

EVALUATING CITIZEN SCIENCE AND HABITAT MANAGEMENT FOR NATIVE
BEE CONSERVATION

by

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A dissertation submitted in partial fulfillment of the
requirements for the degree of

DOCTOR OF PHILOSOPHY IN BIOLOGICAL AND BIOMEDICAL SCIENCES

2026

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To mom, dad, and my sister for supporting all my endeavors no matter the direction. I would never have accomplished this dream without all of you. To Siobhan, Jasmine, Hailey, Steven, and Joe, thank you. Your friendship, encouragement, open ears, and shoulders to lean on meant more than you'll ever know.

ACKNOWLEDGMENTS

I would like to give the biggest thank you to my advisor Dr. Mary Jamieson. Without her guidance I would have never been able to accomplish what I have today. She believed in me every step of the way and allowed me to grow in and outside of the lab. I am forever grateful for all the care, kindness, and empathy she has shown me throughout this process. I owe all my success, opportunities, and accomplishments to her.

I would also like to thank my committee members, Dr. Benjamin Sadd and Dr. Thomas Raffel, for their guidance and support throughout this entire process. Without Dr. Sadd's influence in my undergraduate years, I would not have had a once in a lifetime opportunity to study stingless bees in Costa Rica which led me to develop an interest in bee research. Another big thank you to Dr. Raffel for spending considerable time helping me with my kryptonite: *statistics*.

I would like to thank Kathy Lesich, Cathy Starnes, and all the office staff for their help and patience. They always had an open door for questions, and I will forever cherish their conversation and wisdom. Additionally, I would like to thank all the undergraduate students, namely Alivia Burton, Katya Eskander, Sabrina Mohler, Heather Krawczyk, and Emmaline Allen who willingly walked into tick filled fields and endured bee stings day after day to help gather the data for my dissertation. Last but certainly not least, I would like to thank Joe Young and Dr. Siobhan Branfield for helping me navigate grad school these last few years. Most importantly, I must thank them for their friendship and being a voice of reason when I needed it most.

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ABSTRACT

EVALUATING CITIZEN SCIENCE AND HABITAT MANAGEMENT FOR NATIVE BEE CONSERVATION

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Adviser: Mary A. Jamieson, Ph.D.

Pollinators across the globe are experiencing population declines at concerning rates. Bees, a particularly important pollinator group, are threatened by many stressors, namely loss of floral resources and parasites are thought to be leading drivers of decline. Land management agencies have been spearheading efforts to restore habitat quality in natural areas through various restoration management techniques such as removal of invasive species, prescribed fire application, and restorative wildflower plantings. These management tools have been shown to improve floral resource availability although gaps persist in our understanding of how they impact bees and their interaction networks. Moreover, environmental attributes in the surrounding local and landscape context influence bee communities, yet little is known about how these factors impact vulnerable species, such as bumble bees.

My dissertation research aimed to address these shortcomings through four distinct projects described here in chapters 2-5. Chapter one discusses the current status of native bee conservation, describing factors that threaten bees. Chapter two assesses the use of the citizen science platform iNaturalist for bee research and conservation. We

found the platform is a valuable source of open access bee data and can be a useful research tool with consideration of data quality. Chapter three investigates the use of different restoration management techniques applied in a degraded wetland. In this study, invasive shrub removal had a positive effect on floral resources, and variation in bee community traits was best explained by bloom cover. Chapter four further examines the effect of prescribed fire management on plant and bee communities in prairies and wetlands. We found that prescribed burns improved the native plant community, but only in restored prairies. Moreover, bee community response was mediated by functional traits, namely nesting strategy. Finally, chapter five evaluates parasitic infection prevalence by conopid flies and a trypanosome in bumble bees across Southeastern Michigan. This study showed that larger bees generally had higher infection prevalence. Additionally, conopid fly increased with urbanization and decreased with bumble bee abundance. Floral richness was positively associated with bee infection by trypanosomes. Overall, my dissertation research provides insights to inform land management and native bee conservation.

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LIST OF ABBREVIATIONS

AIC	Akaike information criterion
ANOVA	Analysis of Variance
DAG	Directed Acyclic Graphs
IUCN	International Union of Conservation of Nature
NLCD	National land cover database
NMDS	Non-metric multi-dimensional scaling
SEM	Structural Equation Modeling
USFWS	U.S Fish and Wildlife Service

CHAPTER ONE

BACKGROUND

1.1 Pollinator decline and monitoring

Insects across the globe are experiencing a loss of abundance and diversity at unparalleled rates, including many critically important groups such as pollinators (Cornelisse et al., 2025; Wagner et al., 2021; Zattara & Aizen, 2021). A recent study has shown that bees are the most at risk of extinction amongst all pollinating groups (Cornelisse et al., 2025). While bees are increasing in record numbers each year, the number of species recorded is drastically decreasing (Zattara & Aizen, 2021). Bees in particular support the reproductive success of nearly 80% of the world's flowering plants, a third of agricultural crops, and a multitude of other ecosystem services making their conservation a high priority (Gallai et al., 2009, Potts et al., 2016; Wagner et al., 2021). Many bee species have already been declared ‘threatened’, ‘vulnerable’, or ‘endangered’ by the International Union of Conservation of Nature (IUCN) and United States Fish and Wildlife Service (USFWS). This includes over 25% of the United States bumble bees with reports of population declines and range reductions greater than 80% for some species (Cameron et al., 2011). In 2017, the Rusty Patched Bumble Bee (*Bombus affinis*) became the first bee to be added to the U.S. Endangered Species List.

The reality, however, for many bee species is that there are simply not enough data to make accurate decisions about their conservation status, distributions, or population changes (Chesshire et al., 2023; Orr et al., 2021). Fortunately, monitoring efforts for bees are growing, such as the creation of the U.S. National Native Bee

Monitoring Research Coordination Network and programs like Bumble Bee Watch that span across the nation. Other publicly accessible platforms, such as iNaturalist, have also helped contribute records of the world's bees with over three million observations on the platform to date. Continued monitoring of bee species will remain critical to detect changes in distributions and populations and update conservation statuses for this vital pollinator group. Moreover, this is increasingly important as landscapes continue to change across the globe. Citizen science platforms, such as iNaturalist, are likely to become important tools for documenting bees in these landscapes and other private areas.

1.2 Threats to bee persistence and tools to mitigate their decline

Like many pollinators, bees, are threatened by a multitude of stressors including habitat loss and degradation, climate change, and pesticide exposure (Cameron & Sadd, 2020, Potts et al., 2010; Wagner et al., 2021). It is thought that their decline is not caused by any one of these pressures but rather a combination of them all (Goulson et al., 2015). Among the leading factors is the loss of floral resources associated with habitat degradation and land use change (Potts et al., 2010). The loss of diverse floral resources not only reduces nutritional availability and nesting opportunities for bees, but it can also amplify the impacts of other stressors. For example, bumble bees who foraged in landscapes with less abundant floral resources displayed higher pathogen infections than those that foraged in areas with greater resource availability (McNeil et al., 2020).

At the landscape level, combatting this issue is often left in the hands of land management agencies who are responsible for employing different restoration management techniques to try to improve habitat quality and subsequently help to

mitigate this issue. This can include deploying any number or combination of techniques such as invasive species removal, herbicide applications, forestry mowing, prescribed fire, etc. The impact of restoration management techniques on plants has historically been well studied, however, the influence of these tools on bee communities is often more complex and remains understudied (Hanberry et al., 2021; Payne et al., 2024).

Other leading factors that threatened the health of the bee community include parasite and pathogen infections. This is particularly noted in honey and bumble bee populations, especially for some species that harbor increased rates of pathogen infection (Cameron & Sadd, 2020; Cameron et al., 2016). Parasitoids, such as conopid fly larvae (*Conopidae*, *Diptera*), are lethal for adult bumble bees which in turn directly reduces colony size and threatens colony success (Schmid-Hempel & Durrer, 1991). Other pathogen infections are caused by smaller invaders, such as *Crithida bombi*, a protozoan and the microsporidian *Vairimorpha bombi*. These infections can also lead to decreased colony size and success as they often reduce foraging rates in workers (Cameron & Sadd, 2020, Meeus et al., 2011) potentially causing devastating impacts on wild bumble bee populations as colonies fail to produce new gynes in the spring.

These pathogenic invaders are transmitted between individuals via fecal deposits on shared floral resources (Adler et al., 2018; Drurrer et al., 1994; Graystock et al., 2015). It's estimated that approximately 10% of flowers in any given area are likely carrying pathogens (Strange et al., 2021), however, specific floral traits can influence pathogen dynamics. For example, floral shape can mediate susceptibility to contact with infected fecal matter as long tubular flowers, are less likely to be defecated on compared to wide,

shallow flowers (e.g. Bodden et al., 2019). Moreover, some floral nutrients are thought to have medical properties, such as sunflower pollen which mechanically scrapes pathogens from an individual's gut lining (e.g. Figueroa et al., 2023). Additionally, honey bees and commercial bumble bee colonies are also thought to be responsible for transmission of pathogens to wild bumble bees (Colla et al., 2006; Graystock et al., 2014; Koch et al., 2017; Murray et al., 2013) with the latter group currently having no regulations on colony health once these bees leave manufacturing (Strange et al., 2021). Continued monitoring of bee populations and further investigations into the applied impact of habitat quality and resource availability for bees on parasite infections is needed to mitigate the impact of these threats.

CHAPTER TWO

CITIZEN SCIENCE FOR POLLINATOR RESEARCH: A 10 YEAR REGIONAL ASSESSMENT OF INATURALIST DATA

2.1 Introduction

Scientists have documented widespread reductions in insect abundance and diversity across the globe, resulting from anthropogenic disturbances including land-use shifts, habitat degradation, and climate change (Wagner et al., 2021). Given the critical role of pollinating insects in ecosystem services, these downward trends have generated significant alarm (Potts et al., 2016; Wagner et al., 2021). While recent studies have quantified pollinator declines (e.g., Bartomeus et al., 2013; Cameron et al., 2011; Forister et al., 2021), data on the population status of most species remains insufficient (Chesshire et al., 2023; Orr et al., 2021). Furthermore, uncertainty with respect to drivers of decline makes it difficult to predict population trajectories. Documenting changes in pollinator abundances and species distributions due to environmental change therefore remains a critical scientific challenge. In recent years, citizen science, also known as participatory and community science, has become an important component of biodiversity inventory and monitoring programs (Encarnação et al., 2021; Gallagher et al., 2024; McKinley et al., 2017). Digital citizen science applications have great potential for enhancing pollinator research, especially as public interest in pollinator conservation grows and technologies advance. In particular, iNaturalist (www.iNaturalist.org) stands out as an invaluable community engagement and information tool for natural resource managers, conservation biologists, science educators, ecologists, biogeographers, and other

researchers (Callaghan et al., 2022; Echeverria et al., 2021; Gallagher et al., 2024; McKinley et al., 2017; Mesaglio & Callaghan et al., 2021).

Community participants have contributed to iNaturalist creating a rich, open-source dataset useful for understanding spatiotemporal variability in species distributions and patterns of biodiversity, yet it remains an underutilized resource. Recently, however, there has been increased use of iNaturalist data in research with studies investigating pollinator response to climate and land-use change (e.g., Forister et al., 2021, Hemberger et al., 2021) as well as to evaluate species distribution patterns (e.g., Boyd et al., 2022; Evans et al., 2022; Portman et al., 2023; Veit et al., 2022). A key value of iNaturalist is access to open data covering a large spatial extent, often not readily accessible to researchers (Chessire et al., 2023; Putman et al., 2021; Seregin et al., 2020). For example, in a study examining *Yucca* plant phenology in the USA, iNaturalist data covered a greater spatial extent in comparison to data from the National Ecological Observatory and National Phenology Networks (Barve et al., 2020). Portman et al. (2021) examined iNaturalist data to demonstrate that bee nectar-concentrating behavior is more common across species than previously known. Moreover, Fogel et al. (2023) documented wing de-melanization of the Eastern carpenter bee (*Xylocopa virginica*) in urban environments and at higher rates than predicted by insect collections. These studies illustrate how iNaturalist contributes to diverse research topics, including studies on species' temporal and distributional changes, behavioral ecology, and life-history characteristics.

Here we present a regional evaluation of iNaturalist as a citizen science tool for pollinator research. Specifically, we examine butterfly and bee data in the North Central

USA to highlight key attributes that contribute to species' coverage, especially with respect to bees, as they are the primary pollinators of flowering plants, including many crops (Khalifa et al., 2021; Ollerton, 2021). While many bee species are known to be in decline, there is a lack of data for most species and geographic biases in data limit our understanding of threats (Chessire et al., 2023; Jamieson et al., 2019; Rousseau et al., 2024; Wagner et al., 2021). In this study, examination of the butterfly dataset serves as a reference to establish community engagement in the region and explore biases among these two taxa. Butterflies are often identified as the most charismatic pollinators, known to attract public interest, and accordingly have had a long history of community-based monitoring (Reis & Oberhauser, 2015). Although bees have not traditionally shared this advantage, citizen science efforts are rapidly growing with greater interest in these essential pollinators. In this study, our key objectives were to **(1)** characterize and compare attributes of iNaturalist butterfly and bee data within the region, **(2)** examine user participation and data coverage with attention to implications for bee data quality, and **(3)** inform best-use practices for improving data coverage and quality. We expected that butterflies would be better represented in comparison with bees, and that in general, observations would be skewed toward larger-bodied pollinators. Further, we anticipated that the number of bee species detected across the region would be limited by the challenges of photographing and/or identifying smaller-bodied bees. Finally, we hypothesized that the majority of observations would be centered around urban areas, with greater citizen science participation in cities with well-established citizen science programs.

2.2 Methods

In this study, we used ‘Research Grade’ butterfly (Superfamily Papilionoidea) and bee (Epifamily Anthophila) observations observed between January 1st, 2014, to December 31st, 2023, across a 14-state region in the North Central USA downloaded in April and May 2024 (iNaturalist, 2024). In iNaturalist, the term ‘Research Grade’ indicates that at least two iNaturalist users assign the same taxonomic identity to an observation, and there is greater than two-thirds majority agreement from crowd-sourced identifications. States included in this region conform with the North Central region of the Entomological Society of America. We used species-level data from all states, excluding observations west of the foothills of the Rocky Mountains (-105.302 longitude in Colorado) due to the biogeographical influence of the continental divide on species distributions. We first compare the number of species documented at the state-level, mapping observations using QGIS (QGIS.org, 2023) and making note of species of conservation concern. State and city shapefiles and population data were downloaded from US census data for each state (<https://www.census.gov/>). The subset of cities analyzed within states included the capital city, three most populated cities, and three cities with the largest universities. When two of the largest universities were located in the same city, we selected a city with the next largest student population. If a capital or university city overlapped with one of the most populated cities, we did not add an additional city. County data were downloaded from ESRI (<https://www.esri.com/en-us>). All statistical analyses were then completed in R (R version 4.4.3 (2025-02-28)).

To create maps, filtered ‘Research Grade’ butterfly and bee data were downloaded separately for each state and joined in QGIS to create two datasets. These datasets were clipped to US census boundaries to remove errors and joined in QGIS with state, county, and city datasets. At the state-level, we evaluated the relationship between sampling effort and species documented (i.e., species’ coverage) via rarefaction using the iNEXT package (Hsieh et al., 2016). To assess our null hypothesis that bee data coverage was proportional across land cover types, we loaded all bee observations into ArcGIS Pro where the 2023 National Land Cover Database cover types were sampled at each point at which an observation occurred, and the output table was joined back to the table of observations. Using a Pivot table in excel, we generated a summary table, including each NLCD class, the percentage of space occupied by that given NLCD class as based on percent of all pixels in the NLCD raster occupied by some cover type, and the number of observations found in each cover type. In R, this summary table was imported and analyzed where data was reclassified into land cover types (i.e. forest, agriculture, wetland, grassland, urban, other). We subsequently used this dataset to perform a χ^2 goodness of fit test to assess our null hypothesis.

We then used negative binomial generalized linear mixed effect models to analyze the relationship between butterfly and bee data and year in which they were observed. Separate models were created to include either number of butterfly observations, butterfly species, bee observations, or bees species as response variables. Each model included year as a predictor and state as a random effect. Models were created using the glmmTMB package (Brooks et al., 2017) and assumptions were

checked with the DHARMA package (Hartig, 2024). To further examine limitations of bee data, we additionally examined user participation, data quality, and species coverage. First, a Spearman's rank-order correlation analysis was performed using the `cor.test` function to explore the relationship between number of observations and species documented across cities, hypothesizing there would be a positive relationship. Then, we assessed determinations by identifiers for a subset of 100 haphazardly selected observations of *Andrena*, *Bombus*, and *Lasioglossum*. We categorized identifiers as professional taxonomists, trusted identifiers, or novice identifiers. An identifier's status was determined based on information provided in the user's iNaturalist biography. Trusted identifiers were individuals with known expertise in bee taxonomic identification, including graduate students and/or individuals working with known taxonomists. Other users were classified as novice identifiers. An additional quality assessment was performed to examine identifiers of bee species with a single observation in our dataset. We suspected these observations were likely rare or difficult to identify species and were interested in the level of identifier experience.

2.3 Results

2.3.1 Data coverage in the North Central USA

For both butterflies and bees, observations exhibited a pattern of aggregation around cities (**Figure 2.1a, b**), although there was good geographic spread into rural areas. Butterfly observations displayed better spatial coverage across the region in comparison with bees. The completeness of butterfly and bee species inventoried within states varied, ranging from ~60 to 85% of known butterfly species (Mean $\pm$ SD = 73% $\pm$

10) and ~10 to 52% of bee species (Mean $\pm$ SD = 29% $\pm$ 12). Over the 10-year period, 308 butterfly species were documented from 367,505 observations, whereas 383 bee species were documented from 221,370 observations. Based on best available knowledge (published species lists and expert taxonomic records) of species richness in the region, we estimate that approximately 93% of butterfly species and 36% of bee species were identified during this timeframe. Moreover, nearly 90% of ‘Verifiable’ observations (those with a picture and location/date) for butterflies advanced to ‘Research Grade’, whereas approximately 75% of bee observations had confirmed identifications.

Ohio, Illinois, Minnesota, and Michigan were leading states in terms of user participation and species coverage for butterflies and bees. For butterflies, species richness in some states, such as Wisconsin, Ohio, and Minnesota, reached an asymptote indicating that identifiable species were relatively well-sampled (**Figure 2.1c**). Other states (e.g., North Dakota, South Dakota, Iowa), however, were poorly sampled. For bees, analyses indicate efforts to improve species documentation is needed throughout the region— species richness asymptotes were not reached in any state (**Figure 2.1d**). Notably, the asymptote of bee rarefaction curves was markedly lower than the known bee species richness for states, likely due to challenges with photo-based determinations in addition to the difficulty of adequately capturing identifiable photos of smaller-bodied bees. For butterflies and bees, sampling effort increased significantly over the 10-year period, enhancing species coverage, especially since 2020 (**Figure 2.2**). Year was significantly positively associated with both number of butterfly observations ($\beta = 0.41$, $z = 24.78$, $p < 0.01$) and species documented ($\beta = 0.09$, $z = 16.53$, $p < 0.01$) as well as the

number of bee observations ($\beta = 0.57$, $z = 27.96$, $p < 0.01$) and species documented ($\beta = 0.19$, $z = 19.68$, $p < 0.01$).

2.3.2 Butterfly and bee species detection

Based on observation frequency, the leading species of butterflies and bees observed consisted mostly of large-bodied species. Butterfly observations were dominated by Monarchs (*Danaus plexippus*), which made up 14% of total butterfly observations. Other species in the top five included Eastern tiger swallowtail (*Papilio glaucus*), Black swallowtail (*Papilio polyxenes*), Red admiral (*Vanessa atalanta*), and Silver-spotted skipper (*Epargyreus clarus*). Approximately 37% of bee observations were for two species – the Common eastern bumble bee (*Bombus impatiens*) and European honey bee (*Apis mellifera*), which comprised 23% and 15%, respectively. Rounding out the top five bee species documented were Brown-belted bumble bee (*Bombus griseocollis*), Eastern carpenter bee, and Two-spotted bumble bee (*Bombus bimaculatus*). Bumble bees accounted for 60% of total bee observations, with 14 species in the top 25 overall. Together, bumble bees and the European honey bee represented 75% of total bee observations. Notably, however, seven medium- to small-bodied bee species from five genera, including *Halictus*, *Agapostemon*, *Anthidium*, *Augochlora*, and *Colletes*, also made the top 25.

Many butterfly and bee species of conservation concern were documented over the 10-year period. Users contributed 2126 observations for butterfly species globally ranked by NatureServe as vulnerable or imperiled, including records for 22 species of conservation concern (**Table 2.1**). Of these species, four are listed as Endangered and one

as Threatened under the U.S. Fish & Wildlife (USFWS) Endangered Species Act. Observations for most of these butterfly species were uncommon (<50 total) over the time period, except in the case of the Karner blue butterfly (*Plebejus samuelis*) which had more than 600 observations. For bees, users contributed 12,435 observations for 15 species of conservation concern, which included one Endangered species, the Rusty patched bumble bee (*Bombus affinis*), which had ~2800 verified observations. For two vulnerable bumble bees, the American (*Bombus pensylvanicus*) and Golden Northern (*Bombus fervidus*) bumble bees, users contributed ~4600 and ~3600 observations, respectively. Generally, observations for most other bee species of conservation concern were uncommon (<100), except in the case of *Bombus fraternus* and *Bombus terricola*, which had 477 and 413, respectively. Notably, over half (~56%) of bee species in our dataset have an unranked conservation status, whereas only five butterfly species are unranked (**Table 2.1**), indicating a need for improved bee species' assessments.

2.3.3 A closer look at bees: iNaturalist user participation

iNaturalist bee data benefited from participation by a small group of individuals, who we refer to as 'super users'. More than 30,680 iNaturalist users contributed observations to the dataset evaluated. Of all users, about 91% contributed fewer than 10 observations and 55% contributed only one observation. 'Super observers', defined here as those who uploaded more than 100 observations, contributed 43% of observations despite making up about 1% of users. For 'super observers' contributing bee observations, there was no relationship between the number of observations and bee species documented (**Figure 2.3a**), with significant variability in user contributions. For

example, the most prolific contributor uploaded 2711 observations and documented 20 bee species from two states, whereas another user contributed 825 observations of 134 species from eight states, the highest number of species by a single user. The second highest number of species documented was from a user who contributed 757 observations, largely from Minneapolis-Saint Paul, MN, for 102 bee species. These observations were elevated to ‘Research Grade’, largely due to the efforts of a small group of ‘super identifiers’, defined as those who identified more than 100 observations. From an examination of the top 50 ‘super identifiers’, we found that the five leading individuals were taxonomists or trusted identifiers, who individually contributed between 25,000 and 94,000 identifications across the region and 10-year period (**Figure 2.3b**). For the dataset examined, the leading identifiers of bees were John Ascher, Joel Neylon, Kyle Price, Nina Fogel, and Zach Portman.

2.3.4 Bee data coverage and quality

The number of bee observations across land cover classes differed significantly from expected based on total land cover area for each category ($\chi^2 = 1,259,701$, $df = 5$, $p < 0.001$; **Figure 2.4**). The number of observations in agricultural lands, grasslands, and forests were fewer than expected based on land cover area. The majority of ‘Research Grade’ iNaturalist bee observations were from urban areas with developed land cover, ranging from open to high intensity development. We expected this finding as the number of observations can be partly explained by greater human populations in urban areas.

Across the region, the five counties with the most bee species documented were Hennepin and Ramsey, MN (125 and 104, respectively); Hancock, IL (95); St. Louis,

MO (94); and Medina, OH (88). Counties ranged between 0 and 125 bee species documented (Mean = 12 species $\pm$ 14 SD). Approximately 42% had 10 or more bee species and only 3% had 50 or more documented species. While most of these counties contain metropolitan areas, at least one rural county was in the top five due to ‘super observer’ A. Moorehouse, who helped document 95 bee species in Hancock County, IL. Across cities in the region, there was a significant positive correlation between the number of bee observations and bee species documented (Spearman’s $\rho = 0.61$, $p < 0.01$; **Figure 2.5**). Within cities examined, users documented on average 27 bee species ($\pm$ 17 SD), which was a little more than half the number of butterfly species (43 ± 18 SD). The greatest number of bee species documented were from Saint Paul and Minneapolis, MN; Madison, WI; St. Louis, MO; Chicago, IL; and Cleveland, OH which are cities with well-known organized pollinator citizen science programs that benefit from participation by university researchers and taxonomic experts.

Analyses of data quality for three select bee genera indicated that most observations were identified by at least one or more taxonomists, namely J. Ascher, Z. Portman, J. Gibbs, and a small group of trusted identifiers. For the genus *Andrena*, 94% of observations were identified by a taxonomist and an additional 4% by a trusted identifier (total = 98% by individuals with known expertise). *Bombus* had 48% of observations identified by taxonomists and 45% by trusted identifiers (total = 93%). The genus *Lasioglossum* had 79% of observations identified by taxonomists and 11% by trusted identifiers (total = 90%). When looking at identifications for bee species with only one observation, most observations were identified by taxonomists. This review resulted

in the identification of a False Sunflower Cuckoo Nomad Bee (*Holcopasites heliopsis*) by J. Ascher which was noted as a new state occurrence record for Ohio.

2.4 Discussion

2.4.1 Discussion and conclusions

Growing participation and data across the region over the last decade highlight iNaturalist's importance as a tool for community engagement and science, and as a valuable tool for non-lethally documenting vulnerable species (**Figure 2.6**). As expected, observations of both taxonomic groups were driven by larger-bodied species and aggregated around urban areas. While our analyses showed that butterflies had greater data coverage for documented species, bee data fared well in terms of total observations and species documented, especially with respect to bumble bees. The fact that bee species coverage lagged behind butterflies, nonetheless, highlights a potential global issue for bee data on the platform. We propose that better bee species coverage could be achieved through improved photography and recruitment of macrophotographers as well as organized community projects, such as those that exist in Minneapolis-Saint Paul, MN and St. Louis, MO. Further, we recommend that organized iNaturalist community science programs should target under-surveyed areas, especially grassland and forest habitats where an abundance of bee species and populations reside.

