a baseline to assess the impact of conservation efforts for bumble bee species in the Twin Cities MN metro area. If there are habitat improvements, an increase in the occupancy and estimated abundances could indicate a positive effect of these improvements on rusty-patched bumble bee populations.

### 5.2.3 Future directions

Habitat enhancements to support the rusty-patched bumble bee and other bees of conservation concern can be improved with more information on habitat associations and needs. Additional studies examining habitat associations are recommended. Natural history information with details on nesting habitat and floral preferences could enhance our understanding of habitat requirements. Habitat enhancements can also be improved by refining land management techniques to increase floral availability, particularly when exotic plants are removed. Examination of bumble bee communities using occupancy modeling in other regions are recommended to estimate detection probabilities and survey effort needed to aid in the development of efficient and effective survey methods.

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# APPENDIX A
# BLOOMING PLANTS AND FLORAL AREA

List of blooming plants found during vegetative surveys and the floral area per floral unit. Abbreviations for plant families are listed below.

| Family | Genus | Species | Common name | Floral unit | floral area (mm²) | Shape | Source |
|---|---|---|---|---|---|---|---|
| Ana | Rhus | glabra | sumac | panicle | 403.225 | triangle | MNwildflowers |
| Api | Daucus | carota | QueenAnne'sLace | umbel | 5819.3699 | circle | Field |
| Api | Pastinaca | sativa | Wildparsnip | umbel | 126.61265 | circle | MNWildflowers |
| Api | Zizia | aurea | NA | umbel | 3534.3919 | circle | Field |
| Asc | Asclepias | incarnata | SwampMilkweed | umbel | 1519.76 | circle | Field |
| Asc | Asclepias | syriaca | CommonMilkweed | umbel | 3367.8463 | circle | Field |
| Asc | Asclepias | tuberosa | ButterflyMilkweed | umbel | 2714.0904 | circle | Field |
| Asc | Asclepias | verticillata | WhorledMilkweed | umbel | 399.93347 | circle | Field |
| Asp | Hemerocallis | fulva | Orangedaylily | single | 18376.065 | circle | Field |
| Ast | Achillea | millefolium | Yarrow | flatcyme | 1756.2727 | circle | Field |
| Ast | Ageratina | altissima | Whitesnakeroot | umbel | 2863.8056 | circle | Field |
| Ast | Anaphalis | margaritacea | PearlyEverlasting | panicle | 4751.4794 | circle | Field |
| Ast | Arctium | lappa | NA | single | 880.96625 | circle | Field |
| Ast | Arctium | minus | Lesserburdock | single | 934.34625 | circle | Field |
| Ast | Carduus | acanthoides | Spinyplumelessthistle | single | 2073.9386 | circle | Field |
| Ast | Carduus | nutans | MuskThistle | single | 2426.7176 | circle | Field |
| Ast | Centaurea | stoebe | SpottedKnapweed | single | 687.7856 | circle | Field |
| Ast | Cirsium | arvense | CanadaThistle | single | 206.0154 | circle | Field |
| Ast | Cirsium | discolor | FieldThistle | single | 1358.4896 | circle | Field |
| Ast | Cirsium | vulgare | BullThistle | single | 829.15625 | circle | Field |
| Ast | Coreopsis | palmata | Stifftickseed | single | 923.54465 | circle | Field |
| Ast | Echinacea | purpurea | Purpleconeflower | head | 6818.6984 | circle | Field |
| Ast | Erechtites | hieraciifolius | Burnweed | head | 18.0864 | circle | Field |
| Ast | Erigeron | annuus | Annualfleabane | single | 265.7696 | circle | Field |
| Ast | Erigeron | canandensis | Canadianhorseweed | spike | 25827 | rectangle | Field |
| Ast | Erigeron | philadelphicus | Philadelphiafleabane | single | 197.70767 | circle | MNWildflowers |
| Ast | Erigeron | strigosus | Prairiefleabane | single | 171.9464 | circle | Field |
| Ast | Eupatorium | perfoliatum | Boneset | umbel | 4582.1 | rectangle | Field |
| Ast | Eutrochium | maculatum | JoePyeweed | panicle | 10201.86 | circle | Field |
| Ast | Grindelia | squarrosa | Gumweed | single | 606.6794 | circle | Field |
| Ast | Helianthus | grosseserratus | Sawtoothsunflower | single | 3957.185 | circle | Field |
| Ast | Helianthus | maximiliani | Maximiliansunflower | head | 3125.5639 | circle | Field |