Here, we demonstrated that a small number of 'super users' made large contributions to documenting bee diversity, but even with these contributions less than 50% of known bee species in the region were accounted for. In comparison to butterflies, bee identification via photographs can be more challenging. Some smaller-bodied bees

may not be able to be resolved to species-level from images given that accurate determination for many species involves examination of microscopic structural differences (e.g., sculpting) or hidden features (e.g., mouthparts) and requires taxonomic expertise. Greater participation by iNaturalist observers with combined naturalist and macrophotography skills in association with identifiers with taxonomic expertise (e.g., Ascher, Portman, Gibbs) could enhance data coverage and quality in future years.

Data presented in this study, including more than 12,000 observations for 15 bee species of conservation concern, have contributed to the assessment and monitoring of at-risk species. For example, observations have extended and clarified the range of species such as the Endangered Rusty patched bumble bee (pers. comm. T. Smith, USFWS). Furthermore, at USFWS, verified iNaturalist observations have been used in the assessment of critical habitat for Threatened and Endangered species, identification of at-risk populations, documentation of local extirpations, and tracking of species recovery. Additionally, iNaturalist data has helped document species' range shifts over time. For example, iNaturalist data showed that the range of the Carpenter mimic leafcutter bee (*Megachile xylocopoides*) is expanding northward, as would be predicted with warming trends (unpublished data). In the case of the Common eastern bumble bee, a native species to eastern North America, observations show a northwestern range expansion (Evans et al., 2022), with individuals far from their native range that presumably escaped managed colonies (Looney et al., 2019). iNaturalist has been useful for tracking the spread of introduced species, such as the Giant resin bee (*Megachile sculpturalis*) in the USA (Dubaic & Lanner, 2021).

Alongside organized monitoring efforts, incorporation of iNaturalist and other citizen science data can ameliorate gaps in knowledge and improve pollinator species' assessments and conservation planning (Rousseau et al., 2024; Woodard et al., 2020). For example, iNaturalist data were incorporated into the 'Regional Species of Greatest Conservation Need in the Midwestern USA' report (Terwilliger Consulting Inc, 2021). Further, these data have been used in assessments by national and international conservation groups, such as the USFWS, NatureServe, and the International Union for Conservation of Nature (IUCN). Given the evolving nature and increase of iNaturalist data over time, this platform will continue to increase in its utility for species' assessments and monitoring as well as in addressing research questions about species response to global change factors, like climate and land use change.

2.4.2 Considerations for using iNaturalist in research

While there are limitations to iNaturalist data that should be considered, there are innumerable benefits for pollinator research, especially when coupled with greater data quality control. Structured citizen science projects with training protocols alongside increased participation by experts can reduce biases and the incidence of misidentification (Callaghan et al., 2021; Di Cecco et al., 2021; Mason & Arathi, 2019). Recently developed strategies are being implemented by iNaturalist and community organizers to mitigate data quality concerns. For example, identifiers work together, calling on each other to help with problematic observations and determinations as well as to meet the two-thirds agreement required for overturning misidentifications. Tools have also been developed to objectively assess identifier reliability in relation to particular taxa

(e.g., geospatial models of known species distributions). Greater crosstalk between macrophotographers and taxonomists could also improve bee data quality. For example, macrophotographers could be trained to capture critical morphological traits, which in turn would enhance computer vision models.

Spiesman et al. (2021) addresses concerns with and ways to improve computer vision models, highlighting the importance of image quality. Even with better computer vision models, the contributions of taxonomists will be essential (Callaghan et al., 2022). Research evaluating the accuracy of bumble bee identifications by citizen scientists estimated error rates ranging from 30–50% by novice users in comparison to experts (Gratton & Zuckerberg, 2019; MacPhail et al., 2020). In this study, we showed that taxonomic experts contribute most bee identifications, helping to maintain data quality. Thus, strategies to incentivize greater and continued participation by taxonomists as well as macrophotographers should be considered. Improved training and continued enhancements to iNaturalist models may help reduce common errors by novice users, such as attempting to guess at species-level identifications when uncertain. In this case, project organizers should remind citizen scientists to only identify to a taxonomic level for which they have certainty. Training programs should also emphasize that the second verified identification will move an observation to ‘Research Grade’ and should be made with caution. A key strength of iNaturalist’s open platform—determinations can be verified and improved overtime, transparently.

iNaturalist data have enhanced our understanding of the distribution, phenology, and relative abundances of pollinator taxa. Notably, iNaturalist observations contributed

>70% of butterfly and bee occurrence data in the Global Biodiversity Information Facility (GBIF) dataset for our study region and time period (<https://doi.org/10.15468/dl.vvfdj7>). Research using iNaturalist and GBIF certainly has limits, and thus studies should be designed appropriately. For example, relative abundance data must be viewed cautiously with an understanding of biases. In some cases, presence/absence or trait-based data may be more appropriate for pollinator research. With consideration of these limits, iNaturalist data could be used in ecological niche, species distribution, and occupancy detection models (e.g., Loiselle et al., 2008; Tingley & Beissinger, 2009). Geographic biases could also be addressed by acknowledging an urban bias and focusing on unanswered questions in the field of urban ecology. With consideration of known limitations and concerted efforts to improve data coverage and quality, iNaturalist can serve as an invaluable data source in future pollinator research.

Table 2.1. Summary of iNaturalist ‘Research Grade observations’ in North Central USA (2014-2023) by global conservation rankings. Species of conservation concern are listed followed by the number of observations in parentheses. The number of species is provided for secure and unranked species. U.S. Fish and Wildlife-listed *Endangered and **Threatened species are in bold.

	Butterfly species	Bee Species
Critically Imperiled (G1)	<i>Plebejus samuelis</i>* (665) <i>Oarisma poweshiek</i>* (6)	
Imperiled (G2)	<i>Pieris virginiensis</i> (144) <i>Argynnis diana</i> (40) <i>Atrytone arogos</i> (31) <i>Neonympha mitchellii</i>* (20) <i>Callophrys irus</i> (19) <i>Celastrina humulus</i> (18) <i>Erora laeta</i> (2) <i>Hesperia dacotae</i>** (2)	<i>Bombus affinis</i>* (2829) <i>Megachile fortis</i> (34) <i>Megachile rugifrons</i> (4) <i>Andrena mentzeliae</i> (1)
Vulnerable (G3)	<i>Argynnis idalia</i>* (751) <i>Calephelis muticum</i> (169) <i>Calephelis borealis</i> (123) <i>Euphyes dukesi</i> (42) <i>Amblyscirtes aesculapius</i> (40) <i>Erynnis martialis</i> (28) <i>Celastrina neglectamajor</i> (6) <i>Hesperia ottoe</i> (6) <i>Erynnis lucilius</i> (5) <i>Euphilotes rita</i> (5) <i>Pyrgus xanthus</i> (3) <i>Stinga morrisoni</i> (1)	<i>Bombus pensylvanicus</i> (4597) <i>Bombus fervidus</i> (3826) <i>Bombus fraternus</i> (477) <i>Bombus terricola</i> (413) <i>Bombus appositus</i> (100) <i>Bombus morrisoni</i> (55) <i>Bombus insularis</i> (54) <i>Bombus occidentalis</i> (35) <i>Anthophora occidentalis</i> (5) <i>Nomia universitatis</i> (3) <i>Anthidium psoraleae</i> (2)
Apparently Secure (G4)	39	15
Secure (G5)	242	139
Unranked (SNR)	5	214

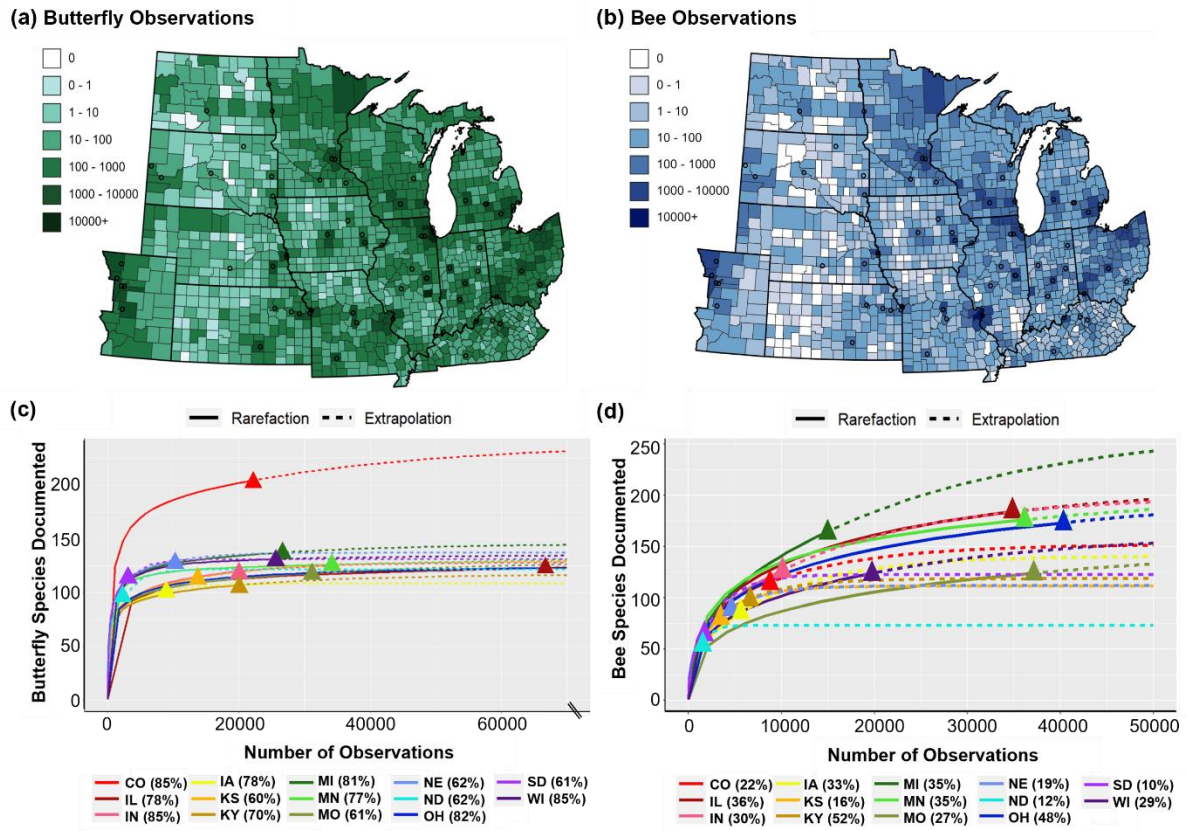


Figure 2.1. Overview of iNaturalist butterfly and bee data for the North Central USA from 2014-2023. Observations are mapped for a) butterflies and b) bees by county. Open black circles are cities evaluated in this study. Graphs show the number of species documented for each state in relationship to observations for c) butterflies and d) bees over the 10-year period. Note the x-axis break in c); the line for Ohio extends the break with a total of 84,064 observations (blue triangle). The percentages displayed next to state abbreviations in the legend indicate the percentage of known species documented in each state (Table A.1).

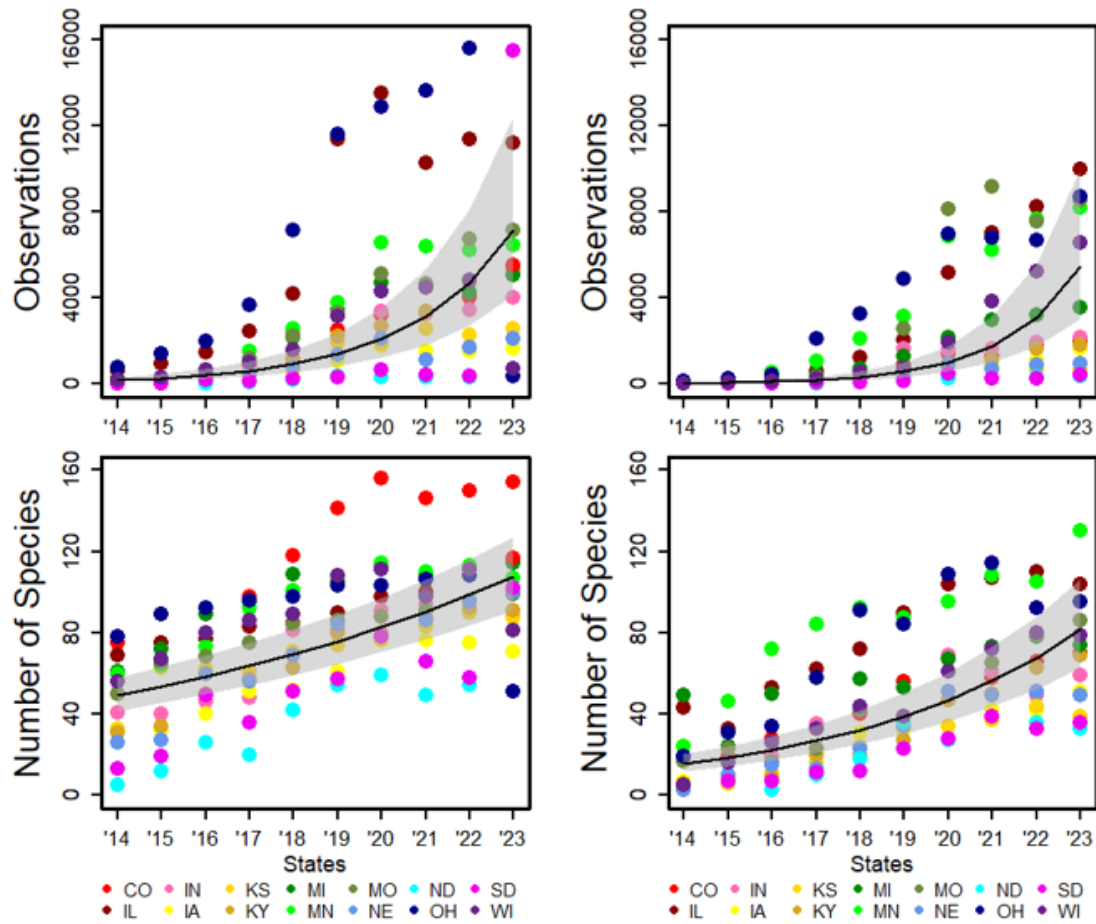


Figure 2.2. Total iNaturalist a) butterfly observations, b) bee observations, c) butterfly species, and d) bee species documented across each state for the North Central USA (2014-2023). Colored circles indicate each state and gray ribbons represent 95% confidence intervals. While our models demonstrate exponential growth, as observations and species documentation increase into the future we'd expect this growth to level off as it approaches some threshold.

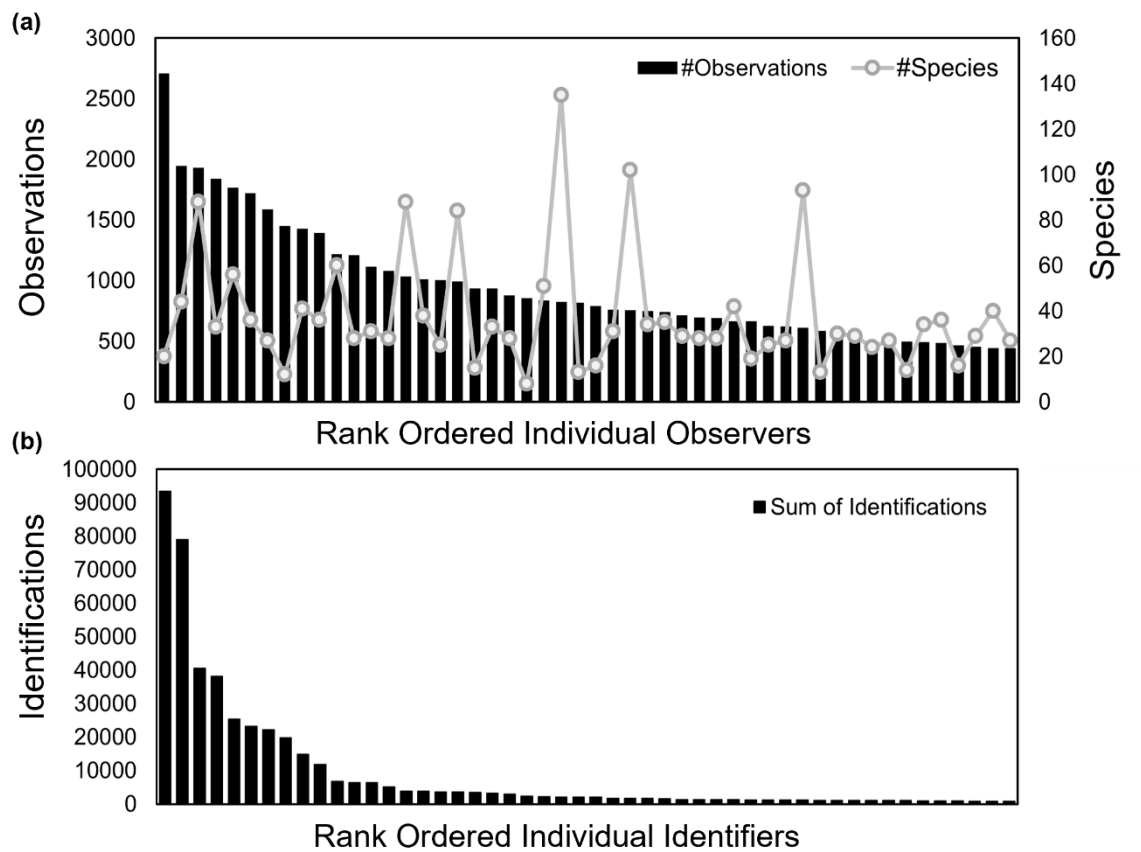


Figure 2.3. Summary of a) bee observations (left axis) and species richness (right axis) rank ordered by leading iNaturalist observers and b) number of bee species identifications rank ordered by leading identifiers from 2014-2023.

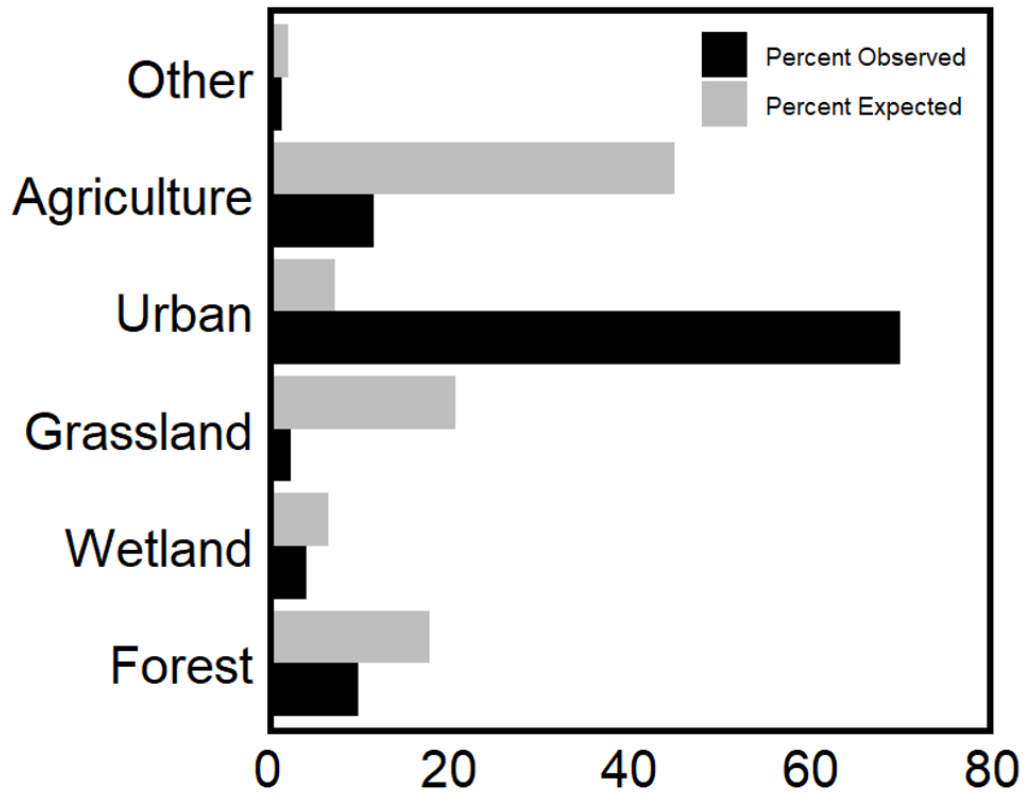


Figure 2.4. The percentage of observed and expected number of bee observations based on land cover area. Black bars show the observed percentage of bees within each land cover category and gray bars show the expected percentage of bees by land cover given total area in each category, assuming no bee preference for habitat or human sampling bias across classes. Landcover types were reclassified by the following combinations of NLCD cover classes: Forest- deciduous forest, evergreen forest, and mixed forest; Wetlands- woody wetlands and emergent herbaceous wetlands; Grassland- dwarf scrub, shrub/scrub, grassland/herbaceous, and sedge/herbaceous; Urban- developed open, developed low, developed medium, and developed high; Agriculture- pasture hay and cultivated crops; Other- open water, ice/snow, barren land, and lichen, moss.

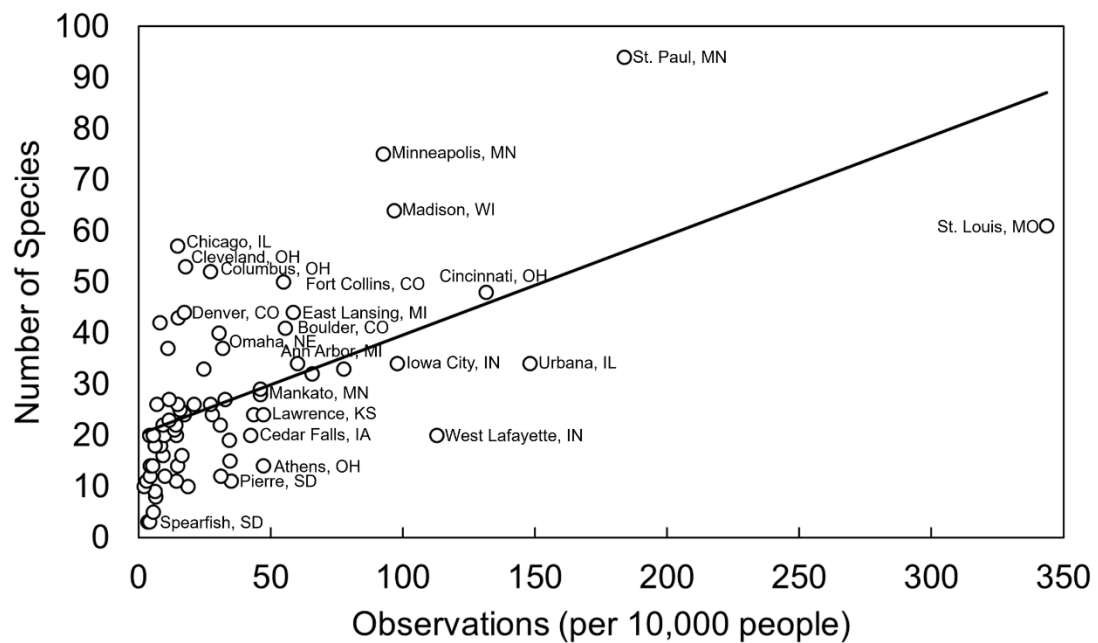


Figure 2.5. Number of bee species documented in relationship to observations in selected cities across the North Central USA from 2014-2023. City labels provided when space allowed. Cities with the highest number of species documented were from areas with organized citizen science programs.



Figure 2.6. Citizen science platforms, such as iNaturalist, provide ecological research opportunities and societal benefits by providing open data. Traditional and photo-based surveys alongside collaborations between ecologists, macrophotographers, taxonomists and community organizers can improve species detection, including at-risk species, such as floral and habitat bee specialists pictured here (left to right: *Andrena erigeniae*, *A. ziziae*, *Lasioglossum vierecki*, and *Chelostoma rapunculi*; photos provided by citizen scientist Joseph Ferraro, pictured here taking photos).

CHAPTER THREE

RESTORING A DEGRADED WETLAND: THE EFFECTS OF HABITAT MANAGEMENT ON PLANT AND BEE COMMUNITIES

3.1 Introduction

Recent declines for important pollinator groups are raising concerns given the critical ecosystem and agricultural services they provide, particularly bees (Cornelisse et al., 2025; Gallai et al., 2009; Potts et al., 2010; Zattara and Aizen, 2021). Among the multitude of stressors threatening this important group, loss of floral resources caused by habitat loss and degradation is considered a leading factor (Cameron et al., 2011, Goulson et al., 2015; Potts et al., 2010). Specifically, the loss of high-quality natural habitats, such as grasslands and wetlands, is an urgent issue for bee conservation. Countless bee species and functional groups rely on these habitats for a variety of nesting substates and native floral hosts, leaving them vulnerable to the impacts of fragmentation and reduced habitat quality (LeBuhn & Luna, 2021; Williams et al., 2010).

One substantial driver of diminishing habitat quality is encroachment from introduced, invasive woody shrubs that shade and outcompete native plants, reducing herbaceous abundance and diversity (Collier et al., 2002; Lanta et al., 2013, Maynard-Bean & Kaye, 2019). Across much of the U.S. there are more than a dozen problematic invasive shrubs, such as Multiflora Rose (*Rosa multiflora*), Glossy Buckthorn (*Rhamnus frangula*), and Autumn Olive (*Elaeagnus umbellata*) (Borland et al., 2009). The latter species is thought to be of special concern given its role in nitrogen fixation and ability to rapidly dominate ecosystems (Catling et al., 1997; Dornbos et al., 2016; Ebinger &

Lehnen, 1981; Eldridge et al., 2011; Oliphant et al., 2017). While autumn olive shrubs provide abundant floral resources for generalist pollinators in the spring (Soley & Sipes, 2020), they pose an imminent threat to floral resource availability throughout the growing season, especially for specialist bees.

Effective methods of managing this invasive shrub include mechanical control (pulling, forestry mowing, and grazing), chemical control (herbicide application), and in some cases prescribed burns (Borland et al., 2009). Removal of a similar invader, Glossy Buckthorn, resulted in increased bee abundance (Fiedler et al., 2012) suggesting mechanical control of invasive shrubs is also an effective tool for bee conservation. Likewise, prescribed burns can improve habitat quality for bees as this practice has shown to promote the native plant community and can increase nesting opportunities via reduced thatch cover (e.g., Basset et al., 2020; McWilliams et al., 2007; Pane & Harmon-Threat, 2017). Additionally, seeding and planting diverse native floral resources can increase the availability of quality, season long nutrition needed to support a variety of bees. While these management tools are often applied with consideration for their influence on the plant community, it is critical to understand how these strategies impact bees.

This study aimed to 1) characterize the plant and bee community and 2) use a three-prong restoration management approach, including autumn olive shrub removal, prescribed burning, and restorative wildflower plantings, to assess how these techniques influence floral resource availability for bees in a threatened, fire adapted wetland. We were also interested in exploring which of these strategies might enhance habitat quality

the greatest in terms of supporting floral resources. We hypothesized that each of these treatments would enhance floral resource availability, in terms of bloom cover and diversity, and thus improve bee abundance. With respect to the relative value of these management tools, we expected that autumn olive shrub removal would have the overall greatest benefit for herbaceous flowering plants given the strong competitive effects of well-established shrubs. Moreover, we predicted that native wildflower plantings would increase bee abundance greater than prescribed burning alone where regeneration of floral resources is limited by species already present in the soil.

3.2 Methods

3.2.1 Experimental design

A multi-year manipulative field experiment was created in a degraded mosaic prairie fen, southern wet meadow habitat (hereafter referred to as a wetland) at the Oakland University Biological Preserve in Southeast Michigan. In the spring of 2021, there was an initial effort to improve the plant community and restore habitat quality by applying a 10-acre prescribed burn. Prior to the burn, 12 – 10 x 10 m plots were established within the preserve, including six unmanaged reference plots that were left unburned and six burned plots. Following the burn, a subset of autumn olive shrubs were cut at the base and then sprayed with herbicide to discourage regrowth.

In the fall of 2021, an additional restoration initiative occurred to transplant wildflower plugs into the preserve resulting in the establishment of an additional 24 – 10 x 10 m plots, all of which were burned the previous spring and received wildflower plantings (See **Table 3.1** for a description of all management treatments applied to each

plot group; **Figure 3.1**). This list included six plots containing present autumn olive shrubs and six where autumn olive shrubs were removed. Given the abundance of autumn olive shrubs within the available area in the preserve, all individuals with a basal circumference smaller than 0.2 m were not considered when creating “autumn olive removed” plots. It should be noted that all other plots, including the unmanaged and burned reference plots, may or may not have contained autumn olive shrubs as they were not assessed for autumn olive presence before establishment.

Transplanted wildflowers in each of the remaining 24 plots were randomly chosen from a 12 species assemblage. Six plots received a high diversity planting of two individuals from all 12 species. Another six plots received a low diversity planting which included four individuals from a subset of six species. All autumn olive plots, present and removed, were planted with two individuals of a subset of six species around the crown drip line of each shrub to account for its competitive advantage. For consistency and to avoid competition between plugs, all flowers were planted 1m apart from one another.

3.2.2 Plant and pollinator surveys

Monthly plant and pollinator surveys were conducted between June-September in 2021, 2022, and 2023. During these surveys all flowering plants in each plot were documented to species level when possible and bloom cover was estimated for each. Species that are known to hybridize or have overlapping taxonomic traits were grouped. For example, *Solidago altissima* and *Solidago canadensis* were combined to create the *Solidago altissima/canadensis* group. Any remaining plants that were unidentifiable in

the field were left to genus level. Autumn olive shrub cover was also estimated in each plot following surveys in 2023.

Active netting was conducted for 15 minutes in each plot to survey bees. During this period, all bees that visited flowering plants were caught and their floral interaction recorded. Timers were stopped each time a bee was caught to ensure equal survey effort within each plot. Collected bees were placed in falcon tubes according to their floral associations and stored in freezers for later identification. Bumble bees were chilled, photographed, and then released to avoid lethal collections. Likewise, Honey bees (*Apis mellifera*) and Eastern Carpenter bees (*Xylocopa virginica*) were recorded but not collected as they are easily identifiable during flight. Once identified, bees were grouped by morphospecies (i.e. bumble bees, honey bees, tiny/small bees, medium/large bees, and green bees) for statistical analysis.

3.2.3 Statistical analysis

Statistical analyses were performed in R version 4.4.3 (R Core Team, 2025). Plant and bee community metrics, i.e. Shannon diversity and Pielou's J evenness, were calculated with the Vegan package (Oksanen et al., 2022). To assess the impact of each habitat management tool on the plant and bee community, we created linear and negative binomial generalized linear regression models in the MASS package (Venables & Ripley, 2002). Models only examined data from surveys conducted in 2023 due to inconsistencies between years and plot was the primary unit of replication in all analyses.

To evaluate the plant community, we included bloom cover, floral richness, Shannon diversity, Pielou's J evenness, native floral richness, native bloom cover,

introduced floral richness, and introduced bloom cover as response variables predicted by autumn olive cover and plot management type. Autumn olive cover following removal was assessed using a linear regression model with a natural log transformation ($\log(x+1)$). This model included management plot as a predictor; however, it only assessed a subset of plots, specifically unmanaged control, burned control, autumn olive present, and autumn olive removal. Due to avoiding dense autumn olive patches during plot selection for low and high diversity planting plots, these management groups were removed from this analysis. For bee community models, we included total bee and morphospecies abundance as response variables with autumn olive cover, plot management type, floral richness, and bloom cover as predictor variables.

We further evaluated the significance of predictors in all models by performing an ANOVA with Type II F tests and Kenward-Roger (df) in the car package (Fox & Weisberg, 2019). We then performed Sidak- adjusted post hoc analyses of estimated marginal means across and between planned paired contrasts of all plot management types (i.e. unmanaged control vs. burned control, autumn olive present vs. removal; low vs. high diversity plants), except in the case of autumn olive cover where we used Tukey post hoc analysis as we were interested in all plot comparisons (Lenth, 2025).

3.3 Results

3.3.1 Habitat overview: the plant and bee community

We documented 87 flowering plant species across all survey years and plots including 59 native species and 27 introduced, non-native species. The most abundant species by total bloom cover were Mountain Mint (*Pycnanthemum virginianum*), Grass-

leaved Goldenrod (*Euthamia graminifolia*), Tall/Canada Goldenrod (*S. altissima/canadensis*), Spotted Joe-Pye Weed (*Eutrochium maculatum*), and the non-native, invasive species Crown Vetch (*Securigera varia*). We also documented a number of wetland associated native species including Blue Flag Iris (*Iris versicolor*), Jewelweed (*Impatiens capensis*), Monkey Flower (*Mimulus ringens*), Great Blue Lobelia (*Lobelia siphilitica*), Flat-Topped Aster (*Doellingeria umbellata*), Swamp Rose (*Rosa palustris*), Turtlehead (*Chelone glabra*), and Swamp Milkweed (*Asclepias incarnata*).

Across all years and plots we documented a total of 4124 floral visitations which represented 58 bee species visiting 38 floral species, 68% of which are native to the region (**Figure 3.2**). Of these floral species, the most visited by all bees were Mountain Mint, Grass-leaved Goldenrod, Spotted Joe-Pye Weed, Tall/Canada Goldenrod, and Giant Goldenrod (*Solidago gigantea*). Among the most observed floral visitors were Honey bees (*Apis mellifera*) and Bumble bees (*Bombus sp.*) with thousands of observations across years. Interestingly, honey bee abundance increased each year with nearly double the individuals in 2023 compared to 2021 leaving them as one of the leading pollinators in the habitat. Other notable observations included the Red-belted Bumble Bee (*Bombus rufocinctus*) and Lemon Cuckoo Bumble Bee (*Bombus citrinus*), two species of conservation concern, as well as a number of uncommon specialist bees: the Sunflower Miner Bee (*Andrena helianthin*) a rare *Helianthus* specialist, the Cloudy-winged Miner Bee (*Andrena nubecula*) an uncommon *Asteraceae* specialist, *Calliopsis nebraskensis* a rare *verbena* specialist, the Bellflower Leafcutter Bee (*Megachile*

campanulae) an uncommon *Campanula* specialist, and the Vigorous Long-horned Bee (*Melissodes subillatus*) an uncommon *Asteraceae* specialist.

3.3.2 Plant and bee community response

We found that the plant and bee community responded differently to habitat management treatments and in some cases were best explained by the local environment (**Tables 3.2 and 3.3**) Planned contrasts revealed that autumn olive removal plots supported more floral diversity (SE = 0.15, $p = 0.053$; Sidak-adjusted) than autumn olive present plots (**Figure 3.3a**). These findings align with the significant reduction in autumn olive shrub cover in removal plots compared to autumn olive present plots (SE = 0.46, $p = 0.022$; Tukey-adjusted) (**Figure 3.3b**). Floral evenness did not differ between management types but did significantly increase with autumn olive cover (**Table 3.2**). Total bloom cover, total species richness, native bloom cover, native species richness, introduced bloom cover, and introduced species richness were not significantly explained by any restoration management type nor autumn olive shrub cover (**Table 3.2**).

While we found that the flowering plant community was most influenced by their invasive woody counterpart, the bee community was best explained by local floral resources. Total bee abundance was positively associated with floral bloom cover (**Table 3.3; Figure 3.4a**). Interestingly, we observed roughly 40% fewer total bees in burn control plots than unmanaged reference plots, although this result was not significant in post hoc analyses (SE= 0.18, $p = 0.077$; Sidak adjusted). Bumble bees, honey bees, and medium/large bees followed a similar positive trend with greater bloom cover resulting in more observed individuals (**Table 3.3; Figure 3.4b,c,d**). Notably, we recorded

approximately 58% fewer honey bees in burn control than unmanaged reference plots (SE=0.25, $p < 0.01$; Sidak-adjusted) (**Figure 3.5a**). We also observed significantly more tiny/small bees in plots with high diversity plantings than low diversity plantings (SE = 0.32, $p = 0.028$; Sidak-adjusted) (**Figure 3.5b**). Green bees were not influenced by any restoration management treatment or local environmental factor (**Table 3.3**).

3.4 Discussion

Our inventory revealed that the Oakland University Biological Preserve's wetland habitat serves as an important reservoir for native regional species, including specialist bees and species of conservation concern. However, it is evident that this wetland is still under substantial pressure from introduced, non-native plant species as they comprised nearly half of all floral richness at the site. Some of these introduced species, especially Canada thistle (*Cirsium arvense*) and autumn olive, are highly competitive and when left untreated can quickly dominate the landscape (Catling et al., 1997; Evans et al., 2013; Gosper et al., 2005; Hodgson 1968; Miller et al., 2013; Moore, 1975). As these species begin to outcompete native floral resources, they pose imminent threats to ecosystem functioning (Eldridge et al., 2011) as well as to specialist bee species whose persistence relies on the availability of their host flowers (Sedivy et al., 2011; e.g. Straka & Bogusch 2017; Westerfelt et al., 2018). Considering these detrimental outcomes, our inventory underscores the imminent need for continued restoration management within the preserve and at similar degraded wet grasslands.

Our analysis identified mechanical and chemical removal of autumn olive shrubs to be an effective management tool for combatting the persistence of this invasive shrub

multiple years after removal. The improved floral diversity we found following autumn olive removal has been documented in a similar study investigating the removal of Glossy Buckthorn from a prairie fen (Fiedler et al., 2012). However, other studies failed to detect improvements specifically to native plant richness and abundance following invasive shrub removal (e.g. Christopher et al., 2014; Cutway 2017; Frappier et al., 2004; Hanula et al., 2009; Swab et al., 2008). Particularly notable was the low floral diversity we observed in autumn olive present versus removed plots despite both groups receiving identical restorative wildflower plantings. While we did not track survival of planted wildflower plugs, future studies should consider identifying key floral species that are resilient to the competitive nature of autumn olive shrubs. Prioritizing such species in restoration efforts could provide season long floral resources for bees which would otherwise be vacant following cessation of autumn olive blooms in spring (Knapp et al., 2023).

The lack of response by the floral community to other restoration management applications in this study was contrary to our expectations, particularly the absence of prescribed burning effects. While we anticipated that prescribed burning would allow native floral resources to outcompete less fire adapted nonnative species, prior research also found minimal prescribed fire impacts on native plants (McWilliams et al., 2007; Novak et al., 2022). Some studies also note taxa dependent responses to burning (e.g. Novak et al., 2022; Rau et al., 2008) which may explain the lack of response from the floral community as a whole. For example, Travnicek et al. (2005) found that Canada thistle was significantly more abundant following prescribed fire application,

demonstrating that non-native species can persist belowground and take advantage of newly uncolonized patches before native species can fill these areas (Rowe, 1983).

As with floral resources, we expected restoration management treatments to have a large impact on the bee community; however, this was not supported by our results. While other studies have found removal of invasive shrubs and plants promoted bee abundance and richness (Fielder et al., 2012; Tonietto & Larkin, 2017; Ulyshen et al., 2022), it is likely that the absence of autumn olive shrub removal and restorative wildflower planting effects on bees in this study was in part due to proximity and mobility between plots. Moreover, contrary to our expectations, prescribed burning appeared to negatively influence honey bee abundance. Considering the lack of response of the floral community, this result may be related to unmeasured floral metrics, patch fidelity, and/or microsite variation (e.g., Knapp et al., 2023). The limited impact of management treatments on the remaining bee community may reflect reduced sensitivity at the morphospecies level. Future studies should consider focusing on the response of specific bee functional groups (Tonietto & Larkin, 2017), especially considering aspects of functionality, such as nesting availability and diet, can be influenced by restoration management and other disturbances (e.g. Brokaw et al., 2023; Bruninga-Socolar et al., 2022; Moretti et al., 2009).

In this small-scale restoration management effort, we provide a snapshot into the value of restoring and preserving wetland habitats, especially in suburban and urban ecosystems. Moreover, we highlight the importance of continued efforts to combat non-native woody invaders for the persistence of the herbaceous plant community, in turn,

ensuring high quality resources exist to support diverse bee communities. The overall decreased autumn olive shrub cover following removal efforts was encouraging and the subsequent improvement to floral diversity suggests its efficacy as a management tool in these habitats. Future studies should carefully consider microsite variation within a given habitat and assess bee functional traits (Tonietto & Larking, 2017) in response to restoration management. Doing so will ensure management decisions are made in alignment with both native plant and bee conservation goals as the latter has historically been neglected in restoration management plans (Harmon-Threatt & Chin, 2016).

Table 3.1. Summary of restoration management treatments applied in 2021 within each plot management group. Each group consisted of six plots for a total of 36 plots established within the preserve.

Plot (N = 6)	Restoration Management Treatments Received
Unmanaged Control	No management
Burned Control	Prescribed burn
Low Diversity Planting	Prescribed burn + low diversity wildflower planting
High Diversity Planting	Prescribed burn + high diversity wildflower planting
Autumn Olive Present	Prescribed burn + low diversity wildflower planting
Autumn Olive Removed	Prescribed burn + low diversity wildflower planting + mechanical and chemical autumn olive shrub removal

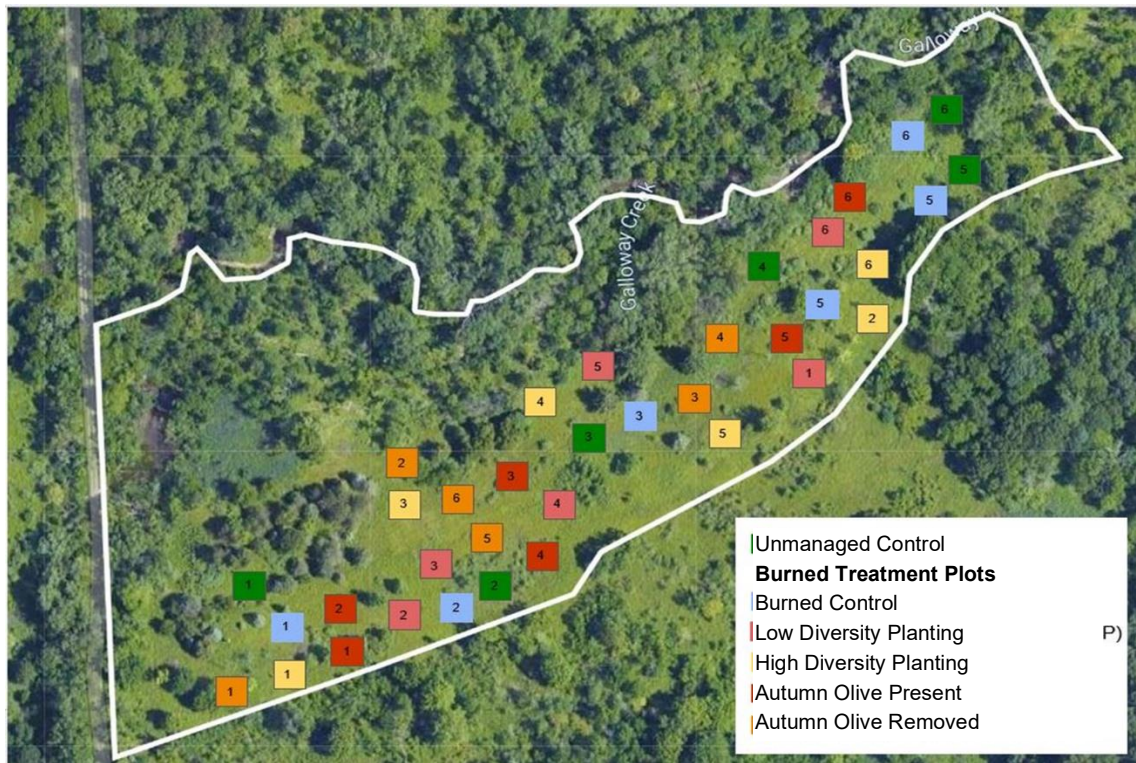


Figure 3.1. Map displaying each 10 x 10 m plot located in the mosaic prairie fen, southern wet meadow habitat in the Oakland University Biological Preserve. Plot color coordinates with the received treatment (N=6).

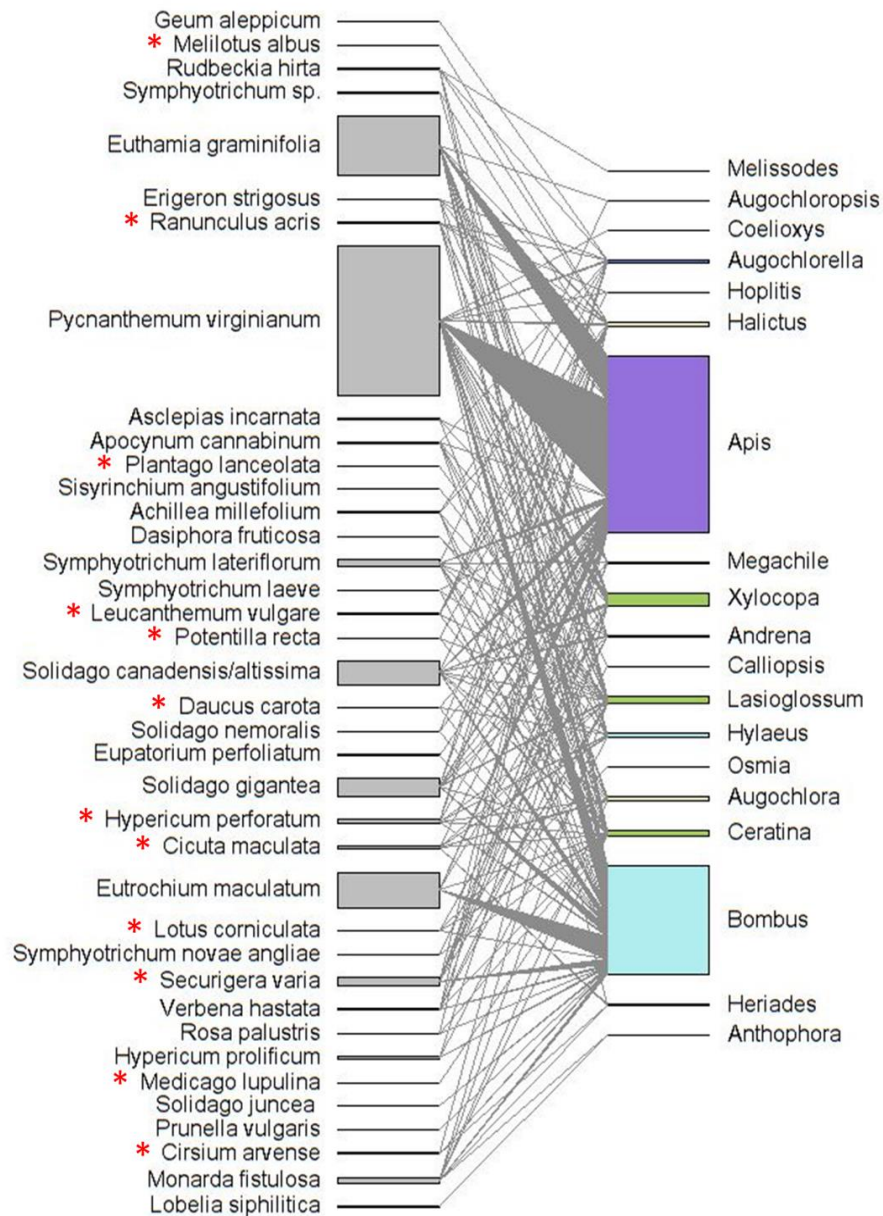


Figure 3.2. Visualized plant-pollinator networks across all plots and years. Gray boxes on the left indicate floral genera and colored boxes on the right indicate bee genera. Box widths represent the abundance of each genus and plant species across the habitat. Gray triangles link bee genera to their associated floral visit with thickness corresponding to the number of interactions. Red asterisks indicate introduced non-native floral species.

Table 3.2. ANOVA results for the plant community response to the effect of restoration management treatments and autumn olive cover. Response variables were fit to linear regression models. * The response variable Autumn Olive Cover was transformed using a natural log transformation ($\log(x+1)$) and was only analyzed across four plot management groups.

Model	Predictor	df	F	P
Total Bloom Cover (m ²)	Treatment	5	0.092	0.993
	Autumn Olive Cover (m ²)	1	2.637	0.115
Total Species Richness	Treatment	5	4.513	0.478
	Autumn Olive Cover (m ²)	1	0.006	0.937
Shannon Diversity	Treatment	5	2.467	0.056
	Autumn Olive Cover (m ²)	1	3.259	0.081
Pielou's J Evenness	Treatment	5	1.548	0.206
	Autumn Olive Cover (m ²)	1	10.121	0.003
Native Bloom Cover (m ²)	Treatment	5	0.138	0.982
	Autumn Olive Cover (m ²)	1	2.620	0.116
Native Floral Richness	Treatment	5	0.719	0.614
	Autumn Olive Cover (m ²)	1	0.219	0.643
Introduced Bloom Cover (m ²)	Treatment	5	0.401	0.844
	Autumn Olive Cover (m ²)	1	0.393	0.540
Introduced Floral Richness	Treatment	5	1.596	0.193
	Autumn Olive Cover (m ²)	1	0.377	0.544
*Autumn Olive Cover (m ²)	Treatment	3	3.483	0.035

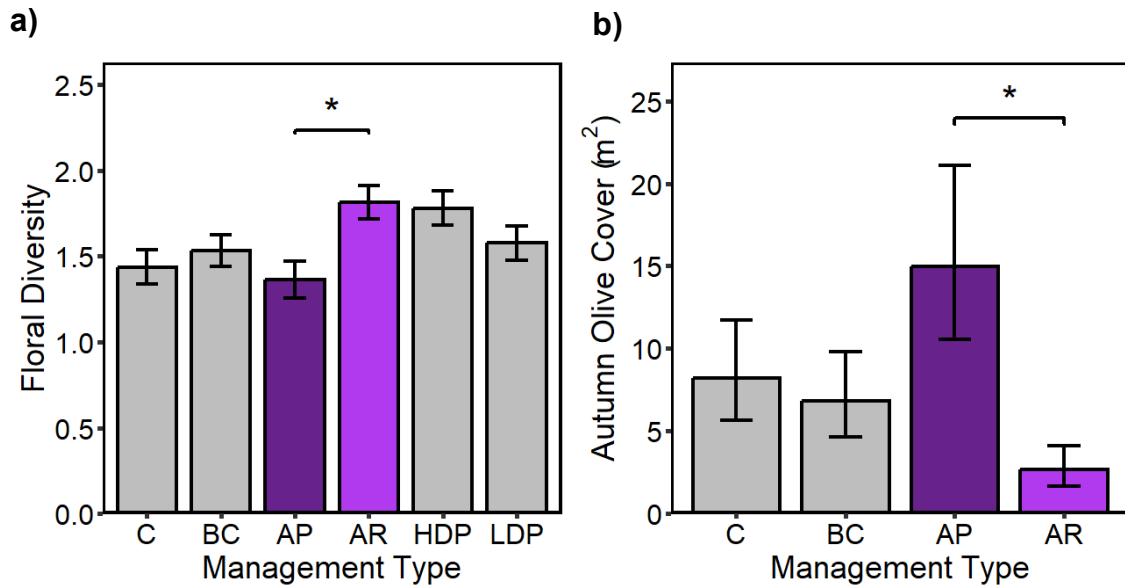


Figure 3.3. Summary of key restoration management treatments for a) floral Shannon diversity and b) autumn olive cover. Graphs display estimated marginal means with ± 1 SE. Significant differences between management plots are indicated by asterisks as follows: * p value ≤ 0.05 . Treatment plots are coded as follows: C = unmanaged control, CB = burn control, AP = autumn olive present, AR = autumn olive removed, HDP = high diversity planting, and LDP = low diversity planting.

Table 3.3. ANOVA results for the bee community response to the effect of restoration management treatments and local environmental factors (i.e. autumn olive cover (m²), floral bloom cover (m²), and floral richness). Response variables were fit to negative binomial generalized linear regression models.