| Ast | Helianthus | pauciflorus | Stiffsunflower | single | 4594.0163 | circle | Field |
| Ast | Heliopsis | helianthoides | Smoothoxeye | single | 2779.0963 | circle | Field |
| Ast | Hieracium | sp. | Hawkweed | head | 404.50265 | circle | Field |
| Ast | Hieracium | umbellatum | NarrowleafHawkweed | head | 408.0744 | circle | Field |
| Ast | Lactuca | canadensis | WildLettuce | single | 81.6714 | circle | Field |
| Ast | Lactuca | serriola | Pricklylettuce | single | 156.06585 | circle | Field |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Ast | Leucanthemum | vulgare | Ox-eyeDaisy | single | 1127.5819 | circle | Field |
| Ast | Ratibida | columnifera | Uprightprairieconeflower | single | 3145.4087 | circle | Field |
| Ast | Ratibida | pinnata | Pinnataprairieconeflower | single | 4775.94 | circle | Field |
| Ast | Rudbeckia | hirta | BlackEyedSusan | single | 3802.6656 | circle | Field |
| Ast | Solidago | canadensis | CanadianGoldenrod | panicle | 7575.45 | triangle | Field |
| Ast | Solidago | juncea | Earlygoldenrod | panicle | 9973.7 | triangle | Field |
| Ast | Solidago | rigida | Stiffgoldenrod | umbel | 87895.158 | rectangle | Field |
| Ast | Solidago | speciosa | Showygoldenrod | panicle | 22578.75 | triangle | Field |
| Ast | Sonchus | arvensis | FieldSowthistle | single | 834.2666 | circle | Field |
| Ast | Symphyotrichum | ericoides | Whiteheathaster | head | 211.1336 | circle | Field |
| Ast | Symphyotrichum | lanceolatum | Whitepanicleaster | single | 283.385 | circle | Field |
| Ast | Tanacetum | vulgare | Commontansy | umbel | 2668.1287 | circle | Field |
| Ast | Taraxacum | officinale | CommonDandelion | head | 646.59665 | circle | Field |
| Ast | Tragopogon | dubius | Goat'sBeard | single | 2025.8024 | circle | MNWildflower |
| Bal | Impatiens | capensis | Jewelweed | single | 153.86 | circle | Field |
| Bra | Alliaria | petiolata | Garlicmustard | head | 55.126154 | circle | MNWildflowers |
| Bra | Berteroa | incana | HoaryAlyssum | head | 440.92665 | circle | Field |
| Bra | Brassica | nigra | Blackmustard | head | 547.1136 | circle | Field |
| Bra | Brassica | rapa | NA | head | 71.144864 | circle | MNWildflowers |
| Bra | Rorippa | islandica | Northernmarshyellowcress | head | 1612.9 | circle | Other |
| Bra | Rorippa | sylvestris | Creepingyellowcress | head | 31.653163 | circle | MNWildflower |
| Bra | Sisymbrium | altissima | NA | head | 56.71625 | circle | MNWildflower |
| Bra | Sisymbrium | loeselii | Smalltumbleweedmustard | head | 56.71625 | circle | MNWildflower |
| Cam | Campanula | rapunculoides | CreepingBellflower | single | 268.66625 | circle | Field |
| Cap | Sambucus | nigra | AmericanBlackelderberry | umbel | 4403.8579 | circle | Field |
| Car | Cerastium | fontanum | Commonmouse-earchickweed | single | 38.465 | circle | Field |
| Car | Myosoton | aquaticum | Giantchickweed | single | 3024.1875 | circle | Other |
| Car | Silene | latifolia | WhiteCampion | head | 415.265 | circle | Field |
| Com | Tradescantia | bracteata | Longbractspiderwort | single | 791.32906 | circle | MNWildflower |
| Com | Tradescantia | occidentalis | Prairiespiderwort | single | 1139.5139 | circle | MNWildflower |
| Con | Calystegia | sepium | HedgeBindweed | single | 2541.5239 | circle | Field |
| Con | Convolvulus | arvensis | FieldBindweed | single | 660.185 | circle | Field |
| Cor | Cornus | rugosa | Roundleaf-dogwood | panicle | 1212.4247 | circle | Field |
| Cuc | Echinocystis | lobata | Wildcucumber | panicle | 3870.96 | rectangle | Other |
| Eup | Euphorbia | esula | LeafySpurge | panicle | 48312.25 | triangle | Field |
| Fab | Amorpha | canescens | Leadplant | spike | 417 | rectangle | Field |
| Fab | Dalea | purpurea | Purpleprairieclover | head | 213.7 | rectangle | Field |
| Fab | Lespedeza | capitata | NA | spike | 2232.1 | rectangle | Field |
| Fab | Lotus | corniculatus | Birds-footTrefoil | head | 376.49385 | circle | Field |
| Fab | Medicago | lupulina | BlackMedick | head | 27.32585 | circle | Field |
| Fab | Medicago | sativa | Alfalfa | head | 160.52465 | circle | Field |