Model	Predictor	df	Chi²	P
Total Bee Abundance	Treatment	5	10.937	0.053
	Autumn Bloom Cover (m ²)	1	2.259	0.133
	Floral Bloom Cover (m ²)	1	11.304	0.001
	Floral Richness	1	0.405	0.525
Bumble Bee Abundance	Treatment	5	5.775	0.329
	Autumn Bloom Cover (m ²)	1	0.561	0.454
	Floral Bloom Cover (m ²)	1	8.853	0.003
	Floral Richness	1	0.686	0.407
Honey bee Abundance	Treatment	5	17.071	0.004
	Autumn Bloom Cover (m ²)	1	1.629	0.202
	Floral Bloom Cover (m ²)	1	6.255	0.012
	Floral Richness	1	0.017	0.895
Tiny/Small Abundance	Treatment	5	11.184	0.048
	Autumn Bloom Cover (m ²)	1	1.311	0.252
	Floral Bloom Cover (m ²)	1	1.073	0.300
	Floral Richness	1	8.501	0.004
Medium/Large Abundance	Treatment	5	6.335	0.275
	Autumn Bloom Cover (m ²)	1	0.250	0.617
	Floral Bloom Cover (m ²)	1	11.036	0.001
	Floral Richness	1	1.275	0.259
Green Bee Abundance	Treatment	5	6.279	0.280
	Autumn Bloom Cover (m ²)	1	0.103	0.748
	Floral Bloom Cover (m ²)	1	0.478	0.489
	Floral Richness	1	2.673	0.102

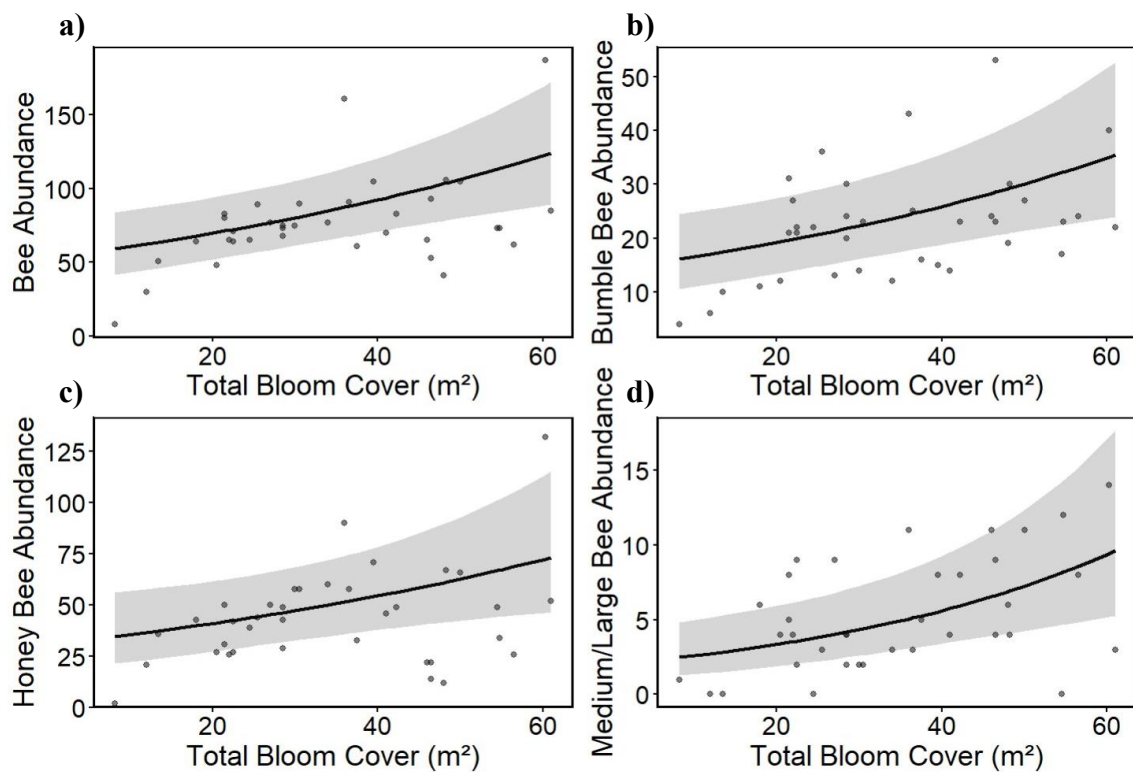


Figure 3.4. Summary of significant relationships between bloom cover and a) total bee abundance, b) bumble bee abundance, c) honey bee abundance, and d) medium/large bee abundance. Solid black lines indicate the predicted abundance derived from negative binomial generalized linear models with shaded regions displaying 95% confidence intervals. Points represent observed raw abundance.

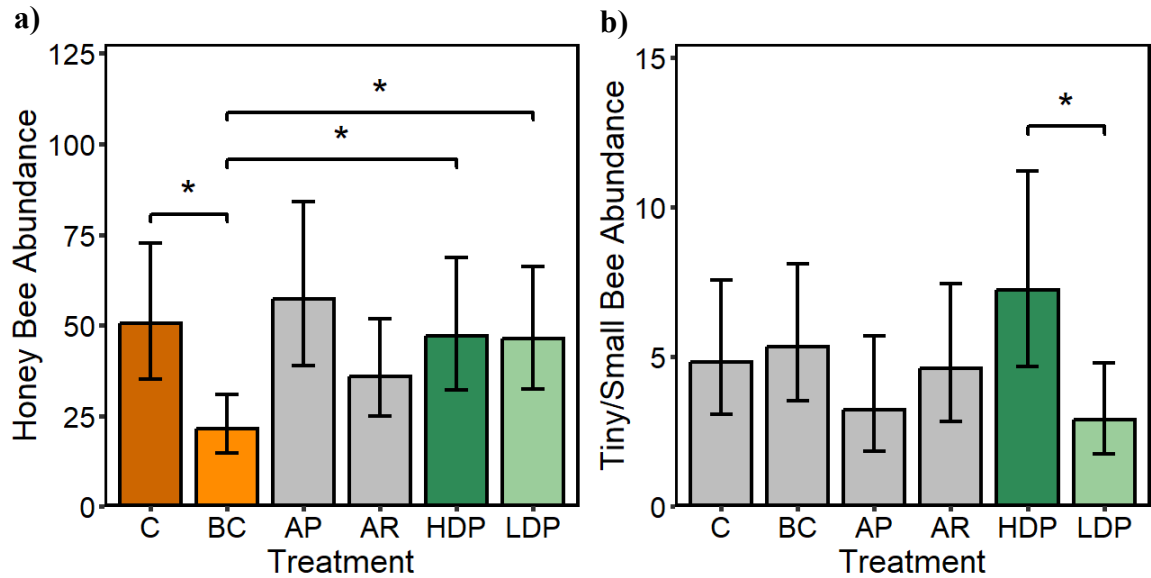


Figure 3.5. Summary of key restoration management treatments for bee morphospecies groups. Graphs display estimated marginal means for a) honey bee and b) tiny/small bee abundance with ± 1 SE. Significant differences between management plots are indicated by asterisk as follows: * $p < 0.05$. Abundance for bumble bees, medium/large bees, and green bees were not significantly different between any restoration management plots. Treatment plots are coded as follows: C = unmanaged control, BC = burn control, AP = autumn olive present, AR = autumn olive removed, HDP = high diversity planting, and LDP = low diversity planting.

CHAPTER FOUR

PLANT-POLLINATOR COMMUNITY RESPONSE TO PRESCRIBED FIRE MANAGEMENT IN VULNERABLE WETLAND AND PRAIRIE HABITATS

4.1 Introduction

Fire has historically been an important process in ecosystem functioning throughout the United States but has been suppressed in modern times (reviewed in Ryan et al., 2013). Interest in reintroducing fire to the landscape has led to increasing use of prescribed burning as a restoration management tool in fire-dependent ecosystems. Our current knowledge of prescribed fire indicates mixed effects on plant communities (e.g. McWilliams et al., 2007; Wroblewski & Kauffman, 2003; Basset et al., 2020; Brokaw et al., 2023) with time since burn, burn intensity, and seasonality influencing responses. For example, in some cases, prescribed fire can reduce invasive plant density (e.g. Emery et al., 2005); however, fire has also been shown to promote the establishment of invasive plants (e.g. Grace et al., 2000; Zouhar et al., 2008). Moreover, fire can impact soil components and plant-soil feedbacks, which may lead to changes in plant communities (Butler et al., 2018; Christensen & Muller, 1975; Henry et al., 2006; McLauchlan et al., 2020; Roberts et al., 2025).

In comparison to plants, there has been significantly less research examining how pollinators, in particular bees, respond to prescribed fire. The majority of what is known about the influence of fire on bee communities focuses on uncontrolled wildfires and is concentrated in the western United States (Mason et al., 2021). Unlike wildfires, prescribed fires notably burn at lower intensity (DeBano et al., 1998) and are often

applied in smaller patches. The intensity of these burns can often be dependent on fuel availability and soil moisture making the habitat type in which this management tool is applied another possibly important factor. In tall grass prairie systems, burns of this nature can increase open ground cover by reducing leaf litter which may benefit ground-nesting bees, which have shown to be more abundant in recently burned habitats (Brokaw et al., 2023; Decker & Harmon-Threatt, 2019). Changes to floral resource availability following prescribed burns are also likely to influence the bee community.

In addition to impacting both the plant and bee communities separately, prescribed burns can impact plant-pollinator interaction networks (Welti & Joern, 2018). Understanding these effects is particularly important in the context of flower-bee interaction networks, which are essential for the success of grassland ecosystems (Fantinato et al., 2016; Jakobsson & Ågren, 2014). Specific metrics, such as nestedness, evenness, network diversity, linkage density, and specialization can be measured to describe the stability of species and robustness of the network (Blüthgen et al., 2006, 2007, 2008; Dupont & Olesen, 2012; Fortuna & Bascompte, 2006; Joppa et al., 2010; Thébault & Fontaine, 2010). Given the mixed effects of fire and the paucity of studies examining prescribed fire effects on bee communities, more research is needed to fill knowledge gaps (Williams et al., 2010; Winfree et al., 2009).

In this study, we examined the overarching question: how does prescribed fire and habitat context influence plant and bee communities and their interactions? We hypothesized that due to variation in both plant and soil attributes, prescribed fire will have differing effects on the plant and bee community depending on habitat type. We

predicted that prescribed fires would reduce invasive floral species and increase native floral species in terms of richness and bloom cover and that this effect would be greatest in restored prairies where fires would be more intense. Moreover, we hypothesized that the response of the bee community to prescribed fire would be mediated by bee functional traits. We predicted that cavity and stem-nesting bees would have reduced abundances following prescribed burning due to their nesting substrates (i.e. plant stems, fallen logs, etc.) being directly disturbed by fire. We expected ground-nesting bee abundance would remain stable following prescribed fire application as their nesting locations are protected from direct disturbance above ground. Moreover, we expected that specialist bees, whose host plants could be impacted by fire, might be more sensitive to this management practice than generalist bees. Finally, we hypothesized that prescribed fire management would alter flower-bee interaction networks via modifications to the plant and bee community.

4.2 Methods

To address these research questions and hypotheses, we conducted field surveys in June-September 2022 across 14 sites and June-August 2023 across 10 sites located in the Tri-County Detroit metropolitan area in Michigan (**Figure 4.1**). Six sites were remnant wetland habitats, namely southern wet meadows and prairie fens (Kost et al., 2007), which are considered vulnerable habitats in our study area. Eight sites were restored prairie habitats, which were previously old fields or otherwise degraded prairies. All sites were characterized by a grass-dominated plant community with diverse forb species and minimal woody vegetation. We selected paired recently burned and non-

recently burned habitats at each site to survey flowering plants and bees. Paired sites varied in distance between one another. Half of the recently burned sites received prescribed fire applications in 2021, and the other half were burned in 2022. Paired non-recently burned areas varied in time since last burn with some sites having never received a prescribed burn, but no area had received a prescribed burn after 2016. During year two of the study, surveys were completed at 10 sites – five remnant wetlands and five restored prairies. These surveys allowed us to assess plant and bee responses to prescribed fire after the second and third-year post-fire. Four of the original sites received additional fire management after the first survey year and thus were excluded from the second year of our project.

4.2.1 Plant and Bee Surveys

Surveys were completed along two 60 m transects at each burned and unburned patch within a site. We haphazardly positioned transects across the patch to best sample representative floral resources. One surveyor walked along each transect actively netting bees for 30 minutes staying within 20m on each side of the transect. During this period, bees were collected only when they were observed visiting the reproductive structure of a flower. Bees that were observed perching on branches or landing on leaves were not collected or recorded. Timers were stopped every time a bee was caught to ensure equal time spent actively surveying transects. Bumble bees were collected, chilled, photographed for identification, and then released. Honey bees and Eastern Carpenter bees were recorded but not collected. Floral visits for all collected and observed bees

were recorded. Collected bees were transported to the lab where they were stored in a freezer until later pinned. Each transect was surveyed three times per site per year.

All flowering plants in bloom were identified to species-level when possible or photographed for later identification. When a plant was unable to be identified to species-level with confidence or two or more species were difficult to distinguish due to hybridization or overlap in taxonomic features, species were grouped into a complex or recorded to genus-level. For example, *Solidago altissima* and *S. canadensis* are known to hybridize, share similar traits, and in some cases can be difficult to distinguish – thus, these species were grouped together. The abundance of each plant species was estimated using the DAFOR scale across each patch, which included both transects. Total bloom cover was calculated based on the percent cover estimate associated with each category in the DAFOR scale (D-Dominant 75%, A-Abundant 50%, F-Frequent 17.5%, O-Occasional 7.5%, R-Rare <5%).

Once active bee surveys were complete, three bee bowls were placed along each transect for a total of six bee bowls per burned or unburned area (N=6). Each bee bowl included blue, white, and yellow cups and were filled with soapy water. Bowls were placed at varying heights depending on the surrounding vegetation and collected after 24-72 hours depending on weather. Trapped bees were collected in whirl packs with 70% alcohol. Bees were stored in the freezer until processed and pinned for later identification. All collected bees were identified to species-level or the highest taxonomic level possible by taxonomic experts (Dr. Robert Jean, Environmental Solution and Innovations Inc.). We assigned bee species functional traits, including nesting strategy,

diet breadth, and sociality. Bees collected via bee bowls were only used for abundance and diversity analyses and were not included in network analyses due to lack of floral visitation information.

4.2.2 Statistical analysis

Statistical analyses were performed in R version 4.4.3 (R Core Team, 2025). Plant and bee diversity metrics were calculated using the *vegan* package (Oksanen et al., 2022). We examined the response of the plant and bee community to prescribed burning at two levels. We characterized prescribed burns based on burn recency in terms of non-recently burned (five or more years prior) and recently burned (burned in the same year or up to two years prior). To further examine the effects of time following prescribed fire application, we also binned prescribed burns into three time since burn categories which included 0.5-2 years post burn, 5-8 years post burn, and 9-12 years post burn. Separate linear mixed-effects models were created for each habitat type in the *lme4* package (Bates et al., 2015) to assess the influence of time since burn category on plant and pollinator communities. Time since burn category and survey year were included as fixed effects with bloom cover, proportion of native bloom cover, total native bloom cover, total floral richness, native floral richness, introduced floral richness, bee species richness, and Shannon bee diversity as response variables. Plot was included as a random effect in each model.

Due to repeated overdispersion of count response variables, negative binomial generalized linear mixed-effects models were created using the package *glmmTMB* (Brooks et al., 2017). These models were used to assess the effects of time since burn

category and survey year on total bee abundance and the abundance of bee functional groups (i.e. sociality, diet breadth, and nesting strategy). In the case of these models, residuals diagnostics were examined with the DHARMA package (Hartig, 2024). All models included site as a random effect. To evaluate the significance of predictors in linear mixed models, we performed an Analysis of Variance (ANOVA) with Type II F tests and Kenward-Roger (df) in the car package (Fox & Weisberg, 2019). For generalized models, we conducted Wald tests using the same package. When necessary, Tukey adjusted pairwise contrasts were performed using estimated marginal means within the emmeans package (Lenth, 2025).

We further evaluated differences in plant and bee communities between burn recency and habitat type using non-metric multidimensional scaling analysis (NMDS). First, we calculated Bray-Curtis dissimilarity matrices use the vegdist function in the vegan package followed by a PERMANOVA (adonis) to examine differences in community composition by burn recency, habitat type, and their interaction (i.e. burn recency * habitat type) and SIMPER to highlight significant species driving community differences. NMDS ordination was performed using the metaMDS function (also using Bray-Curtis dissimilarities) to visualize community composition and calculate significant species vectors within the ordination. This function automatically standardizes data using a Wisconsin double standardization and then a square root transformation to reduce the influence of dominant species.

All flower-bee network metrics including nestedness (Weighted NODF), evenness, linkage density, modularity (ModularityQ), and specialization (H^2) were

calculated using the Bipartite package (Dormann et al., 2009; Oksanen et al., 2022).

Weighted NODF was used to account for the presence and absence of species as well as the frequency of their interactions (Almeida-Neto & Ulrich et al, 2011). Networks were built and visualized using the igraph package (Csardi & Nepusz, 2006).

4.3 Results

4.3.1 Plant and Bee Surveys

Across sites and years, approximately 227 floral species, including 156 native and 71 introduced species were recorded. The three most documented flowers across sites were *Erigeron strigosus* (Prairie Fleabane), *Monarda fistulosa* (Bee Balm), and *Daucus carota* (Queen Anne's Lace). The three most abundant native species across sites included *Eutrochium maculatum* (Joe-Pye Weed), *M. fistulosa*, and *E. strigosus*. The top three introduced species across sites were *Centaurea stoebe* (Spotted Knapweed), *Lythrum salicaria* (Purple Loosestrife), and *D. carota*. In total, we recorded 10000 flower-bee interactions, with 5133 interactions occurring in burned and 5995 in unburned areas. The most visited flowers were among the most abundant, including native species *E. maculatum* and *M. fistulosa* followed by two introduced species, *C. stoebe* and *L. salicaria*. Bees in the genus *Bombus* were the most observed floral visitors, with almost 4,000 visits making up 35% of total bee visits, followed by *Apis mellifera* (Honey Bee) with ~2500 floral visits or 21% of total visits.

Across sites and years, we documented approximately 173 bee species representing 31 genera across seven families. Dominant genera representing smaller-bodied bees included *Lasioglossum*, *Ceratina*, and *Halictus*. Through active netting of

foraging bees, we collected 2773 individuals representing 143 species and an additional 6435 observed *Bombus*, *A. mellifera*, and *Xylocopa virginica* (Eastern Carpenter Bee). Through passive sampling via bee bowls, we collected 1084 individuals representing 87 species. Active sampling resulted in 80 unique species, whereas passive sampling yielded 27 unique species. We uploaded 857 bumble bee photos to iNaturalist, representing 9 species including vulnerable Michigan species such as *B. fervidus* (Golden Northern Bumble Bee) (G3/G4; S3), *B. auricomus* (Black and Gold Bumble Bee) (G5; S2), *B. rufocinctus* (Red-belted Bumble Bee) (G5;S3), *B. citrinus* (Lemon Cuckoo Bumble Bee) (G4;S3), *B. perplexus* (Confusing Bumble Bee) (G5;S3) and members of the subgenus *pyrobombus*. Other notable species documented in this study included *Macropis ciliata* (Fringed Loosestrife Oil-collecting Bee), a rare specialist of *Lysimachia*, *Dufourea monardae* (Beebalm Sweat Bee), an uncommon *Monarda* specialist, *Pseudopanurgus rudbeckiae* (Rudbeckia Miner Bee), an uncommon *Asteraceae* specialist, *Andrena hirticincta* (Hairy-belted Miner Bee), an uncommon *Solidago* specialist, and *Andrena asteris* (Aster Miner Bee), an uncommon *Asteraceae* specialist. Our collection also included three *Dufourea harveyi* (Cinquefoil Sweat Bee) individuals which were noted as the first physical specimens of this species seen by taxonomist Dr. Rob Jean. This is an uncommon-rare bee species and floral specialist of *Potentilla*.

4.3.2 Factors influencing variation in plant communities

We found the native plant community had the greatest response to prescribed fire application; however, this effect varied between habitat types (**Table 4.1; Figure 4.2**). In restored prairies, native floral richness, native bloom cover, and the proportion of native

bloom cover were greater following recent prescribed burns (i.e. 0.5-2 years post burn and 5-8 years post burn) than in areas that had never been burned (**Figure 4.2a,b,c**). In remnant wetlands, native floral richness and bloom cover were greatest in patches that had not received a burn in 9-12 years but were lowest in patches that had been burned 5-8 years prior (**Figure 4.2d,e**). Interestingly, the proportion of native floral bloom cover was not significantly different between any burn category in this habitat (**Figure 4.2f**).

Overall, floral species richness differed between time since burn categories with significantly fewer species in patches burned 5-8 years prior than in patches burned 0.5-2 years prior ($\chi^2 = 8.74$, $p = 0.03$) and 9-12 years prior ($\chi^2 = 11.39$, $p = 0.015$), however, this pattern was only detected in remnant wetlands (**Table 4.1**). Total bloom cover and introduced floral species richness were not impacted by prescribed fire application.

Interestingly, restored prairies hosted ~ 40% more total bloom cover and nearly three times more non-native floral species (mean = 13.4 ± 3.47 SE) than remnant wetlands (mean = 4.77 ± 3.05 SE). The opposite pattern was true for native floral species richness, with 1.3 times more species in remnant wetlands (mean = 25.9 ± 7.15 SE) than restored prairies (mean = 19.5 ± 6.36 SE).

NMDS results indicate that plant community composition varied significantly by habitat type and its interaction with burn recency ($p < 0.01$ for both effects) (**Figure 4.3a**). However, burn recency alone did not explain variation in the composition of the plant community ($p = 0.70$). The top five floral resources explained approximately 17.3% of the dissimilarity between the plant communities across habitat types which included *C. stoebe*, *E. maculatum*, *M. fistulosa*, *L. salicaria*, and *E. strigosus* ($p < 0.01$ for all species).

4.3.3 Factors influencing variation in bee communities

While we did not find an effect of prescribed fire on total bee abundance and diversity, we found that burning significantly impacted community structure between habitat types. PERMANOVA results indicate that bee community composition was best explained by habitat type ($p < 0.01$) and its interaction with burn recency ($p < 0.01$) (**Figure 4.3b**). Burn recency alone did not explain any differences in bee community structure ($p = 0.27$). The top five bee species responsible for driving differences between bee communities found in the two habitat types were *Bombus impatiens* (Common Eastern Bumble Bee), *A. mellifera*, *X. virginica*, *Lasioglossum versatum* (Experienced Sweat Bee), and *Augochlora plura* (Pure Sweat Bee). Together these species explained approximately 56% of the dissimilarity between restored prairies and remnant wetlands.

Bee community responses across habitat types were mediated in part by functional traits. Prescribed fire appeared to negatively influence aboveground-nesting bees, whose abundance was significantly lower in recently burned than non-recently burned patches (**Figure 4.4a,c**). Moreover, prescribed fire was the single best predictor of stem-nesting bee abundance across both habitat types (**Table 4.2a,b; Figure 4.4b,d; Figure C.1**). Specifically, we found twice as many stem-nesting bees in non-recently burned patches compared to recently burned patches (mean = 20.5 ± 14.4 SE; mean = 10.3 ± 8.01 SE respectively). This result was primarily shaped by bees in the genus *Ceratina*, which also had twice as many individuals recorded in non-recently burned patches compared to recently burned patches (mean = 20.2 ± 14.0 SE; mean = 10.1 ± 7.83 SE, respectively). Interestingly, wood-nesting bees in remnant wetlands had roughly

three times the number of individuals in patches burned 0.5-2 years prior ($p < 0.001$) and four times in patches burned 9-12 years prior ($p < 0.001$) than patches burned 5-8 years prior. This relationship was largely driven by bees in the genus *Augochlorella* and *Xylocopa*. Subsocial bee abundance followed a similar trend with more individuals observed in patches burned 9-12 years prior than other burn categories, however, this effect was only observed in remnant wetland habitats (**Table 4.2b**). In restored prairies, generalist bees had the greatest abundance observed in never burned patches although this effect was only nearly significant (**Table 4.2a**). Eusocial, solitary, specialist, hive-nesting, cavity-nesting, and ground-nesting bees were not significantly impacted by prescribed fire.

4.3.4 Flower-bee interaction networks

Flower-bee interaction networks in both restored prairies and remnant wetlands illustrated key differences in floral and bee communities across habitat types. Interestingly, when looking at visualized interaction networks, we see that some genera display different foraging patterns between habitats (**Figure 4.5**). For example, *Apis* shows stronger links to a few floral resources in remnant wetlands compared with more diverse and dispersed links with floral resources in restored prairies (**Figure 4.5**). Across metrics, prescribed fire was the best predictor of variation in the structure of flower-bee interaction networks, however, this effect was dependent on habitat type (**Table 4.3**). Prescribed fire application in restored prairies positively influenced network modularity compared to patches that had never been burned (**Figure 4.6a**) but appeared to negatively impact weighted NODF in patches burned 0.5-2 years prior compared to areas that had

never been burned ($F = 4.30$, $p = 0.023$). Moreover, prescribed fire application enhanced network evenness the greatest in 0.5-2 year post fire patches in this habitat (**Figure 4.6b**). However, in remnant wetlands network evenness was significantly greater in patches burned 9-12 years prior than patches that had been burned 0.5-2 years prior and 5-8 years prior. (**Figure 4.6c**). Similarly, flower-bee interaction networks in remnant wetlands experienced reduced linkage density in patches that had recently been burned 0.5-2 years and 5-8 years prior (**Figure 4.6d**). Network specialization (H^2) and nestedness were not explained by prescribed fire or survey year (**Table 4.3**).