| Fab | Melilotus | officinalis | WhiteSweetClover | panicle | 282.9 | rectangle | Field |
| Fab | Melilotus | officinalis | YellowSweetClover | panicle | 335.4 | rectangle | Field |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Fab | Securigera | varia | CrownVetch | head | 506.4506 | circle | Field |
| Fab | Strophostyles | helvola | NA | single | 3629.025 | circle | Other |
| Fab | Trifolium | arvense | RabbitfootClover | head | 100.2 | rectangle | Field |
| Fab | Trifolium | hybridum | AlsikeClover | head | 260.0234 | circle | Field |
| Fab | Trifolium | pratense | RedClover | head | 482.8064 | circle | Field |
| Fab | Trifolium | repens | WhiteClover | head | 232.2344 | circle | Field |
| Fab | Vicia | americana | Americanvetch | spike | 557.2 | rectangle | Field |
| Fab | Vicia | cracca | Cowvetch | head | 1371.3 | rectangle | Field |
| Hyp | Hypericum | perforatum | St.Johnswort | single | 190.5 | circle | Other |
| Lam | Agastache | foeniculum | Anisehyssop | spike | 1152.5 | rectangle | Field |
| Lam | Leonurus | cardiaca | Motherwort | spike | 629 | rectangle | Field |
| Lam | Mentha | arvensis | Wildmint | spike | 190.5 | rectangle | Other |
| Lam | Monarda | fistulosa | WildBergamot | head | 1816.1839 | circle | Field |
| Lam | Nepeta | cataria | Catnip | spike | 1520.7 | rectangle | Field |
| Lam | Perovskia | atriplicifolia | Russiansage | spike | 2453.6 | rectangle | Field |
| Lam | Prunella | vulgaris | Self-healing | spike | 967.74 | rectangle | Field |
| Lam | Pycnanthemum | virginianum | Virginiamountainmint | head | 2122.64 | circle | Field |
| Lam | Stachys | hispida | NA | spike | 3024.1875 | rectangle | Other |
| Lam | Stachys | palustris | Marshhedgenettle | spike | 3024.1875 | rectangle | Other |
| Lam | Stachys | tenuifolia | NA | spike | 3024.1875 | rectangle | Other |
| Lam | Teucrium | canadense | Canadagermander | spike | 3629.025 | rectangle | Other |
| Lyt | Lythrum | salicaria | Purpleloosestrife | spike | 1922.6 | rectangle | Field |
| Mal | Abutilon | theophrasti | Velvetleaf | single | 325.88539 | circle | Field |
| Nyc | Mirabilis | nyctaginea | Fouro'clock | umbel | 415.265 | circle | Field |
| Ona | Oenothera | biennis | Commoneveningprimrose | single | 333.1226 | circle | Field |
| Oxa | Oxalis | stricta | YellowWoodSorrel | single | 86.54625 | circle | Field |
| Pla | Veronicastrum | virginicum | Culver'sroot | spike | 1612.9 | rectangle | Other |
| Pol | Persicaria | amphibium | Waterknotweed | spike | 589.14286 | rectangle | Field |
| Pol | Persicaria | careyi | Carey'ssmartweed | spike | 210.1 | rectangle | Field |
| Pol | Persicaria | maculosa | Lady'sthump | spike | 135.4 | rectangle | Field |
| Pol | Polygonum | pensylvanicum | PennsylvaniaSmartweed | spike | 168.2 | rectangle | Field |
| Pol | Rumex | crispus | CurlyDock | spike | 16590.7 | rectangle | Field |
| Ran | Clematis | virginiana | Devil'sdarningneedle | umbel | 1711.9987 | circle | Field |
| Ros | Potentilla | argentea | Silvercinquefoil | single | 72.3456 | circle | Field |
| Ros | Potentilla | norvegica | NorwegianCinquefoil | single | 1063.0784 | circle | Field |
| Ros | Potentilla | pensylvanica | Prairie/Pennsylvaniacinquefoil | single | 3024.1875 | circle | Other |
| Ros | Potentilla | recta | Sulphurcinquefoil | single | 3629.025 | circle | Other |
| Ros | Potentilla | simplex | Cinquefoil | single | 126.61265 | circle | MNWildflowers |
| Ros | Rosa | acicularis | PricklyWildRose | single | 3165.3163 | circle | MNWildflowers |
| Scr | Linaria | vulgaris | ButterandEggs | spike | 644.14725 | rectangle | Field |
| Scr | Verbascum | thapsus | CommonMullein | spike | 3688.1 | rectangle | Field |
| Sol | Solanum | dulcamara | Bittersweetnightshade | single | 362.86625 | circle | Field |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sol | Solanum | ptycanthum | Easternblacknightshade | single | 70.84625 | circle | Field |
| Ver | Verbena | bracteata | BigbractVervain | cluster | 197.83227 | circle | Other |
| Ver | Verbena | hastata | BlueVervain | spike | 245.6 | rectangle | Field |
| Ver | Verbena | Stricta | HoaryVervain | spike | 683.8 | rectangle | Field |

| **Abr** | | **Plant family** |
|---|---|---|
| Ana | = | Anacardiaceae |
| Api | = | Apiaceae |
| Asc | = | Asclepias |
| Asp | = | Asphodelaceae |
| Ast | = | Asteraceae |
| Bal | = | Balsaminaceae |
| Bra | = | Brassicaceae |
| Cam | = | Campanulaceae |
| Cap | = | Caprifoliaceae |
| Car | = | Caryophyllaceae |
| Com | = | Commelinaceae |
| Con | = | Convolvulaceae |
| Cor | = | Cornaceae |
| Cuc | = | Cucurbitaceae |
| Eup | = | Euphorbiaceae |
| Fab | = | Fabaceae |
| Hyp | = | Hypericaceae |
| Lam | = | Lamiaceae |
| Lyt | = | Lythraceae |
| Mal | = | Malvaceae |
| Nyc | = | Nyctaginaceae |
| Ona | = | Onagraceae |
| Oxa | = | Oxalidaceae |
| Pla | = | Plantaginaceae |
| Pol | = | Polygonaceae |
| Ran | = | Ranunculaceae |
| Ros | = | Rosaceae |
| Ros | = | Roseceae |
| Scr | = | Scrophulariaceae |
| Sol | = | Solanaceae |
| Ver | = | Verbenaceae |