4.4 Discussion

Our findings indicate that prescribed fire has a positive overall impact on floral resource availability for bees. The increased native bloom cover and species richness documented in patches immediately following prescribed fire application supports its use as an effective management strategy for improving habitat quality for bees. Moreover, the increased proportion of native bloom cover and subsequent reduction of introduced bloom cover in restored prairies immediately following burns appeared to persist 5-8 years post burn. This result is encouraging, especially considering our analysis uncovered restored prairies are under substantial pressure from non-native plant species. The absence of prescribed fire effects on introduced bloom cover in remnant wetlands and species richness across habitats suggests that while fire may not sufficiently reduce these invaders, it also did not appear to facilitate their invasions. These results are promising as some invasive species can benefit from the removal of competitors and leaf litter after fire (D'Antonio, 2000; Travnicek et al., 2005). Despite the high abundance of introduced

non-native plants, our results indicate that restored prairies do provide a variety of floral resources and can still support abundant, diverse bee communities. Moreover, the large number of native floral species documented in remnant wetlands suggests these habitats may persist as havens for bees, particularly specialists who rely on their native host plants (e.g. Straka & Bogusch, 2017).

While we found no effects of prescribed fire on total floral bloom cover and species richness across habitats, other studies have also shown little to no difference in the plant community as a whole following the application of prescribed fire (e.g. McWilliams et al., 2007; Novak et al., 2022). Moreover, many forb species have been documented to respond individually to prescribed burning (Novak et al., 2022; Rau et al., 2008), so it is reasonable to assume there may be additional impacts hidden at lower taxonomic levels. Further, differences in hydrology and available fuel load in remnant wetlands may make it more difficult for prescribed fires to burn hot enough to influence plants at the community level. These factors likely explain the missing effects of fire on the proportion of native floral bloom cover we documented in this habitat type despite positive results we found in restored prairies.

Prescribed fire had a generally neutral impact on the bee community overall, except in the case of aboveground-nesting bees, particularly stem-nesting bees, which were 50% less abundant in recently burned patches compared with non-recently burned patches. This effect largely appears to be driven by the negative effect of prescribed fire on bees in the genus *Ceratina*. This is likely due to the direct damage to the pithy stems in which these bees nest, resulting in the death of any overwintering individuals inside

and therefore fewer survivors that emerge in the next growing season. Moreover, smaller bodied bees have a flight range that does not typically exceed 80 meters (Greenleaf et al., 2007), making recolonization from other populations to these burned patches difficult in cases where habitat connectivity is low. The negative implications of burning on this nesting group, similarly on wood-nesting and subsocial bees, can be neutralized by leaving areas of refugia in and near these patches for these bees to more easily repopulate these areas. Bruninga-Socolar et al. (2021) found similar results, that the proportion of stem-nesting bees increased as frequency of burn decreased. Although this effect was greatest in combination with bison grazing, it also suggests that infrequent fires can allow for populations to rebound post burn and may benefit this group in the long term. Surprisingly, we did not see any influence of treatment on ground nesting bees as we might have expected as prescribed fire has been shown to promote this group in tallgrass prairies (Brokaw et al., 2023) and other habitats (Ulyshen et al., 2021). Likewise, the absence of prescribed fire effects on bee diversity was contrary to some studies that documented declines in bee diversity with time since burn (Gelles et al., 2023; Potts et al., 2003; Moylett et al., 2020).

While we did not find prescribed fire had an impact on plant and bee diversity metrics, community structure of both plants and bees was highly dependent on the interaction between burn recency and habitat type. The difference in our NMDS results are indicative of the complexity behind why these communities are assembled differently between habitat type in recently burned and non-recently burned patches. As we have seen from many of our results the impacts of prescribed burns and habitat type may be

highly context dependent and this context is likely driving plant and bee community structure. For example, plant species between more dry restored prairies versus remnant wetlands are likely habitat specific and combined with the individualized role fire may play in the recovery of such species could result in greater separation between communities. Moreover, prescribed fire is likely to impact a number of important bee species dependent variables, such as nesting availability, floral morphology and phenology, soil chemistry, etc. differently between habitat types. While we did not measure these metrics in this study specifically, it is reasonable to expect this may lead to differences in the community structure of bees.

This relationship between prescribed fire and habitat type, was evident in the impact of prescribed burns on flower-bee interaction networks. The high network modularity and evenness but low weighted NODF we observed in restored prairies following most recent burns suggests that fire can reorganize networks to have less generalist dominated interactions and more evenly compartmentalized interactions. While a decrease in overlapping specialist and generalist visits can weaken network stability in some cases, the improved evenness in restored prairies indicates these networks are still stable. However, the opposite was true for recent burns in remnant wetlands pointing to few species dominating interactions resulting in flower-bee networks at risk of experiencing dramatic change with the loss of one or a few species. Moreover, the low linkage density displayed by remnant wetlands following recent burns suggests lower functional redundancy between flower visits leaving the network vulnerable to species loss. Another study did find prescribed fire influenced different plant-pollinator

interaction network metrics (Welti & Joern, 2018) but to our knowledge this is the first study to look at the impact of this management tool specifically on flower-bee interaction networks. From our results we can conclude that flower-bee networks are generally robust to prescribed fire management in restored prairie habitats but may lead to more instable and vulnerable networks in remnant wetlands.

Overall, more research is needed to understand the combined effects of prescribed fire with other restoration management tools on plant and bee communities. Our results indicate that this management tool can have slightly negative impacts on certain bee functional groups but has minimal impacts on the bee community as a whole. However, caution should be taken to protect stem-nesting bees from negative effects. We recommend land managers leave areas of refuge adjacent to burn patches to ensure recovery of stem nesting bee populations in managed habitats. Areas with at-risk plant and bee species should be managed carefully with prescribed fire and consider species specific impacts. This is especially true in remnant wetland habitats whose flower-bee networks may be more vulnerable to disturbance. Furthermore, future studies are needed to investigate the effects of repeated burning on bees, especially aboveground nesters, to best inform safe burn intervals for bees and management practices for bee conservation.

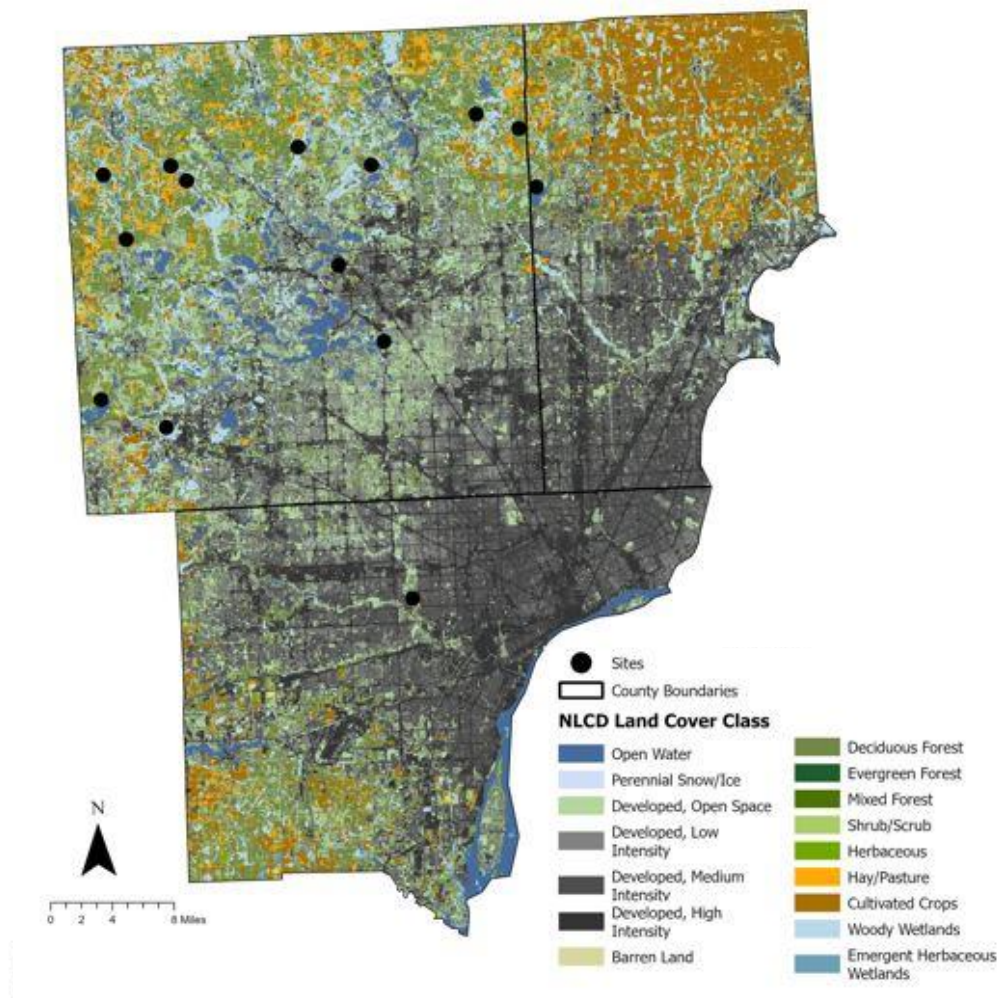


Figure 4.1. Map of study sites indicated by black circles across Tri-County region in the Detroit Metropolitan area in Michigan. Plant and pollinator surveys were completed at these 14 sites in paired burned, unburned areas. Land cover classes were determined using the National Land Cover Database 2019.

Table 4.1. Results from statistical analysis for plant community response to the effect of time since burn category and survey year. Response variables total bloom cover and proportion native bloom cover were fit to linear mixed effects models (test statistic = F) while species richness, native species richness, and introduced species richness were fit to generalized mixed effects models (test statistic = χ^2).

Habitat Type	Plant Community Response	Predictor	df	Test Statistic	P
Restored Prairie	Bloom Cover	Time Since Burn	2	0.13	0.878
		Survey Year	1	12.84	0.002
	Native Bloom Cover (proportion)	Time Since Burn	2	18.80	<0.001
		Survey Year	1	0.15	0.697
	Native Bloom Cover	Time Since Burn	2	13.61	0.001
		Survey Year	1	10.10	0.001
	Introduced Bloom Cover	Time Since Burn	2	10.56	0.005
		Survey Year	1	5.64	0.018
	Species Richness	Time Since Burn	2	5.41	0.067
		Survey Year	1	0.03	0.869
	Native Species Richness	Time Since Burn	2	15.05	<0.001
		Survey Year	1	1.64	0.201
	Introduced Species Richness	Time Since Burn	2	4.01	0.135
		Survey Year	1	2.66	0.103
Remnant Wetland	Bloom Cover	Time Since Burn	2	2.37	0.306
		Survey Year	1	4.98	0.026
	Native Bloom Cover (proportion)	Time Since Burn	2	0.23	0.892
		Survey Year	1	0.43	0.514
	Native Bloom Cover	Time Since Burn	2	11.93	0.003
		Survey Year	1	6.41	0.011
		Site	5	43.65	<0.001
	Introduced Bloom Cover	Time Since Burn	2	1.17	0.558
		Survey Year	1	0.043	0.514
	Species Richness	Time Since Burn	2	7.75	0.021
		Survey Year	1	0.34	0.560
	Native Species Richness	Time Since Burn	2	6.50	0.039
		Survey Year	1	2.05	0.153
	Introduced Species Richness	Time Since Burn	2	3.57	0.168
		Survey Year	1	1.42	0.233

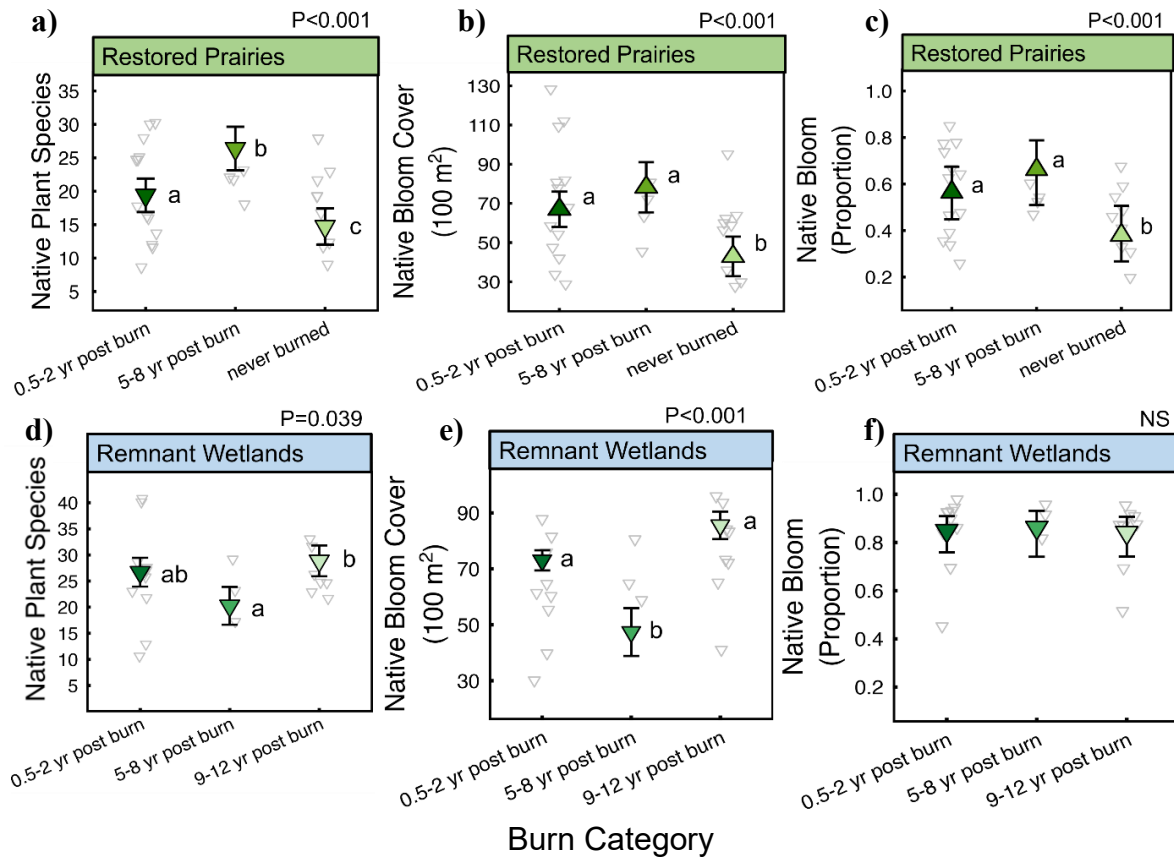


Figure 4.2. Differences in the native plant community across time since burn categories. Green triangles show estimated marginal means with ± 1 SE for a) native plant species richness, b) native bloom cover, and c) proportion of native bloom cover in restored prairies; and for d) native plant species richness, e) native bloom cover, and f) proportion of native bloom cover in remnant wetland habitats. Gray triangles display raw means. Different letters associated with time since burn categories within each panel indicate significant differences ($p < 0.05$). Separate models were used to analyze native plant metrics for each habitat type.

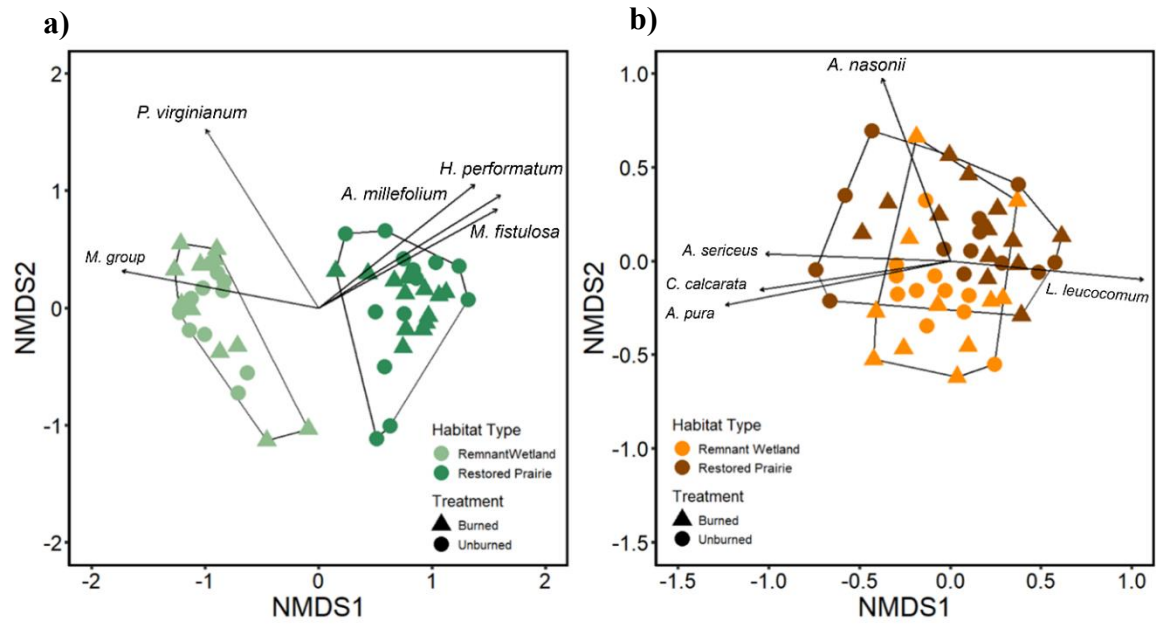


Figure 4.3. NMDS displaying a) plant and b) bee community composition across sites. Listed are the top five species significantly ($p < 0.01$) associated with ordination axes and their arrows represent the strength of this association. Both plant and bee community composition was significantly different between habitat types ($p < 0.01$; $p < 0.01$) and the interaction of habitat and burn recency ($p < 0.01$; $p < 0.01$). *M. group* is short for the combined plant grouping of *Mentha arvensis* and *Mentha canadensis*.

Table 4.2. Results from statistical analysis for bee community response to the effect of time since burn category and survey year between a) restored prairie and b) remnant wetland habitats. Species richness and Shannon diversity were fit to linear mixed effects models. Total bee abundance and all bee functional group response variables were fit to negative binomial generalized mixed effects models. *The aboveground-nesting group is comprised of stem, cavity, and wood-nesting bees combined.

a) Restored Prairie				b) Remnant Wetland			
Response	Predictor	df	P	Response	Predictor	df	P
Bee Abundance	Time Since Burn	2	0.330	Bee Abundance	Time Since Burn	2	0.395
	Survey Year	1	<0.001		Survey Year	1	0.010
Species Richness	Time Since Burn	2	0.415	Species Richness	Time Since Burn	2	0.488
	Survey Year	1	0.619		Survey Year	1	0.665
Shannon Diversity	Time Since Burn	2	0.071	Shannon Diversity	Time Since Burn	2	0.496
	Survey Year	1	0.002		Survey Year	1	0.588
Eusocial	Time Since Burn	2	0.127	Eusocial	Time Since Burn	2	0.719
	Survey Year	1	<0.001		Survey Year	1	0.021
Solitary	Time Since Burn	2	0.154	Solitary	Time Since Burn	2	0.932
	Survey Year	1	0.550		Survey Year	1	0.364
SubSocial	Time Since Burn	2	0.088	SubSocial	Time Since Burn	2	<0.001
	Survey Year	1	0.650		Survey Year	1	0.006
Generalist	Time Since Burn	2	0.054	Generalist	Time Since Burn	2	0.378
	Survey Year	1	<0.001		Survey Year	1	0.009
Specialist	Time Since Burn	2	0.137	Specialist	Time Since Burn	2	0.493
	Survey Year	1	0.470		Survey Year	1	0.797
Cavity-Nesting	Time Since Burn	2	0.479	Cavity-nesting	Time Since Burn	2	0.666
	Survey Year	1	0.662		Survey Year	1	0.108
Ground-nesting	Time Since Burn	2	0.274	Ground-nesting	Time Since Burn	2	0.422
	Survey Year	1	<0.001		Survey Year	1	0.001
Stem-nesting	Time Since Burn	2	0.027	Stem-nesting	Time Since Burn	2	<0.001
	Survey Year	1	0.539		Survey Year	1	0.253
Wood-nesting	Time Since Burn	2	0.856	Wood-nesting	Time Since Burn	2	<0.001
	Survey Year	1	0.276		Survey Year	1	<0.001
Aboveground-nesting*	Time Since Burn	2	0.022	Aboveground-nesting*	Time Since Burn	2	<0.001
	Survey Year	1	0.251		Survey Year	1	<0.001

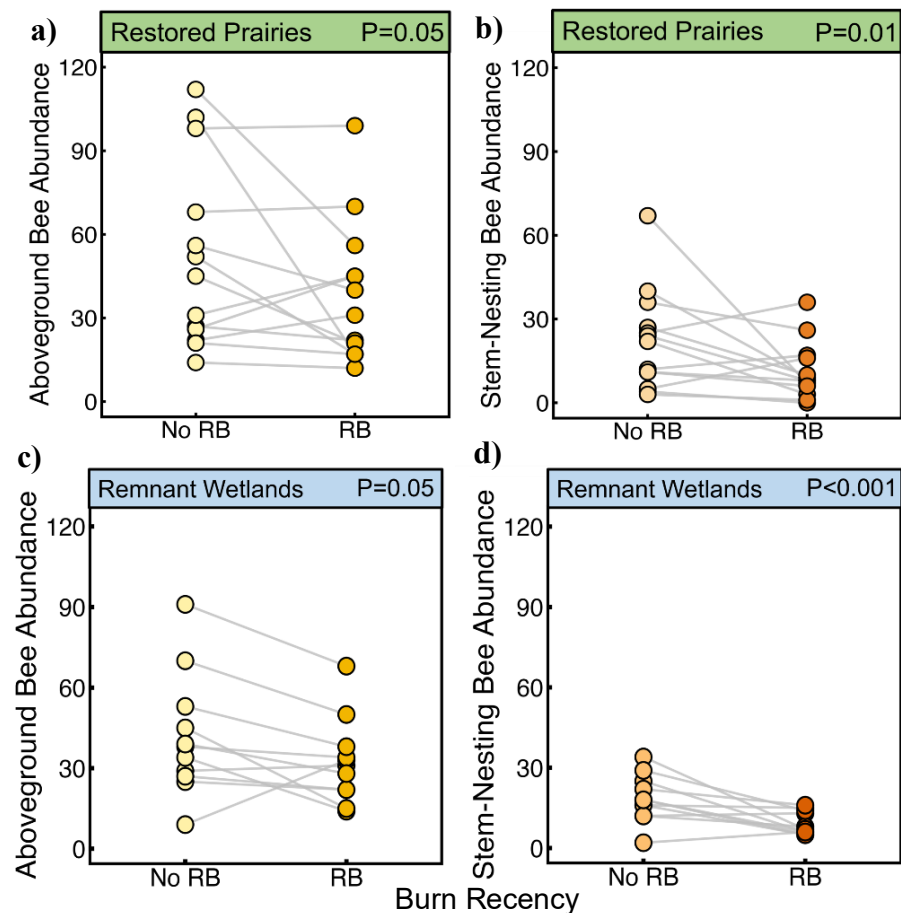


Figure 4.4. Differences in abundance between non-recently burned (No RB) and recently burned (RB) areas for a) aboveground-nesting bees and b) stem-nesting bees in restored prairies; and for c) aboveground-nesting bees and d) stem-nesting bees in remnant wetland habitats. Colored circles indicate observed abundance of stem nesting bees and are connected to corresponding paired patch by gray lines. The slope of each line indicates the direction of the relationship. Separate models were used to analyze bee abundance for each habitat type.

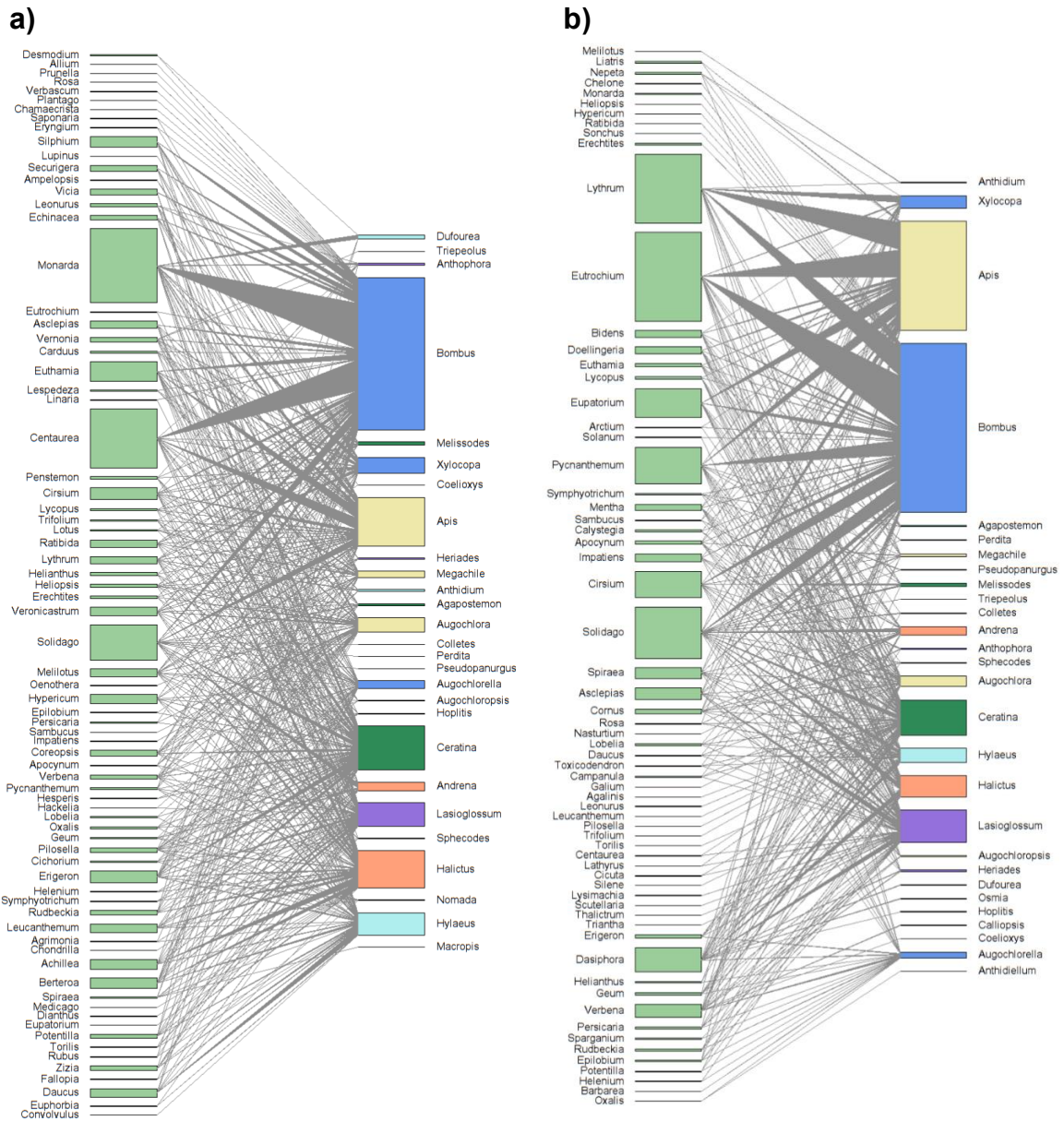


Figure 4.5. Visualized flower-bee networks representing bee visitations in a) restored prairie and b) remnant wetland habitats. Green boxes on the left indicate floral genera and colored boxes on the right indicate bee genera. Box widths represent interaction totals (i.e. total visits each plant received and each bee made). Gray lines link bee genera to their associated floral resource, with line thickness corresponding to the number of interactions (i.e. wider links represent more visitations).