# APPENDIX B

# BEE ABUNDANCE, SPECIES RICHNESS, AND PRESENCE OF UNCOMMON SPECIES PER SITE

| Site number | County | Street Name | Latitude | Longitude | Abund. | Rich. | Uncomm. |
|---|---|---|---|---|---|---|---|
| 1 | Anoka | Cleary Rd Nw | 45.36489905 | -93.4160056 | 9 | 4 | No |
| 2 | Anoka | Gopher Dr Ne | 45.39290117 | -93.21595553 | 240 | 6 | No |
| 3 | Anoka | Viking Blvd Ne | 45.31889696 | -93.15987582 | 35 | 6 | No |
| 4 | Anoka | Viking Blvd Nw | 45.32044853 | -93.35041028 | 48 | 5 | No |
| 5 | Anoka | 161st Ave Nw | 45.26288852 | -93.32444969 | 10 | 3 | No |
| 6 | Anoka | 7th Ave Nw | 45.26450225 | -93.37732176 | 17 | 2 | No |
| 7 | Anoka | Birch St | 45.14584733 | -93.07525486 | 8 | 2 | No |
| 8 | Anoka | Hodgson Rd | 45.15165446 | -93.13561915 | 40 | 3 | No |
| 9 | Anoka | Interstate 35e | 45.17511094 | -93.02966641 | 42 | 7 | Yes |
| 10 | Anoka | Lexington Ave Ne | 45.17532787 | -93.16296617 | 46 | 4 | No |
| 11 | Anoka | Viking Blvd Ne | 45.35327427 | -93.12550986 | 62 | 7 | Yes |
| 12 | Carver | County Road 51 | 44.7681247 | -93.84894409 | 0 | 0 | No |
| 13 | Carver | County Road 50 | 44.71690605 | -93.79635019 | 51 | 7 | Yes |
| 14 | Carver | Highway 25 | 44.80389279 | -93.88982196 | 12 | 4 | No |
| 15 | Carver | Highway 7 | 44.90581922 | -93.90748588 | 4 | 3 | No |
| 16 | Carver | County Road 20 | 44.96362955 | -93.90157439 | 2 | 2 | Yes |
| 17 | Carver | Highway 5 | 44.76331966 | -93.98005729 | 18 | 4 | No |
| 18 | Carver | Rolling Acres Rd | 44.86722425 | -93.63713835 | 14 | 4 | No |
| 19 | Carver | 150th St | 44.73228724 | -93.87382206 | 9 | 2 | No |
| 20 | Carver | Powers Blvd | 44.87612818 | -93.54976535 | 11 | 3 | No |
| 21 | Carver | Tacoma Ave N | 44.77666277 | -93.90907724 | 74 | 7 | Yes |
| 22 | Carver | Main St W | 44.75036381 | -93.64798556 | 6 | 4 | No |
| 23 | Carver | County Road 10 N | 44.93067324 | -93.83207154 | 34 | 4 | No |
| 24 | Carver | County Road 10 | 44.82447379 | -93.74267615 | 66 | 6 | Yes |
| 25 | Dakota | Nicolai Ave | 44.63270839 | -92.81270546 | 0 | 0 | No |
| 26 | Dakota | Goodwin Ave | 44.67717708 | -92.95424087 | 0 | 0 | No |
| 27 | Dakota | Chippendale Ave W | 44.66525761 | -93.13662432 | 0 | 0 | No |
| 28 | Dakota | Dodd Blvd | 44.61615717 | -93.26333318 | 61 | 6 | Yes |
| 29 | Dakota | Denmark Ave | 44.61822366 | -93.15710232 | 14 | 4 | Yes |
| 30 | Dakota | Blaine Ave | 44.62681431 | -93.0553591 | 0 | 0 | No |
| 31 | Dakota | 280th St W | 44.54382194 | -93.2112185 | 0 | 0 | No |
| 32 | Dakota | Highway 52 | 44.53256961 | -92.93322318 | 0 | 0 | No |
| 33 | Dakota | 190th St E | 44.67316736 | -92.81409582 | 10 | 4 | No |
| 34 | Dakota | 295th St E | 44.52171539 | -92.95487364 | 9 | 4 | Yes |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 35 | Dakota | 290th St E | 44.52965327 | -93.06636741 | 0 | 0 | No |
| 36 | Dakota | Northfield Blvd | 44.63863649 | -92.96940104 | 0 | 0 | No |
| 37 | Dakota | Cannon Falls Blvd | 44.59182259 | -92.86325296 | 2 | 2 | No |
| 38 | Dakota | Jefferson Trl W | 44.81834746 | -93.10395983 | 9 | 3 | No |
| 39 | Dakota | County Road 11 | 44.75768755 | -93.24793792 | 87 | 6 | No |
| 40 | Dakota | Akron Ave | 44.74460808 | -93.08538401 | 88 | 7 | Yes |
| 41 | Hennepin | Interstate 94 | 45.07656433 | -93.35800129 | 18 | 4 | No |
| 42 | Hennepin | Interstate 494 | 44.96017119 | -93.4601232 | 33 | 5 | No |
| 43 | Hennepin | Interstate 94 | 45.12988868 | -93.48767248 | 71 | 5 | Yes |
| 44 | Hennepin | Highway 12 | 45.00956456 | -93.66516608 | 20 | 4 | No |
| 45 | Hennepin | Highway 55 | 44.98363091 | -93.4044415 | 50 | 5 | No |
| 46 | Hennepin | Highway 169 N | 45.03358409 | -93.40061467 | 33 | 4 | No |
| 48 | Hennepin | Main St | 45.19980697 | -93.55286543 | 30 | 3 | Yes |
| 49 | Hennepin | Watertown Rd | 44.99317481 | -93.68142367 | 0 | 0 | No |
| 51 | Hennepin | Rebecca Park Trl | 45.06595135 | -93.76328155 | 172 | 5 | No |
| 52 | Hennepin | County Road 10 | 45.10195684 | -93.5578024 | 18 | 3 | No |
| 53 | Hennepin | Diamond Lake Rd N | 45.20960923 | -93.46324896 | 48 | 4 | No |
| 54 | Hennepin | Highway 7 | 44.94270448 | -93.3497873 | 24 | 4 | Yes |
| 55 | Ramsey | Old Highway 10 | 45.07555064 | -93.17238997 | 0 | 0 | No |
| 56 | Ramsey | Interstate 35w | 45.05321707 | -93.18837642 | 41 | 4 | No |
| 57 | Ramsey | Interstate 694 | 45.06441874 | -93.21643129 | 153 | 6 | Yes |
| 58 | Scott | Mushtown Rd | 44.65198455 | -93.41995624 | 102 | 6 | Yes |
| 59 | Scott | 230th St W | 44.61610318 | -93.62214876 | 6 | 2 | No |
| 60 | Scott | Harlow Ave | 44.63694932 | -93.56268391 | 3 | 3 | No |
| 61 | Scott | Panama Ave | 44.56974614 | -93.44039567 | 15 | 3 | No |
| 62 | Scott | 250th St W | 44.58630578 | -93.66017502 | 321 | 7 | Yes |
| 63 | Scott | 250th St W | 44.5871946 | -93.63333734 | 101 | 6 | Yes |
| 64 | Scott | Hickory Blvd | 44.57579158 | -93.72231894 | 4 | 2 | No |
| 65 | Scott | Highway 169 | 44.77602296 | -93.52877065 | 0 | 0 | No |
| 66 | Scott | Lucerne Blvd | 44.63519449 | -93.35964952 | 0 | 0 | No |
| 67 | Scott | County Road 78 | 44.7612154 | -93.51179289 | 224 | 7 | Yes |
| 68 | Washington | 34th St N | 44.99771098 | -92.97286796 | 51 | 5 | No |
| 69 | Washington | Kimbro Ave N | 45.06607199 | -92.89356033 | 41 | 6 | No |
| 70 | Washington | Paul Ave N | 45.17609941 | -92.79649925 | 160 | 8 | No |
| 71 | Washington | Manning Trl N | 45.24932565 | -92.88995417 | 813 | 8 | Yes |
| 72 | Washington | Military Rd | 44.86245605 | -92.92583655 | 0 | 0 | No |
| 73 | Polk | Saint Croix Trl N | 45.21983586 | -92.76492537 | 46 | 8 | Yes |
| 74 | Washington | Manning Ave N | 44.9589008 | -92.86272036 | 7 | 1 | No |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 75 | Washington | Manning Ave S | 44.90128528 | -92.86251059 | 38 | 4 | No |
| 76 | Washington | Saint Croix Trl S | 44.93925357 | -92.77108874 | 13 | 5 | Yes |
| 77 | Sherburne | Highway 10 | 45.26844211 | -93.53957334 | 0 | 0 | No |
| 78 | Sherburne | Elk Lake Rd Nw | 45.33065139 | -93.60126346 | 0 | 0 | No |
| 79 | Wright | Interstate 94 | 45.23064916 | -93.63366302 | 6 | 2 | No |
| 81 | Scott | Flying Cloud Dr | 44.81956814 | -93.50426823 | 0 | 0 | No |
| 82 | Hennepin | Mn-7 | 44.92410325 | -93.45486358 | 8 | 1 | No |
| 83 | Anoka | County Hwy 10 | 45.11951516 | -93.23298419 | 17 | 2 | No |
| 84 | Anoka | Mn-610 | 45.14294169 | -93.27000944 | 156 | 5 | Yes |
| 85 | Anoka | Bunker Lake Blvd Nw | 45.22042953 | -93.28014151 | 55 | 4 | No |
| 86 | Anoka | Norris Lake Rd Nw | 45.36758158 | -93.45366257 | 8 | 3 | No |
| 87 | Anoka | Fawn Lake Dr Ne | 45.40175091 | -93.04701702 | 38 | 6 | No |
| 88 | Anoka | Armstrong Blvd Nw | 45.27743148 | -93.48762552 | 2 | 1 | No |
| 89 | Ramsey | Highway 36 W | 45.00958922 | -93.09505862 | 136 | 6 | No |
| 90 | Dakota | Shepard Rd | 44.91560828 | -93.13442461 | 10 | 3 | No |
| 91 | Ramsey | Highway 36 E | 45.01198712 | -93.01123158 | 14 | 2 | No |
| 92 | Washington | Woodbury Dr | 44.87310876 | -92.90320152 | 372 | 9 | Yes |
| 93 | Washington | 115th St N | 45.11599393 | -92.90509645 | 59 | 7 | Yes |
| 94 | Washington | Manning Ave N | 45.04458758 | -92.86297285 | 35 | 5 | No |
| 95 | Hennepin | Bush Lake Rd E | 44.856028 | -93.362941 | 459 | 9 | Yes |
| 97 | Hennepin | Highway 55 | 45.050005 | -93.557461 | 71 | 6 | No |
| 98 | Washington | | 44.82445 | -92.8 | 24 | 6 | No |