Table 4.3. Results from statistical analysis on the effect of time since burn category and survey year on flower-bee interaction network metrics. Response variables were fit to linear mixed effects models. Separate models were created for each habitat type.

Habitat Type	Network Response	Predictor	<i>df</i>	<i>F</i>	P
Restored Prairie	ModularityQ	Time Since Burn	2	10.71	0.001
		Survey Year	1	8.08	0.009
	Weighted NODF	Time Since Burn	2	4.54	0.026
		Survey Year	1	0.09	0.770
	Linkage Density	Time Since Burn	2	0.69	0.515
		Survey Year	1	9.05	0.007
	Evenness	Time Since Burn	2	4.28	0.029
		Survey Year	1	20.27	<0.001
	Specialization (H ²)	Time Since Burn	2	1.56	0.232
		Survey Year	1	0.45	0.510
	Nestedness	Time Since Burn	2	1.56	0.238
		Survey Year	1	0.05	0.829
Remnant Wetland	ModularityQ	Time Since Burn	2	2.13	0.345
		Survey Year	1	0.12	0.731
	Weighted NODF	Time Since Burn	2	0.19	0.907
		Survey Year	1	0.004	0.953
	Linkage Density	Time Since Burn	2	8.29	0.016
		Survey Year	1	0.01	0.910
	Evenness	Time Since Burn	2	8.10	0.017
		Survey Year	1	0.33	0.567
	Specialization (H ²)	Time Since Burn	2	3.55	0.169
		Survey Year	1	0.00	0.991
	Nestedness	Time Since Burn	2	3.11	0.211
		Survey Year	1	0.02	0.887

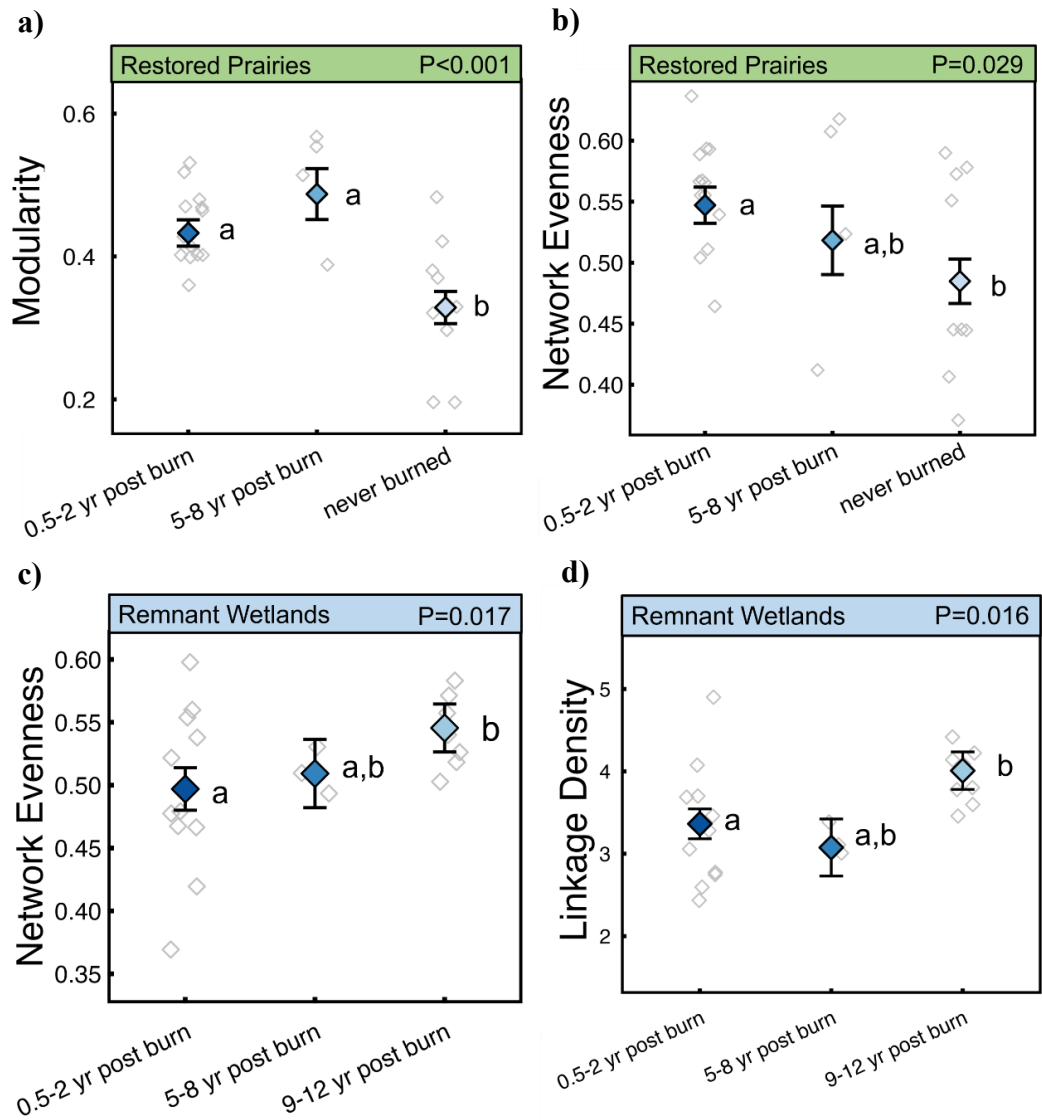


Figure 4.6. Differences in flower-bee network metrics across time since burn categories. Blue triangles indicate estimated marginal means with ± 1 SE for a) modularity (modularity Q) and b) evenness in restored prairies; and for c) evenness and d) linkage density in remnant wetlands across time since burn categories. Gray triangles show raw means for all network metrics. Different letters associated with time since burn categories within each panel indicate significant differences ($p < 0.05$). Separate models were used to analyze network metrics for each habitat type.

CHAPTER FIVE

INVESTIGATING FACTORS INFLUENCING BUMBLE BEE PARASITISM: THE ROLE OF ENVIRONMENTAL ATTRIBUTES

5.1 Introduction

Bumble bees (*Bombus spp.*) provide critical agricultural and ecosystem services across the globe. Through their unique ability to “buzz” pollinate they are essential pollinators of blueberries, tomatoes, tree fruits, and other crops (Shipp et al., 1994; Strange, 2015; Stubbs & Drummond, 2001). In the United States and Canada, several bumble bee species are imperiled, with population reductions of up to 96% (Cameron et al., 2011). Of the 57 *Bombus* species that reside in North America, 20 are currently considered vulnerable, threatened, or endangered (IUCN, 2022). This decline is thought to be caused by a combination of stressors, such as habitat loss, pesticide exposure, and climate change (Cameron & Sadd, 2020; Goulson et al., 2015). Parasites and pathogens are also considered to be a leading threat, especially for vulnerable bumble bees, with evidence that these species have higher infection prevalence (Cameron & Sadd, 2020; Cameron et al., 2016).

Bumble bees are susceptible to a variety of parasites ranging in size and virulence (Chen et al., 2025; Meeus et al., 2011). One relatively common and deadly endoparasitoid, the conopid fly (*Conopidae, Diptera*), directly parasitizes host bumble bees by laying eggs within their abdomen, thus killing their host at pupation (Schmid-Hempel & Durrer, 1991). Species in this family have been shown to infect bumble bees, honey bees, and other solitary bee species (Gibson et al., 2016; Parsons, 1948). Additional parasites, such

as the protozoan *Crithidia bombi* and microsporidian *Varimorpha bombi*, (also referred to as *Nosema bombi*) have been shown to decrease worker foraging rates, reduce the success of colony establishment, and increase worker mortality (Brown et al., 2000; Cameron et al., 2020; Gegear et al., 2006; Meeus et al., 2011).

Many environmental factors contribute to increased infection risks among bumble bees. Microbial pathogenic invaders, such as *C. bombi* and *V. bombi*, are transmitted via fecal deposits from infected individuals on shared floral resources (Adler et al., 2018; Drurrer et al., 1994; Graystock et al., 2015). Transmission of pathogens has been shown to be mediated by floral traits (McArt et al., 2014); for example, plants with larger, wider inflorescence can increase transmission potential compared to other floral shapes, such as tubular flowers (Bodden et al., 2019; Figueroa et al., 2019; Pinilla-Gallego et al., 2022). Furthermore, the loss of diverse floral resources for bee nutrition due to habitat degradation is likely to have cascading effects on parasite transmission as different floral diets have been shown to influence pathogen infections in various ways (e.g. Brunner et al., 2014; Giacomini et al., 2018; LoCascio et al., 2019; Manson et al., 2010). Moreover, the surrounding landscape composition and proximity to commercial bumble bee colonies are also key factors that influence parasitic infections in wild bumble bees (McNeil et al., 2020; Murray et al., 2013; Piot et al., 2019). Managed commercial bumble bee colonies are thought to be largely responsible for horizontal transmission of pathogens to wild species (Colla et al., 2006; Graystock et al., 2014; Koch et al., 2017; Murray et al., 2013). Unfortunately, there are currently no regulations on monitoring

colony health once commercial colonies have left manufacturing facilities (Strange et al., 2021).

Our research aimed to characterize the prevalence of two common bumble bee parasites, the conopid fly and *C. bombi*, in Southeast Michigan. Recent surveys for this state in particular report declines for nearly half of its ~20 *Bombus* species, including the presumable extirpation of *B. affinis* from the state (Rowe et al., 2019; Wood et al., 2019). In this study, we investigated the influence of local and landscape scale environmental attributes on bumble bee parasitism by conopid flies and *C. bombi*. Specifically, we examined the following explanatory factors: individual traits, including bumble bee species and size; local environmental attributes, including habitat type, floral richness, bloom cover, and host density; and surrounding landcover characteristics, including percent forest cover and a natural to urban gradient.

We hypothesized that prevalence of conopid flies and *C. bombi* infections in bumble bees would be density dependent, with higher levels of infection associated with greater floral bloom cover and bumble bee abundance. We predicted that increased availability of floral resources would attract more hosts, as bumble bees have been shown to prefer dense floral patches (e.g. Barley et al., 2022), therefore increasing transmission potential between infected floral resources. Moreover, we predict an influx of hosts and nutritional resources provided by greater floral bloom cover will attract more adult conopid flies to these areas resulting in increased endoparasitoid infections. Additionally, we hypothesized that prevalence of both parasites would differ between habitat types as a result of differences in floral resource availability and host density. We predicted that

restored prairie habitats would display greater infection prevalence compared to remnant wetlands as these drier soils would provide increased nesting opportunities and subsequently more bumble bee hosts. Finally, we hypothesized these effects would be mediated by the surrounding landscape context. We predicted that habitats with greater surrounding open natural cover (i.e. grassland and wetland cover) would reduce parasitic infection as these areas provide connectivity between resources and thus less aggregation among shared floral patches. We expected the opposite to be true for increasing urbanization as less connectivity between floral patches would result in greater aggregation among shared floral resources and subsequent attraction of adult conopid flies to these areas.

5.2 Methods

5.2.1 Plant and Bumble bee community surveys

To assess parasitic infections across Southeast Michigan, bumble bee community surveys occurred at 12 sites spanning an urban-rural gradient. Within each site, 120 m transects were established in two patches. It should be noted that due to site size, one of our sites was comprised of only one patch. All flowering plant species within each patch were inventoried to species level or left to the next highest taxonomic group. In cases where two or more floral species are known to hybridize or they cannot be confidently differentiated in the field, these species were combined into one group. For example, *Solidago altissima* and *Solidago canadensis* were combined into their own group *Solidago altissima/canadensis*. Each species then had their bloom cover estimated and totaled across patches.

Bumble bee community surveys were conducted across each transect for 30 minutes for a combined total of one hour. All bumble bees were captured, photographed, and then released unless kept for parasite screening. Each individual's associated floral visit was also recorded. Due to competition between bumble bees and honey bees, we also recorded honey bees and their floral visits. It should be noted that two restored prairie sites, Lyon Oaks County Park and Oakland University's Biological Preserve, did not receive bumble bee community surveys.

5.2.2 Bumble bee collections

Bumble bee collections for parasite screening occurred during and after community surveys between July 18th and August 1st, 2023. Collections included *B. impatiens* and *B. griseocollis* workers as these species are common in our study area and represent two different subgenera. *B. impatiens*' status as a widely used commercial species also makes it an important target species as it is likely a source of pathogen transmission to imperiled bumble bees. We collected ~15-20 workers from both species and recorded their floral visit when applicable. Individuals were transported in coolers and stored in -80° freezers.

5.2.3 Bee dissections and parasite screening

First, the forewing of each bumble bee was removed, and the radial cell was measured using ImageJ as a proxy for body size (Schneider et al., 2012). The average of three measurements was used for a final value. Following removal of the wings, each bee was washed in a series of ethanol baths to remove any possible environmental contaminants. Once washed, each bee's abdomen was removed and dissected. Upon

opening the abdomen each bee received a presence (1) or absence (0) score for conopid fly larvae. After, the fore and hind gut of each bee was removed and homogenized in 250 μ L of TBS in a 1.5 mL microcentrifuge tube. A random subset of four bees per species per site (n= 88) were screened for *C. bombi* via molecular detection methods derived from Tripodi et al. (2018).

5.2.4 Characterizing the surrounding landscape

We characterized the surrounding landscape at each site using the landcover classes established in the 2019 National Land Cover Database (NLCD). We created 500 m buffer zones around the centroid of each surveyed patch in ArcGIS Pro. Using a zonal histogram, we extracted the number of pixels represented by each cover class within the buffer zone. We then averaged the number of pixels across the two patches for a final site total and calculated the percent total area of each land cover type surrounding each site.

For the purpose of our study, we grouped cover classes into the following cover types: Forest (deciduous forest, evergreen forest, and mixed forest cover), Wetland (woody wetland and emergent herbaceous wetland cover), and Grassland (shrub/scrub and grassland/herbaceous cover). We assessed urbanization via impervious surface as defined by the NLCD. Due to collinearity between landcover variables we used Principal Component Analysis (PCA) to create a gradient from open-natural areas (comprised of the wetland and grassland cover types) to urban areas represented by PCA 1.

5.2.5 Statistical analysis

The effect of environmental and individual attributes on the prevalence of conopid fly and *C. bombi* infections were assessed in R version 4.4.3 (R Core Team,

2025) using piecewise structural equation modeling (SEM) in the piecewiseSEM package (Lefcheck, 2016). Models were created based on a causal framework demonstrating the relationship between all individual, local, and landscape predictors and their effects on parasite infection prevalence (**Figure 5.1**). Each piecewise SEM included separate linear regression models using floral richness, bloom cover, and bumble bee host density as response variables. For both floral richness and bloom cover we included habitat type, surrounding percent forest cover, and PCA1 (open natural to urban gradient) as predictors. For bumble bee host density, we included these predictors with the addition of bloom cover. Our core infection models examining conopid fly parasitism and *C. bombi* infection were built using generalized linear regression models with a binomial distribution. Both models included proportion infected as response variables with bumble bee size, bumble bee host density, floral richness, and bloom cover as core predictors. Additional predictors were only added to the model if they failed the test of directional separation (d-sep) indicating a missing link. This resulted in adding PCA1 as a predictor to the conopid fly parasitism model ($p < 0.01$). We assessed overall SEM fit using Fishers C test (Shipley, 2013). Due to high collinearity between bumble bee species identity and bumble bee body size, separate SEMs were run for each of these predictors. Bumble bee body size resulted in models with lower AIC values and was therefore used as the core individual trait predictor in this study.

5.3 Results

5.3.1 Bumble bee community overview

Across the 10 sites surveyed, we documented 636 bumble bees representing eight species: *Bombus bimaculatus*, *B. griseocollis*, *B. impatiens*, *B. vagans*, *B. auricomus*, *B. citrinus*, *B. fervidus*, and *B. perplexus*. The latter four species are considered vulnerable and species of conservation concern in Michigan. Bumble bee abundance varied among sites with the lowest supporting 21 individuals and the highest 121 individuals (mean = 63.6 ± 32.78 SD). Bumble bee species richness ranged between three and six species (mean = 4.4 ± 0.97 SD). For our two focal species, we recorded 76 *B. griseocollis* (mean = 7.6 ± 8.91 SD) and 407 *B. impatiens* (mean = 40.7 ± 27.84 SD) during bumble bee community surveys. Bumble bees were documented visiting flowers from 32 plant species, 17 of which were also visited by honey bees. Across sites we observed a total of 252 honey bees with individual site abundances varying between five and 50 individuals (mean = 25.2 ± 16.61 SD).

5.3.2 Infection prevalence across species and sites

We collected 396 *B. impatiens* and *B. griseocollis* individuals in total and found that 73 of these individuals were infected by conopid fly endoparasitoids. Infections were documented across all 12 sites with prevalence varying between 5% and 38% (mean = 18.1%; SE ± 0.03). On average, *B. griseocollis* had 22.4% of individuals infected across sites (n= 156) which was slightly higher than the 15.8% of *B. impatiens* individuals infected (n= 240). Both habitat types exhibited similar infection prevalence, with remnant wetlands hosting an average of 19.9% (± 5.4 SE) of infected individuals and restored prairies with slightly fewer infections at 17.2% (± 3.42 SE).

Of the subset of bumble bees assessed for *C. bombi* infection (n=88), we found a total of 31 infected individuals resulting in an average prevalence of 35.2% ($\pm$ 30.3 SE) across all sites. Two of these 12 sites contained zero infected individuals. On average across sites, *B. griseocollis* had an infection rate of 45% ($\pm$ 13.9 SE) compared to only 27.1% ($\pm$ 12.11 SE) of *B. impatiens*, however, this difference was not statistically significant. *C. bombi* infection prevalence followed a similar pattern among habitat types with remnant wetlands hosting more infected individuals (36.4% $\pm$ 9.1 SE) than restored prairies (34.1% $\pm$ 9.04 SE). Seven of these individuals across four sites were co-infected by both the parasitoid larvae and *C. bombi*.

5.3.3 Factors explaining variation in plant and bee community

Our analysis reported satisfactory global fit for both the conopid fly SEM (Fisher's C = 4.13, df = 12, p = 0.98) and *C. bombi* SEM models (Fisher's C = 9.50, df = 14, p = 0.80) (**Figure 5.2**). Directed-separation tests indicate no remaining missing links between predictors for either SEMs. Habitat type was a leading predictor of bloom cover and bumble bee density but not floral richness (**Table 5.1; Figure 5.2**). Restored prairies supported greater floral bloom cover and roughly twice as many bumble bees (mean = 86 $\pm$ 8.18) than remnant wetlands (mean = 41.2 $\pm$ 6.96) (**Figure 5.3**). Surprisingly, we did not find that bloom cover was an important predictor of bumble bee density despite their shared positive relationships with habitat type. In fact, bloom cover had a weak, though non-significant, negative relationship with bumble bee density (**Table 5.1**). Sites with increased forest cover in the surrounding landscape supported significantly more floral species and bloom cover than sites surrounded by low forest cover (**Table 5.1, Figure**

5.2). Contrary to our expectations, neither floral species richness nor bloom cover were influenced by the amount of open, natural or urban cover in the surrounding landscape.

5.3.4 Factors explaining variation in parasite prevalence

We found that individual, local, and landscape factors were important in influencing the prevalence of conopid fly and *C. bombi* infections (**Table 5.1**). Our investigation revealed that bumble bee size had a positive relationship with infection prevalence for both parasites, although its effect on conopid fly infection only neared significance (**Table 5.1, Figure 5.4a,b**). Bumble bee density was negatively associated with conopid fly infection but was unrelated to *C. bombi* infection (**Table 5.1; Figure 5.4a**). For every 10 additional bees in a given area, the odds of being infected by a conopid fly decreased by roughly 12 percent. Interestingly, floral richness was the only significant local predictor to explain infection prevalence, with greater *C. bombi* infections present in areas with increased floral richness (**Figure 5.4b**). Bloom cover and habitat type were not significant predictors in either infection model (**Table 5.1**). However, floral richness and bloom cover were significant covariates in both SEMs, with greater bloom cover correlating with increased floral richness and vice versa (**Table 5.1, Figure 5.2a,b**). Finally, we found the only landscape predictor to explain a significant amount of variation in conopid infection prevalence was the amount of surrounding open, natural and urban cover (PCA 1) (**Table 5.1**). We found that with every 1-unit increase in urban cover (or decrease in natural, open cover) in the surrounding landscape, the odds of being parasitized by a conopid fly increased by roughly 46% (**Figure 5.4a**). Neither landscape characteristic influenced the prevalence of *C. bombi* infections.

5.4 Discussion

Our analysis revealed substantial parasite prevalence in wild bumble bees sampled across southeastern Michigan. Infections from at least one of our focal parasites were present in the bumble bee community at every site in our study, suggesting similar habitats across the state may be experiencing parallel trends. Comparatively, conopid fly infections were moderately higher here than previously reported in Europe and Canada (Macfarlane & Pengelly, 1974; Otterstatter, 2004; Schmid-Hempel & Durrer, 1991) but lower than rates documented in Massachusetts (Gillespie, 2010). Likewise, *C. bombi* infections in southeast Michigan were comparable to other reports across North America but were not nearly as high as the 80% documented in some studies (Adler et al., 2018; Figueroa et al., 2019; Gillespie, 2010; Graystock et al., 2020; Malfi & Roulston, 2014). Continued bumble bee health assessments in these areas will remain imperative for early detection of future outbreaks and identification of potential drivers of infection.

Of the drivers investigated in this study, we did not find one to be all encompassing but rather found individual, local, and landscape factors worked intricately with one another to explain infection prevalence. Like much of the literature, we found bumble bee size to be an important driver of infection (e.g. Malfi & Roulston, 2014; Otterstatter, 2004). Larger bees in our study harbored higher prevalence of conopid fly parasitism as previously documented (Malfi & Roulston, 2014; Müller et al., 1996), although other studies have shown this endoparasitoid at higher rates in intermediate body sizes (Gillespie, 2010; Otterstatter, 2004). We also documented an uptick in *C. bombi* infections in larger bumble bees despite mixed results from previous studies

(Adler et al., 2018; Cohen et al., 2021; Malfi & Roulston, 2014; Van Wyk et al., 2021).

These patterns may be in part due to greater foraging potential possessed by larger bodied bees, which in turn increases the risk of encountering adult conopid flies and infected floral resources. Moreover, higher levels of foraging stress may also make larger bumble bees more susceptible to parasitism from stress-associated reduction in immunocompetency in these individuals (e.g. Deshwal & Mallon, 2014; Doums & Schmid-Hempel, 2000; König & Schmid-Hempel, 1995). Interestingly, we did not find that bumble bee species identity impacted infections from conopid endoparasitoids or *C. bombi* as has been previously reported (Gillespie, 2010).

Contrary to our predictions, we found evidence suggesting greater bumble bee density in the local environment may be causing an inverse density dependent effect as these areas had reduced conopid fly infection prevalence. One likely explanation is that the presence of abundant competent and non-competent hosts reduced conopid fly hunting efficiency and subsequently the likelihood of bumble bee hosts being captured. On the contrary, this effect may also be driven by conopid fly infections causing a reduction in bumble bee survival and subsequently abundance in areas with high prevalence (Malfi et al., 2018). These results suggest restored prairies may provide indirect benefits for bumble bees as these habitats supported significantly greater host density. Studies have found inverse density dependent effects for other pathogens (Cohen et al., 2022; Fearon et al., 2023; Ivers et al., 2022), however, we did not find this trend to be true for *C. bombi* infections in our populations. In fact, we did not find any impact of the local bumble bee community on *C. bombi* infection prevalence despite previous

findings and our expectation that greater host density would increase transmission via shared floral resources at sites (e.g. Goulson et al., 2012; Theodorou et al., 2016; Whitehorn et al., 2013).

Floral richness; however, played a significant role in promoting *C. bombi* infection, despite our expectation that diversifying shared floral visits would decrease infections. These results are likely best explained by the composition of the floral community as studies have shown various floral traits, particularly floral shape, have the ability to regulate transmission potential (e.g. Adler et al., 2020; Pinilla-Gallego et al., 2022). For example, an area comprised of a large diversity of wide, shallow flowers (i.e. crateriform, rotate, etc) is likely to have higher transmission than areas comprised of mostly tubular and campanulate flowers (Bodden et al., 2019; Figueroa et al., 2019; Pinilla-Gallego et al., 2022). While floral traits were not analyzed in this study, we noted that majority of species at florally rich sites with high infection prevalence were generally wide, shallow floral species whereas sites with low richness and prevalence had relatively even species composition in terms of shape. Moreover, components of floral nutrition, such as pollen from sunflowers (*Helianthus*) and other Asteraceae (e.g. Figueroa et al., 2023; Fowler et al., 2022; Giacomini et al., 2018), and various nectar metabolites have been shown to reduce *C. bombi* infection (Koch et al., 2019; Palmer-Young et al., 2016). Therefore, it is plausible that an underlying medicinal quality to floral resources at our sites could have influenced infection prevalence. Interestingly, we did not document any *Helianthus* species present at the time of collection at any site, although we did document other Asteraceae species at sites. Future studies should analyze floral traits and examine

community composition in terms of nutritional content when investigating local drivers of parasite infections, especially for wild bumble bees.