# APPENDIX C
# RESULTS OF IMPACT OF LAND USE ON BUMBLE BEE MEASURES

| **Abundance** | Pseudo$R^2$=0.18 | null.deviance=128.8 | Df.diff =-5 | LogLik.diff=-9.14 | Chisq=18.28 | $p$=0.003 |
|---|---|---|---|---|---|---|
| term | estimate | std.error | t value | p.value | conf.low | conf.high |
| **wooded** | **5.065** | **1.750** | **2.895** | **0.004** | **1.525** | **8.842** |
| pasture | 2.604 | 1.620 | 1.607 | 0.108 | -0.557 | 5.936 |
| **floral_area** | **0.018** | **0.009** | **2.003** | **0.045** | **-0.001** | **0.045** |
| **developed** | **1.468** | **0.632** | **2.325** | **0.020** | **0.216** | **2.708** |
| wetlands | 0.893 | 1.622 | 0.551 | 0.582 | -2.610 | 4.962 |

| **Abundance (crops)** | Pseudo$R^2$=0.08 | null.deviance=117.3 | Df.diff =-1 | LogLik.di=-3.96 | Chisq=7.929 | $p$=0.0051 |
|---|---|---|---|---|---|---|
| term | estimate | std.error | t value | p.value | conf.low | conf.high |
| **crops** | **-1.840** | **0.558** | **-3.295** | **0.001** | **-3.010** | **-0.607** |

| **Richness** | $R^{2=}$=0.17 | *adj* $R^{2=}$=0.12 | Residual SE=1.91 | $F$=3.57 | $p$<0.001 | $df$=5,87 |
|---|---|---|---|---|---|---|
| term | estimate | std.error | t-value | p.value | conf.low | conf.high |
| **wooded** | **5.421** | **2.531** | **2.141** | **0.035** | **0.389** | **10.452** |
| pasture | 2.876 | 2.322 | 1.239 | 0.219 | -1.739 | 7.492 |
| **floral_area** | **0.030** | **0.013** | **2.265** | **0.026** | **0.004** | **0.057** |
| developed | 1.548 | 0.895 | 1.730 | 0.087 | -0.231 | 3.327 |
| wetlands | 1.402 | 2.334 | 0.601 | 0.550 | -3.237 | 6.041 |

| **Richness (crops)** | $R^{2=}$=0.09 | *adj* $R^{2=}$=0.075 | Residual SE=1.96 | $F$=8.43 | $p$=0.005 | $df$=1,91 |
|---|---|---|---|---|---|---|
| term | estimate | std.error | t-value | p.value | conf.low | conf.high |
| **crops** | **-2.254** | **0.776** | **-2.904** | **0.005** | **-3.795** | **-0.712** |

| **Rare** | null.deviance=125.02 | df.null=92 | logLik=-57.84 | Deviance=115.69 | df.residual=89 | |
|---|---|---|---|---|---|---|
| term | estimate | std.error | statistic | p.value | conf.low | conf.high |
| wooded | 2.426 | 2.754 | 0.881 | 0.378 | -3.022 | 7.953 |
| pasture | 3.124 | 2.651 | 1.178 | 0.239 | -2.035 | 8.478 |
| floral area | 0.020 | 0.016 | 1.285 | 0.199 | -0.009 | 0.057 |
| developed | 1.552 | 1.088 | 1.427 | 0.154 | -0.522 | 3.784 |
| wetlands | 3.956 | 2.607 | 1.518 | 0.129 | -1.080 | 9.346 |

| **Rare (crops)** | null.deviance=125.02 | df.null=92 | logLik=-59.58 | Deviance=-59.58 | df.residual=91 | |
|---|---|---|---|---|---|---|
| term | estimate | std.error | statistic | p.value | conf.low | conf.high |
| **crops** | **-2.087** | **0.905** | **-2.306** | **0.021** | **-3.964** | **-0.385** |