Florally rich sites also shared a positive relationship with percent forest cover suggesting forests indirectly mediated *C. bombi* infection prevalence. It is likely that edge effects in these transects supported greater floral richness and in turn more infected bumble bees. Interestingly, surrounding forest cover had no relationship with bumble bee density despite forests providing important nesting opportunities for bumble bees (Mola et al., 2021) and supporting higher abundances (e.g. Clake et al., 2022; Söber et al., 2020). Perhaps the most notable finding in the surrounding landscape was the increase in conopid fly infections with greater urban cover. Given the absence of links to other drivers in our study, this increase is likely best explained by some other unmeasured mechanism of exposure such as metabolic stress and other host comorbidities (Deshwal & Mallon, 2014; Ivers et al., 2022; Koch et al., 2022), or from a direct urban effect on conopid adults themselves. As expected, the presence of greater open, natural cover in the surrounding landscape reduced conopid fly infection prevalence likely by providing bumble bees with increased habitat connectivity to access enemy free patches (e.g. Becker et al., 2015). Our findings suggest that the surrounding landscape may be responsible for creating parasite hotpots, such as in heavily forested and urban areas investigated here, further supporting the need for conservation and restoration efforts to increase areas of refuge for bumble bees.

In this study we identified effects across and between three levels of factors (i.e. individual, local, and landscape) highlighting the complexity of their relationship with

parasite infection prevalence. Continued evaluation of how factors directly and indirectly influence one another is essential to comprehensively understand what drives infection in bumble bees. Land management and conservation decisions aimed at reducing pathogen infections in bumble bees should especially consider this intricacy. Moreover, identifying which habitats and surrounding landscapes may act as parasite hotspots could aid in prioritizing areas for restoration and maximizing outcomes for bumble bees. Low transmission floral species should be given precedence when creating seed mixes in such at risk areas. Future research should continue to investigate a multitude of drivers and their relationships with one another to best promote bumble bee health and create a better understanding of the web of factors that influence infections, particularly for virulent pathogens.

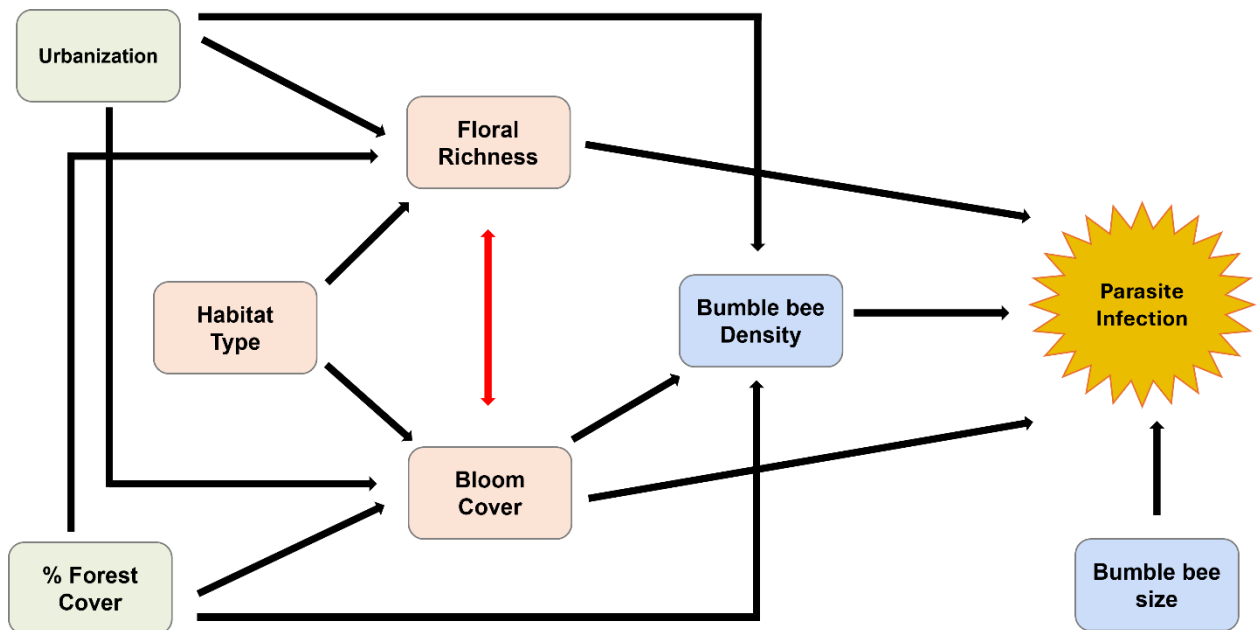


Figure 5.1. Directed Acyclic Graphs (DAG) demonstrating the theoretical relationship between variables and parasite infections that guided the models in piecewise SEM analyses. Colored boxes indicate different factor levels. The green box represents landscape factors, orange boxes represent local factors, and blue boxes represent individual factors. Arrows indicate causal relationships with no feedback loops.

Table 5.1. Standardized path coefficients from piecewise SEM analysis investigating the impact of individual, local, and landscape attributes on parasite prevalence in wild bumble bees. Estimates were not calculated for categorical variables.

Response	Predictor	Estimate	Std Error	Critical Value	Std. Estimate	P
Floral Richness	Urban Gradient	0.17	0.16	1.13	-	0.276
Floral Richness	% Forest	0.37	0.13	2.76	-	0.014
Floral Richness	Habitat Type	-	-	0.97	-	0.348
Bloom Cover	Urban Gradient	0.00	0.09	-0.01	-	0.996
Bloom Cover	%.Forest	0.21	0.08	2.69	-	0.016
Bloom Cover	Habitat Type	-	-	5.37	-	<0.001
Bumble Bee Abundance	Bloom Cover	-15.53	12.78	-1.21	-	0.243
Bumble Bee Abundance	Urban Gradient	0.25	4.65	0.05	-	0.958
Bumble Bee Abundance	% Forest	7.14	4.81	1.49	-	0.158
Bumble Bee Abundance	Habitat Type	-	-	3.42	-	0.004
Fly Parasitism	Bee Size	0.75	0.38	1.94	0.143	0.052
Fly Parasitism	Bumble Bee Abundance	-0.01	0.01	-2.40	-0.201	0.016
Fly Parasitism	Floral Richness	0.50	0.29	1.73	0.232	0.084
Fly Parasitism	Bloom Cover	-0.30	0.31	-0.96	-0.116	0.339
Fly Parasitism	Urban Gradient	0.38	0.13	2.99	0.245	0.003
<i>C. bombi</i> infection	Bee Size	1.59	0.73	2.19	0.267	0.029
<i>C. bombi</i> infection	Bumble Bee Abundance	0.00	0.01	-0.05	-0.007	0.959
<i>C. bombi</i> infection	Floral Richness	1.81	0.66	2.77	0.669	0.006
<i>C. bombi</i> infection	Bloom Cover	-0.50	0.64	-0.78	-0.156	0.435
~~Floral Richness	~~Bloom Cover	0.50	-	2.40	0.503	0.014

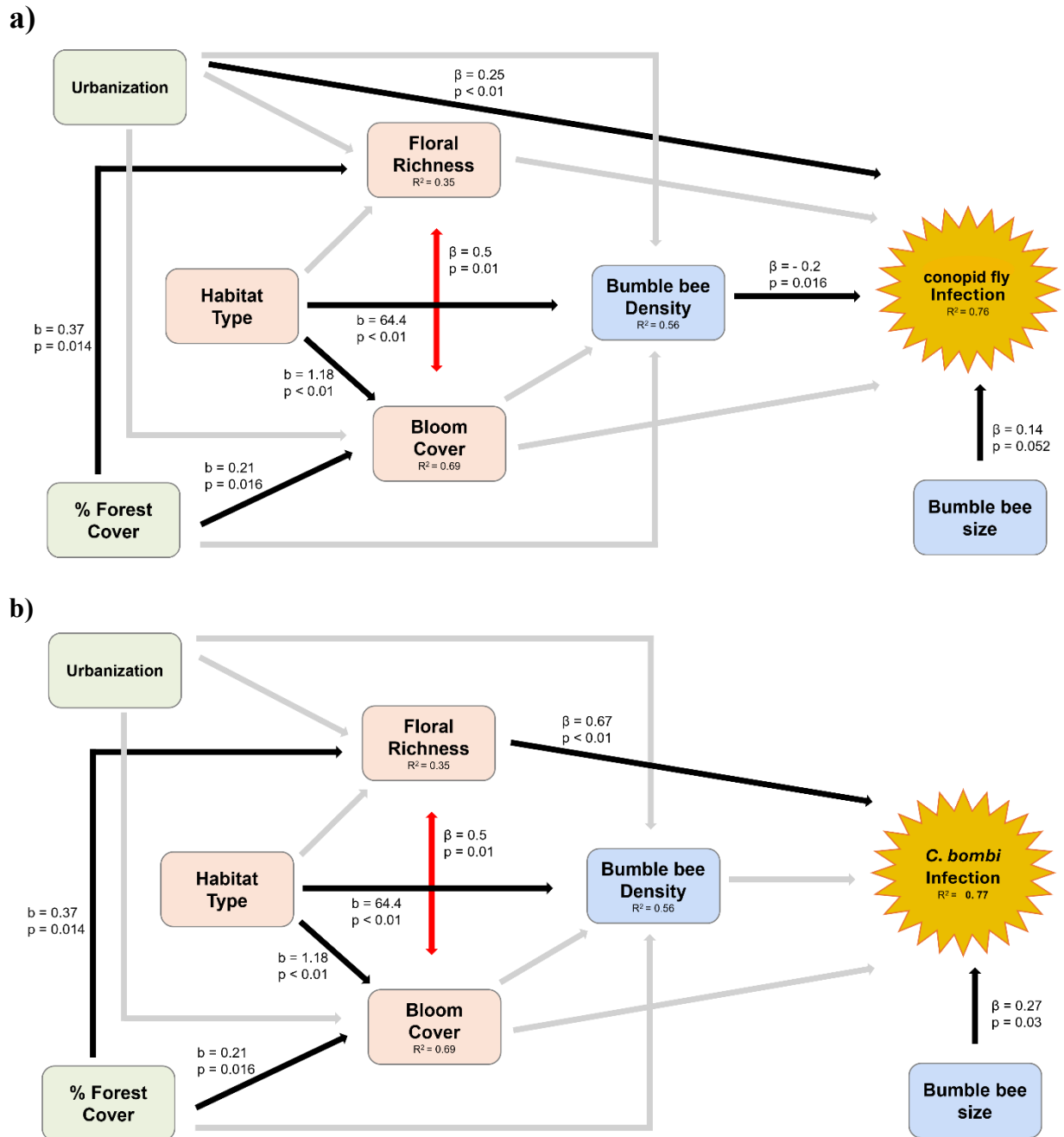


Figure 5.2. Directed Acyclic Graphs (DAG) demonstrating results from piecewise SEM analyses for a) conopid fly and b) *C. bombi* infection prevalence. Colored boxes indicate different factor levels as follows: green boxes represent landscape factors, orange boxes represent local factors, and blue boxes represent individual factors. Black arrows indicate significant causal relationships, gray arrows indicate non-significant relationships, and red arrows indicate significant covariate relationships.

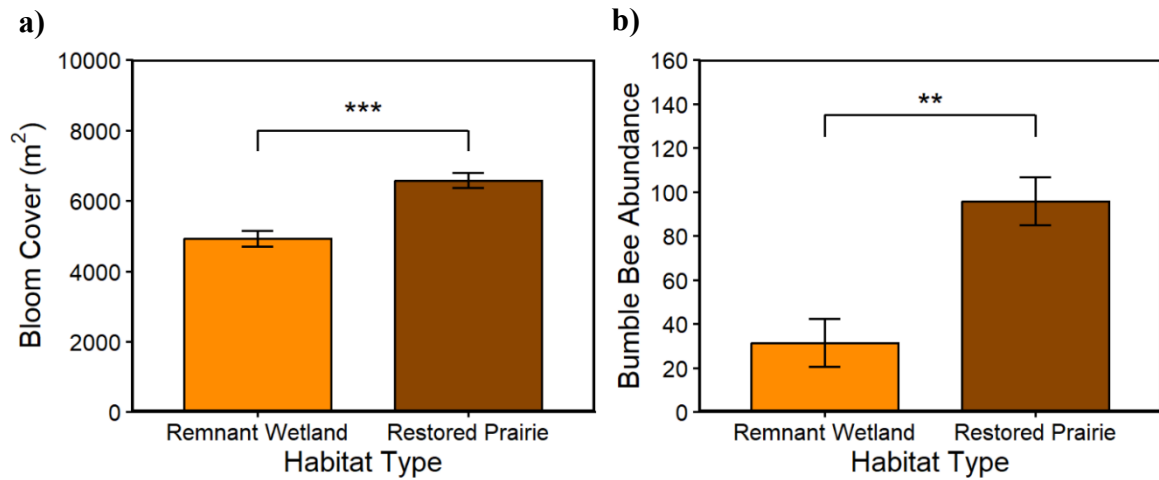


Figure 5.3. Difference between estimated marginal means with ± 1 SE of a) floral bloom cover (m²) and b) bumble bee abundance between habitat types. Asterisks indicate significant differences between habitat types as follows: ** $p < 0.01$ and *** $p < 0.001$.

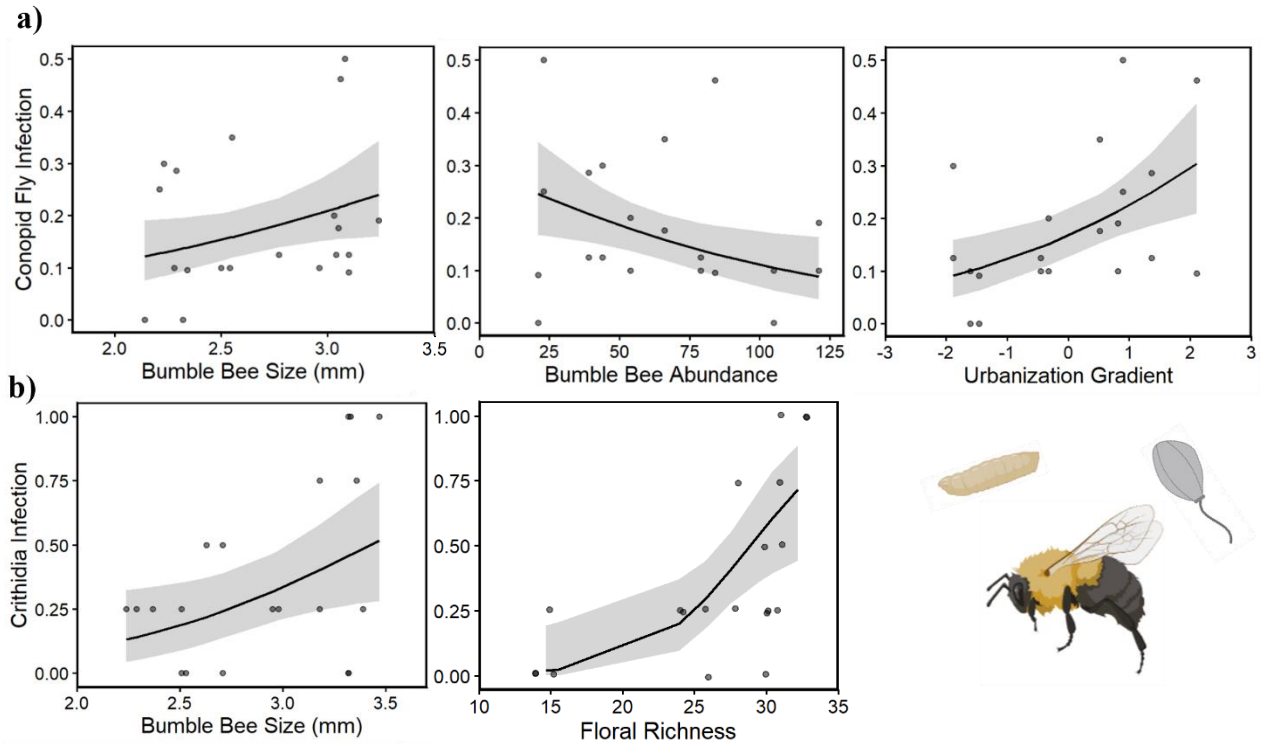


Figure 5.4. Summary of significant predictors of a) conopid fly and b) *C. bombi* infection prevalence from piecewise SEM analysis. Solid black lines indicate the predicted proportion of infection derived from the generalized linear model included in our piecewise SEM model. Shaded regions display 95% confidence intervals. Points represent raw observed infection proportions at each site. Note that these points are different between parasite types due to differences in sample size. *C. bombi* models were created using a subset of all collected bees ($n = 8$ bees per site).

CONCLUSION

Overall, this research contributes to three key areas of pollinator conservation: community engagement, restoration management, and parasite infection. The review and analysis on citizen science participation in butterfly and bee monitoring in iNaturalist allows for considerations for future citizen science projects and improved data quality and coverage for pollinator research on the platform. Increasing community engagement with pollinators not only improves our documentation of species across space and time but can provide public support for important policies. The two projects focused on restoration management inform land management agencies of the impacts of these practices on pollinators to ensure that informed restoration management decisions can be made in alignment with pollinator conservation. My final project served as one of the first documentations of parasite infection prevalence in wild bumble bees across southeastern Michigan; and helps inform researchers and land management agencies of drivers of infection. Overall, by improving monitoring and conservation practices for bees, we can will help mitigate their decline and protect the vital ecosystem services they provide for both natural and agricultural systems.

APPENDIX A
SUPPLEMENTAL MATERIAL FOR CHAPTER 2

Table A.1. Summary of iNaturalist butterfly and bee data by state for the study period (2014-2023). The total number of "research grade" bee and butterfly species observations were determined for each state in the North Central United States (data downloaded April 2024). The number of known butterfly species is based on data from the Butterflies and Moths of North America (www.butterfliesandmoths.org; Lotts and Naberhaus, 2021). *For the number of known bee species, we used best available data from various sources, including published and unpublished state checklists.

State	# iNat Butterfly Observers	# iNat Butterfly Observations	# iNat Butterfly Spp Identified	Rarefied iNat Butterfly Spp Richness	Extrapolated iNat Butterfly Spp Richness	# Known Butterfly Spp	# iNat Bee Observers	# iNat Bee Observations	# iNate Bee Spp Identified	Rarefied iNat Bee Spp Richness	Extrapolated iNat Bee Spp Richness	# Known Bee Spp*
Ohio	8,940	84,065	124	112.65	120.2	152	5,925	40,064	173	147	181	361
Illinois	7,582	67,324	123	117.24	123.35	158	4,893	34,849	183	155	194	511
Minnesota	5,344	34,346	126	122.7	130.25	163	4,000	35,881	176	154	186	502
Missouri	4,628	31,408	118	110.4	126.14	193	2,637	37,012	124	103	133	456
Michigan	5,365	26,136	137	129.9	144.22	169	3,143	14,570	162	124	240	466
96 Colorado	3,375	21,020	203	187.28	231.38	239	2,306	8,313	112	94	150	>500**
Indiana	4,352	20,625	120	110.7	127.78	154	2,537	9,865	126	99	193	414
Wisconsin	4,257	25,822	131	127.37	134.28	155	2,644	19,208	123	100	153	419
Kentucky	3,331	20,187	107	100.02	116.15	152	1,656	6,197	98	80	118	188
Iowa	1950	8,722	101	92.53	108.5	130	1,394	5,356	84	65	140	255
Kansas	1994	13,149	113	102.96	128.79	191	827	2,911	75	58	108	464
Nebraska	1459	9,913	129	119.63	137	208	758	4,163	87	70	113	456
South Dakota	768	2,918	113	99.44	131.04	184	420	1,524	34	50	123	344
North Dakota	430	1,870	93	79.51	121.56	150	265	1,457	45	51	73	369
Regional Total			308			330			383			~1050***

Table A.2. iNaturalist butterfly species observations for the North Central United States (2014-2023). In total, 308 butterfly species were identified from 'research grade' observations during the study period. Taxonomic authorities and conservation statuses were determined via NatureServe (<https://explorer.natureserve.org>; data accessed May 2024). Global conservation rankings: G5=Secure, G4=Apparently Secure, G3=Vulnerable, G2=Imperiled, G1=Critically Imperiled, SNR=Unranked

Butterfly Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Danaus plexippus</i>	50111	(Linnaeus 1758)	G4	
<i>Papilio glaucus</i>	21218	(Linnaeus 1758)	G5	
<i>Papilio polyxenes</i>	16484	Fabricius 1775	G5	
<i>Vanessa atalanta</i>	14985	(Linnaeus 1758)	G5	
<i>Epargyreus clarus</i>	14433	(Cramer 1775)	G5	
<i>Pieris rapae</i>	13453	(Linnaeus 1758)	G5/exotic	
<i>Limenitis arthemis</i>	12355	(Drury 1773)	G5	
<i>Vanessa cardui</i>	12324	(Linnaeus 1758)	G5	
<i>Phyciodes tharos</i>	11780	(Drury 1773)	G5	
<i>Junonia coenia</i>	9031	Hübner [1822]	G5	
<i>Cupido comyntas</i>	8834	(Godart [1824])	G5	
<i>Polites peckius</i>	8300	(Kirby 1837)	G5	
<i>Argynnis cybele</i>	7814	(Fabricius, 1775)	G5	
<i>Asterocampa celtis</i>	7362	(Boisduval and Leconte [1835])	G5	
<i>Papilio troilus</i>	6801	(Linnaeus 1758)	G5	
<i>Limenitis archippus</i>	6746	(Cramer 1775)	G5	
<i>Lon zabulon</i>	6443	(Boisduval and Le Conte [1837])	G5	
<i>Atalopedes huron</i>	5791	(Edwards, 1863)	SNR	
<i>Colias eurytheme</i>	5693	Boisduval 1852	G5	
<i>Polygonia comma</i>	5609	(Harris 1842)	G5	
<i>Polygonia interrogationis</i>	5435	(Fabricius 1798)	G5	
<i>Hylephila phyleus</i>	5306	(Drury 1773)	G5	
<i>Nymphalis antiopa</i>	4164	(Linnaeus 1758)	G5	
<i>Heraclides cresphontes</i>	4151	(Cramer, 1777)	G5	
<i>Euptoieta claudia</i>	3848	(Cramer 1775)	G5	
<i>Lethe anthe don</i>	3784	A. Clark 1936	G5	
<i>Battus philenor</i>	3675	(Linnaeus 1771)	G5	

Table A.2—Continued

Butterfly Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Ancyloxypha numitor</i>	3558	(Fabricius 1793)	G5	
<i>Vanessa virginiensis</i>	3550	(Drury 1773)	G5	
<i>Megisto cymela</i>	3496	(Cramer 1777)	G5	
<i>Cercyonis pegala</i>	3148	(Fabricius 1775)	G5	
<i>Celastrina neglecta</i>	3133	(Edwards 1862)	G5	
<i>Chlosyne nycteis</i>	3113	(E. Doubleday [1847])	G5	
<i>Eurytides marcellus</i>	2972	(Cramer 1777)	G5	
<i>Burnsius communis</i>	2925	(Grote 1872)	G5	
<i>Strymon melinus</i>	2729	Hübner 1818	G5	
<i>Colias philodice</i>	2319	Godart 1819	G5	
<i>Satyrrium calanus</i>	2262	(Hübner [1809])	G5	
<i>Boloria bellona</i>	2105	(Fabricius 1775)	G5	
<i>Phoebis sennae</i>	1865	(Linnaeus 1758)	G5	
<i>Lon hobomok</i>	1740	(T. Harris 1862)	G5	
<i>Libytheana carinenta</i>	1717	(Cramer 1777)	G5	
<i>Thymelicus lineola</i>	1450	(Ochsenheimer 1808)	G5/exotic	
<i>Erynnis baptisiae</i>	1449	(Forbes 1936)	G5	
<i>Asterocampa clyton</i>	1397	(Boisduval and Leconte [1835])	G5	
<i>Polites themistocles</i>	1388	(Latreille [1824])	G5	
<i>Tharsalea hyllus</i>	1332	(Cramer 1775)	G5	
<i>Anatrytone logan</i>	1279	(Edwards 1863)	G5	
<i>Euphyes vestris</i>	1259	(Boisduval 1852)	G5	
<i>Lycaena hypophlaeas</i>	1213	(Boisduval, 1852)	G5	
<i>Euphydryas phaeton</i>	1183	(Drury 1773)	G4	
<i>Pholisora catullus</i>	1176	(Fabricius 1793)	G5	
<i>Pontia protodice</i>	1162	(Boisduval and Le Conte [1830])	G5	
<i>Papilio multicaudata</i>	1134	(W. F. Kirby 1884)	G5	
<i>Nathalis iole</i>	1005	(Boisduval 1836)	G5	
<i>Nymphalis l-album</i>	979	(Esper 1781)	G5	
<i>Lethe appalachia</i>	938	R. Chermock 1947	G4	
<i>Argynnis aphrodite</i>	865	(Fabricius, 1787)	G5	

Table A.2—Continued

Butterfly Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Pyrisitia lisa</i>	851	(Boisduval and Le Conte [1830])	G5	
<i>Phyciodes cocyta</i>	820	(Cramer 1777)	G5	
<i>Coenonympha californica</i>	798	Westwood [1851]	G5	
<i>Satyrrium titus</i>	759	(Fabricius 1793)	G5	
<i>Argynnis idalia</i>	751	(Drury, 1773)	G3	
<i>Plebejus melissa</i>	732	(W. H. Edwards 1873)	G5	
<i>Vernia verna</i>	694	(W. H. Edwards 1862)	G5	
<i>Lon taxiles</i>	671	(W. H. Edwards 1881)	G5	
<i>Plebejus samuelis</i>	665	(Nabokov 1944)	G1	
<i>Papilio canadensis</i>	652	(Rothschild and Jordan 1906)	G5	Name on NatureServe (Pterourus canadensis)
<i>Calycopis cecrops</i>	649	(Fabricius 1793)	G5	
<i>Chlosyne gorgone</i>	630	(Hübner 1810)	G5	
<i>Polygonia progne</i>	596	(Cramer 1775)	G5	
<i>Lethe eurydice</i>	571	(Linnaeus 1763)	G5	
<i>Feniseca tarquinius</i>	556	(Fabricius 1793)	G5	
<i>Callophrys gryneus</i>	530	(Hübner [1819])	G5	
<i>Polites egeremet</i>	530	(Scudder 1863)	G5	Name on NatureServe (Polites egeremet)
<i>Polites mystic</i>	529	(Edwards 1863)	G5	
<i>Celastrina ladon</i>	505	(Cramer 1780)	G4	
<i>Echinargus isola</i>	500	(Reakirt [1867])	G5	
<i>Erynnis horatius</i>	472	(Scudder and Burgess 1870)	G5	
<i>Erynnis juvenalis</i>	470	(Fabricius 1793)	G5	Name on NatureServe (Argynnis edwardsii)
<i>Limenitis weidemeyerii</i>	465	(W. H. Edwards 1861)	G5	
<i>Aglaia milberti</i>	456	(Godart 1819)	G5	
<i>Glaucopsyche lygdamus</i>	449	(Doubleday 1842)	G5	
<i>Satyrrium edwardsii</i>	439	(Grote and Robinson 1867)	G4	
<i>Boloria myrina</i>	392	(Cramer, 1777)	G5	
<i>Abaeis nicippe</i>	374	(Cramer 1779)	G5	
<i>Argynnis atlantis</i>	345	([Schifferrmüller] 1775)	G5	
<i>Cyllopsis gemma</i>	343	(Hübner [1809])	G4	
<i>Anaea andria</i>	335	Scudder 1875	G4	

Table A.2—Continued

Butterfly Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Satyrium liparops</i>	333	(Le Conte 1833) (1793)	G5	
<i>Hermeuptychia sosybius</i>	318	(Fabricius 1793)	G5	
<i>Thorybes pylades</i>	317	(Scudder 1870)	G5	Name on Natureserve (Cecropterus pylades)
<i>Carterocephalus mandan</i>	314	(Pallas 1771)	G5	
<i>Tharsalea dione</i>	297	(Scudder 1868)	G5	
<i>Callophrys henrici</i>	296	(Grote and Robinson 1867)	G5	
<i>Anthocharis midea</i>	277	(Hübner [1809])	G5	
<i>Phyciodes pulchella</i>	276	(Boisduval 1852)	G5	
<i>Polygonia gracilis</i>	268	(Grote and Robinson 1867)	G5	
<i>Argynnis edwardsii</i>	267	Reakirt, 1866	G5	
<i>Satyrium caryaevorus</i>	252	(McDunnough 1942)	G4	
<i>Tharsalea helloides</i>	248	(Boisduval 1852)	G5	
<i>Celastrina lucia</i>	244	(W. Kirby 1837)	G5	
<i>Euchloe olympia</i>	238	(W. H. Edwards 1871)	G5	
<i>Ochlodes sylvanoides</i>	238	(Boisduval 1852)	G5	
<i>Poanes viator</i>	233	(Edwards 1865)	G5	
<i>Satyrium acadica</i>	232	(W.H. Edwards 1862)	G4	
<i>Dione vanillae</i>	225	(Linnaeus 1758)	G5	
<i>Leptotes marina</i>	225	(Reakirt 1868)	G5	
<i>Panoquina ocola</i>	224	(Edwards 1863)	G5	
<i>Erynnis icelus</i>	201	(Scudder and Burgess 1870)	G5	
<i>Amblyscirtes vialis</i>	198	(Edwards 1862)	G5	
<i>Hesperia leonardus</i>	198	T. Harris 1862	G4	
<i>Pieris oleracea</i>	195	(Harris 1829)	G5	
<i>Euphyes dion</i>	192	(Edwards 1879)	G5	
<i>Callophrys niphon</i>	190	(Hübner [1819]) (1793)	G5	
<i>Callophrys augustinus</i>	187	(Westwood 1852)	G5	
<i>Poanes massasoit</i>	175	(Scudder 1863)	G4	
<i>Brephidium exilis</i>	170	(Boisduval 1852)	G5	
<i>Calephelis muticum</i>	169	McAlpine 1937	G3	
<i>Thorybes lyciades</i>	168	Geyer 1832	G5	

Table A.2—Continued

Butterfly Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Chlosyne harrisii</i>	166	(Scudder 1862)	G5	
<i>Colias interior</i>	166	Scudder 1862	G5	
<i>Amblyscirtes hegon</i>	165	(Scudder 1863)	G5	
<i>Papilio rutulus</i>	162	(Lucas 1852)	G5	Name on NatureServe (<i>Pterourus rutulus</i>)
<i>Zerene cesonia</i>	146	(Stoll 1790)	G5	
<i>Pieris virginiensis</i>	144	W. H. Edwards 1870	G2	
<i>Nastra lherminier</i>	141	(Latreille [1824])	G5	
<i>Euphyes conspicua</i>	141	(Edwards 1863)	G4	
<i>Icaricia icarioides</i>	140	(Boisduval 1852)	G5	
<i>Papilio zelicaon</i>	140	Lucas 1852	G5	
<i>Cupido amyntula</i>	139	(Boisduval 1852)	G5	
<i>Polygonia faunus</i>	137	(Edwards 1862)	G5	
<i>Staphylus hayhurstii</i>	130	(W. H. Edwards 1870)	G5	
<i>Danaus gilippus</i>	129	(Cramer 1775)	G5	
<i>Piruna pirus</i>	129	(Edwards 1878)	G5	
<i>Calephelis borealis</i>	123	(Grote and Robinson 1866)	G3	
<i>Tharsalea epixanthe</i>	115	(Boisduval & Le Conte [1835])	G5	
<i>Celastrina echo</i>	113	(W.H. Edwards 1864)	G5	
<i>Atrytonopsis hianna</i>	110	(Scudder 1868)	G4	
<i>Callophrys eryphon</i>	108	(Boisduval 1852)	G5	
<i>Callophrys polios</i>	104	(Cook & Watson 1907)	G5	
<i>Euphydryas anicia</i>	100	(Doubleday [1847])	G5	
<i>Erynnis brizo</i>	98	(Boisduval and Le Conte [1837])	G5	
<i>Thorybes bathyllus</i>	95	(J. E. Smith 1797)	G5	Name on NatureServe (<i>Cecropterus bathyllus</i>)
<i>Euphilotes ancilla</i>	92	(Barnes and McDunnough 1918)	G5	
<i>Tharsalea dorcas</i>	92	(W. Kirby 1837)	G5	
<i>Tharsalea arota</i>	91	(Boisduval 1852)	G5	
<i>Erynnis funeralis</i>	89	(Scudder and Burgess 1870)	G5	
<i>Euchloe ausonides</i>	89	(Lucas 1852)	G5	
<i>Icaricia lupini</i>	89	(Boisduval 1869)	G5	
<i>Papilio eurymedon</i>	88	(Lucas 1852)	G5	Name on NatureServe (<i>Pterourus eurymedon</i>)

Table A.2—Continued

Butterfly Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Argynnis coronis</i>	87	(Behr, 1864)	G5	
<i>Cercyonis oetus</i>	87	(Boisduval 1869)	G5	
<i>Parrhasius m-album</i>	85	(Boisduval and Le Conte [1833]) (1793)	G5	
<i>Callophrys affinis</i>	81	(W. H. Edwards 1862)	G4	
<i>Argynnis hesperis</i>	79	W. H. Edwards, 1864	G5	
<i>Hesperia colorado</i>	79	(Scudder 1874)	G5	
<i>Problema byssus</i>	75	(W. H. Edwards 1880)	G4	
<i>Pontia occidentalis</i>	74	(Reakirt 1866)	G5	
<i>Hesperia uncas</i>	74	W. H. Edwards 1863	G4	
<i>Parnassius smintheus</i>	66	E. Doubleday 1847	G5	
<i>Chlosyne lacinia</i>	64	(Geyer 1837)	G5	
<i>Hesperia sassacus</i>	60	Harris 1862	G5	
<i>Lerema accius</i>	56	(Smith 1797)	G5	
<i>Hesperia juba</i>	54	(Scudder 1872)	G5	
<i>Phyciodes batesii</i>	51	(Reakirt [1866])	G5	
<i>Euphyes bimacula</i>	48	(Grote and Robinson 1867)	G4	Name on NatureServe (Oeneis ridingsii)
<i>Phyciodes picta</i>	47	(Edwards 1865)	G5	
<i>Pontia sisymbrii</i>	46	(Boisduval 1852)	G5	
<i>Polygonia satyrus</i>	44	(W.H. Edwards 1869)	G5	
<i>Amblyscirtes belli</i>	44	Freeman 1941	G4	
<i>Euphyes dukesi</i>	42	(Lindsey 1923)	G3	
<i>Argynnis callippe</i>	40	Boisduval, 1852	G5	
<i>Satyrrium favonius</i>	40	(J.E. Smith 1797)	G4	
<i>Amblyscirtes aesculapius</i>	40	(Fabricius 1793)	G3	
<i>Argynnis diana</i>	40	Cramer 1777	G2	
<i>Glaucopsyche piasus</i>	39	(Boisduval 1852)	G5	
<i>Papilio indra</i>	37	Reakirt 1866	G5	
<i>Nymphalis californica</i>	35	(Boisduval 1852)	G5	
<i>Erynnis telemachus</i>	34	Burns 1960	G5	
<i>Oeneis jutta</i>	34	(Hübner [1806])	G5	
<i>Plebejus idas</i>	33	(Linnaeus 1761)	G5	

Table A.2—Continued

Butterfly Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Urbanus proteus</i>	33	(Linnaeus 1758)	G5	
<i>Cercyonis meadii</i>	31	(Edwards 1872)	G5	
<i>Poladryas arachne</i>	31	(W.H. Edwards 1869)	G5	
<i>Atrytone arogos</i>	31	(Boisduval and Le Conte [1837])	G2	
<i>Polites origenes</i>	30	(Fabricius 1793)	G5	
<i>Satyrium behrii</i>	30	(Edwards 1870)	G5	
<i>Tharsalea rubidus</i>	30	(Behr 1866)	G5	
<i>Icaricia saepiolus</i>	29	(Boisduval 1852)	G5	
<i>Oeneis chryxus</i>	29	(E. Doubleday [1849])	G5	
<i>Hypaurotis crysalus</i>	28	(Edwards 1873)	G5	
<i>Oeneis macounii</i>	28	(W. H. Edwards 1885)	G5	
<i>Phyciodes phaon</i>	28	(Boisduval 1836)	G5	Name on NatureServe (Eurytides phaon)
<i>Erynnis martialis</i>	28	(Scudder [1870])	G3	
<i>Amblyscirtes nysa</i>	27	Edwards 1877	G5	
<i>Chlosyne fulvia</i>	26	(W.H. Edwards 1879)	G4	
<i>Junonia grisea</i>	25	Austin and J. Emmel 1998	G5	Found east of the Rockies in CO. Likely <i>J. coenia</i>
<i>Agriades glandon</i>	24	(de Prunner 1798)	G5	
<i>Erynnis persius</i>	24	(Scudder 1863)	G5	
<i>Neophasia menapia</i>	23	(C. Felder and R. Felder 1859)	G5	
<i>Callophrys sheridanii</i>	22	(W. H. Edwards 1877)	G5	
<i>Tharsalea heteronea</i>	22	(Boisduval 1852)	G5	
<i>Hesperia comma</i>	21	(Linnaeus 1758)	G5	
<i>Oeneis uhleri</i>	21	(Reakirt 1866)	G5	
<i>Chlosyne acastus</i>	21	(W. H. Edwards 1874) (1870)	G4	
<i>Atlides halesus</i>	20	(Cramer 1777)	G5	
<i>Colias alexandra</i>	20	Edwards 1863	G5	
<i>Phyciodes mylitta</i>	20	(W. H. Edwards 1861)	G5	
<i>Telegonus cellus</i>	20	(Boisduval and Le Conte [1837])	G4	
<i>Neonympha mitchellii</i>	20	French 1889	G2	
<i>Erynnis pacuvius</i>	19	(Lintner 1878)	G5	

Table A.2—Continued

Butterfly Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Callophrys mossii</i>	19	(Hy. Edwards 1881)	G4	
<i>Icaricia shasta</i>	19	(W.H. Edwards, 1862)	G4	
<i>Callophrys irus</i>	19	(Godart [1824])	G2	
<i>Hesperia viridis</i>	18	(Edwards 1883)	G5	
<i>Celastrina humulus</i>	18	Scott and Wright 1998	G2	
<i>Callophrys spinetorum</i>	17	(Hewitson 1867)	G5	
<i>Erebia epirodea</i>	17	Butler 1868	G5	
<i>Boloria chariclea</i>	16	(Schneider 1794)	G5	
<i>Boloria eunomia</i>	16	(Esper 1800)	G5	
<i>Erynnis afranias</i>	15	(Lintner 1878)	G5	
<i>Lethe creola</i>	15	(Skinner 1897)	G4	
<i>Neominois ridingsii</i>	14	(W. H. Edwards 1865)	G5	
<i>Oarisma garita</i>	14	(Reakirt 1866)	G5	
<i>Boloria freija</i>	13	(Thunberg 1791)	G5	
<i>Amblyscirtes aenus</i>	12	Edwards 1878	G5	
<i>Cyllopsis perterpida</i>	12	(Dyar 1912)	G5	
<i>Satyrus saepium</i>	12	(Boisduval 1852)	G5	
<i>Lethe portlandia</i>	12	(Fabricius 1781)	G4	
<i>Euphilotes centralis</i>	11	(Barnes and McDunnough 1917)	SNR	
<i>Colias christina</i>	11	Edwards 1863	G5	
<i>Hesperia pahaska</i>	11	Leussler 1938	G5	
<i>Amblyscirtes eos</i>	11	W. H. Edwards 1871	G4	
<i>Atrytonopsis vierecki</i>	11	(Skinner 1902)	G4	
<i>Abaeis mexicana</i>	9	(Boisduval 1836)	G5	
<i>Leptotes cassius</i>	9	(Cramer, 1775)	G5	
<i>Lerodea eufala</i>	9	(Edwards 1869)	G5	
<i>Papilio bairdii</i>	9	W. H. Edwards, 1866	G5	Subspecies of <i>Papilio machaon</i> on NatureServe
<i>Argynnis mormonia</i>	8	Boisduval, 1869	G5	
<i>Chlosyne palla</i>	8	(Boisduval 1852)	G5	
<i>Hesperia metea</i>	8	Scudder 1863	G4	
<i>Anthocharis julia</i>	7	W.H. Edwards 1872	G5	

Table A.2—Continued

Butterfly Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Erebia discoidalis</i>	7	(Kirby 1837)	G5	
<i>Megathymus streckeri</i>	7	(Skinner 1895)	G5	
<i>Anthanassa texana</i>	6	(W.H. Edwards 1863)	G5	
<i>Calpodus ethlius</i>	6	(Stoll 1782)	G5	
<i>Paratrytone snowi</i>	6	(W. H. Edwards 1877)	G5	
<i>Polites draco</i>	6	(Edwards 1871)	G5	
<i>Thorybes nevada</i>	6	(Herrich-Schäffer 1869)	G5	Named on NatureServe (Cecropterus mexicana)
<i>Vanessa annabella</i>	6	(Field 1971)	G5	
<i>Celastrina neglectamajor</i>	6	Tutt, 1908	G3	
<i>Hesperia ottoe</i>	6	W. H. Edwards 1866	G3	
<i>Oarisma poweshiek</i>	6	(Parker 1870)	G1	
<i>Apodemia mejicanus</i>	5	(Behr 1865)	G5	
<i>Boloria frigga</i>	5	(Thunberg 1791)	G5	
<i>Hesperia assinihoia</i>	5	(Lyman 1892)	G5	
<i>Phyciodes pallida</i>	5	(Edwards 1864)	G5	
<i>Polites sabuleti</i>	5	(Boisduval 1852)	G5	
<i>Pyrgus scriptura</i>	5	(Boisduval 1852)	G5	
<i>Phaeostrymon alcestis</i>	5	(W. H. Edwards, 1871)	G4	Name on NatureServe (Satyrium alcestis)
<i>Erynnis lucilius</i>	5	(Scudder and Burgess 1870)	G3	
<i>Euphilotes rita</i>	5	(Barnes and McDunnough 1916)	G3	
<i>Megathymus yuccae</i>	4	(Boisduval and Le Conte [1837])	G5	
<i>Apodemia nais</i>	4	(W.H. Edwards 1877)	G4	
<i>Heraclides rumiko</i>	3	(Shiraiwa & Grishin, 2014)	SNR	Information from butterfliesandmoths.org as Papilio rumiko
<i>Hesperia nevada</i>	3	(Scudder 1874)	G5	
<i>Oarisma edwardsii</i>	3	(W. Barnes 1897)	G5	Name on NatureServe (Copaeodes edwardsii)
<i>Oeneis melissa</i>	3	(Fabricius 1775)	G5	
<i>Polites otho</i>	3	(J. E. Smith 1797)	G5	Name on NatureServe (Polites otho)
<i>Polygonia oreas</i>	3	(W.H. Edwards 1869)	G5	
<i>Polites rhesus</i>	3	(W. H. Edwards 1878)	G4	
<i>Pyrgus xanthus</i>	3	W. H. Edwards 1878	G3	

Table A.2—Continued

Butterfly Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Cissia rubricata</i>	2	(W. H. Edwards, 1871)	SNR	
<i>Phoebis marcellina</i>	2	(Cramer, 1777)	SNR	Information from butterfliesandmoth.org
<i>Adelpha Eulalia</i>	2	(E. Doubleday, [1848])	G5	
<i>Anartia jatrophae</i>	2	(Linnaeus, 1763)	G5	
<i>Apodemia mormo</i>	2	(C. Felder and R. Felder 1859)	G5	
<i>Copaeodes aurantiaca</i>	2	(Hewitson 1868)	G5	
<i>Papilio palamedes</i>	2	(Drury, 1773)	G5	Named on NatureServe (<i>Pterourus palamedes</i>)
<i>Phoebis agarithe</i>	2	(Boisduval 1836)	G5	
<i>Pieris marginalis</i>	2	Scudder, 1861	G5	
<i>Amblyscirtes osleri</i>	2	(Skinner 1899)	G4	
<i>Thorybes confusus</i>	2	E. Bell, 1923	G4	
<i>Erora laeta</i>	2	(Edwards 1862)	G2	
<i>Hesperia dacotae</i>	2	(Skinner, 1911)	G2	
<i>Ascia monuste</i>	1	(Linnaeus, 1764)	G5	
<i>Celotes nessus</i>	1	(Edwards 1877)	G5	
<i>Dione moneta</i>	1	Hübner [1825]	G5	Information from butterfliesandmoths.org
<i>Dryas iulia</i>	1	(Fabricius 1775)	G5	
<i>Glutophrissa drusilla</i>	1	(Cramer, 1777)	G5	
<i>Hemiargus ceraunus</i>	1	(Fabricius, 1793)	G5	
<i>Historis acheronia</i>	1	(Fabricius, 1775)	G5	Information from butterfliesandmoths.org
<i>Kricogonia lyside</i>	1	(Godart 1819)	G5	
<i>Mestra amymone</i>	1	(Ménétriés, 1857)	G5	
<i>Oeneis alberta</i>	1	Elwes, 1893	G5	
<i>Phoebis philea</i>	1	(Linnaeus, 1763)	G5	
<i>Poladryas minuta</i>	1	(W. H. Edwards 1861)	G5	
<i>Pyrgus centaureae</i>	1	(Rambur [1842])	G5	
<i>Satyrium sylvinus</i>	1	(Boisduval 1852)	G5	
<i>Strymon istapa</i>	1	(Reakirt, [1867])	G5	
<i>Zestusa dorus</i>	1	(W. H. Edwards 1882)	G5	
<i>Amblyscirtes phylace</i>	1	(Edwards 1878)	G4	
<i>Colias meadii</i>	1	W. H. Edwards, 1871	G4	

Table A.2—Continued

Butterfly Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
Pholisora mejicanus	1	(Reakirt, [1867])	G4	
Polites carus	1	(W. H. Edwards, 1883)	G4	
Satyrrium californica	1	(Edwards, 1862)	G4	
Stinga morrisoni	1	(W. H. Edwards, 1878)	G3	

<i>Total # Observation</i>	367,505
<i>Total # Species</i>	308
<i># Species</i>	
SNR	5
G5	242
G4	39
G3	12
G2	8
G1	2

Table A.3. iNaturalist bee species observations for the North Central United States (2014-2023). In total, 296 bee species were identified from 'research grade' observations during the study period. Taxonomic authorities and conservation statuses for species were determined via NatureServ (<https://explorer.natureserve.org>; data accessed May 2024). Global conservation rankings: G5=Secure, G4=Apparently Secure, G3=Vulnerable, G2=Imperiled, G1=Critically Imperiled, SNR=Unranked

Bee Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Bombus impatiens</i>	50020	Cresson 1863	G5	
<i>Apis mellifera</i>	33928	Linnaeus 1758	G5/Exotic	
<i>Bombus griseocollis</i>	32257	(De Geer 1773)	G5	
<i>Xylocopa virginica</i>	16820	(Linnaeus 1771)	G5	
<i>Bombus bimaculatus</i>	15424	Cresson 1863	G5	
<i>Halictus ligatus</i>	7159	Say 1837	G5	
<i>Bombus auricomus</i>	6616	(Robertson 1903)	G5	
<i>Melissodes bimaculatus</i>	4702	(Lepeletier 1825)	SNR	
<i>Bombus pensylvanicus</i>	4597	(De Geer 1773)	G3	
<i>Bombus rufocinctus</i>	4231	Cresson 1863	G5	
<i>Agapostemon virescens</i>	4175	(Fabricius 1775)	G5	
<i>Bombus fervidus</i>	3826	(Fabricius 1798)	G3	
<i>Bombus citrinus</i>	3252	(Smith 1854)	G4	
<i>Bombus affinis</i>	2829	Cresson 1863	G2	
<i>Bombus ternarius</i>	2603	Say 1837	G5	
<i>Anthidium manicatum</i>	2365	(Linnaeus 1758)	G5/Exotic	
<i>Bombus vagans</i>	1710	Smith 1854	G4	
<i>Bombus huntii</i>	1606	Greene 1860	G5	
<i>Anthidium oblongatum</i>	1324	(Illiger 1806)	G5/Exotic	
<i>Augochlora pura</i>	1320	(Say 1837)	G5	
<i>Bombus perplexus</i>	1287	Cresson 1863	G5	
<i>Halictus rubicundus</i>	916	(Christ 1791)	G5	
<i>Bombus borealis</i>	834	Kirby 1837	G4	
<i>Colletes inaequalis</i>	833	Say 1837	G5	
<i>Melissodes desponsus</i>	682	Smith 1854	SNR	
<i>Halictus confusus</i>	662	Smith 1853	G5	
<i>Anthophora terminalis</i>	623	Cresson 1869	G5	

Table A.3—Continued

Bee Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Megachile latimanus</i>	614	Say 1823	G5	
<i>Bombus nevadensis</i>	611	Cresson 1874	G4	
<i>Ptilothrix bombiformis</i>	550	(Cresson 1878)	G5	
<i>Peponapis pruinosa</i>	540	(Say 1837)	G5	
<i>Bombus fraternus</i>	477	(Smith 1854)	G3	
<i>Svastra obliqua</i>	462	(Say 1837)	SNR	
<i>Andrena wilkella</i>	415	(Kirby 1802)	SNR/Exotic	
<i>Megachile sculpturalis</i>	414	Smith 1853	G5/exotic	
<i>Bombus terricola</i>	413	Kirby 1837	G3	
<i>Hylaeus modestus</i>	353	Say 1837	G5	
<i>Andrena milwaukeensis</i>	327	Graenicher 1903	G5	
<i>Andrena erigeniae</i>	316	Robertson 1891	SNR	
<i>Andrena rudbeckiae</i>	269	Robertson 1891	SNR	
<i>Anthophora abrupta</i>	266	Say 1838	G5	
<i>Andrena dunningi</i>	263	Cockerell 1898	G5	
<i>Hylaeus leptcephalus</i>	257	(Morawitz 1871[“1870”])	SNR/Exotic	
<i>Triepeolus lunatus</i>	243	(Say 1824)	SNR	
<i>Megachile rotundata</i>	220	(Fabricius 1787)	G5/Exotic	
<i>Andrena hirticincta</i>	217	Provancher 1888	SNR	
<i>Calliopsis andreniformis</i>	212	Smith 1853	G5	
<i>Stelis louisae</i>	192	Cockerell 1911	SNR	
<i>Andrena carlini</i>	189	Cockerell 1901	G5	
<i>Megachile pugnata</i>	187	Say 1837	G5	
<i>Andrena nubecula</i>	185	Smith 1853	SNR	
<i>Megachile xylocopoides</i>	179	Smith 1853	G5	
<i>Osmia cornifrons</i>	174	(Radoszkowski 1887)	G5/Exotic	
<i>Augochlorella aurata</i>	163	(Smith 1853)	G5	
<i>Paranthidium jugatorium</i>	152	(Say 1824)	SNR	
<i>Osmia taurus</i>	149	Smith 1873	G5/Exotic	
<i>Andrena vicina</i>	143	Smith 1853	G5	
<i>Osmia lignaria</i>	142	Say 1837	G5	
<i>Epeolus bifasciatus</i>	139	Cresson 1864	SNR	

Table A.3—Continued

Bee Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Lasioglossum fuscipenne</i>	136	(Smith 1853)	SNR	
<i>Andrena helianthi</i>	135	Robertson 1891	SNR	
<i>Dieunomia heteropoda</i>	127	(Say 1824)	G5	
<i>Megachile campanulae</i>	125	(Robertson 1903)	G5	
<i>Bombus flavidus</i>	124	Eversmann 1852	G5	
<i>Osmia bucephala</i>	120	Cresson 1864	G5	
<i>Halictus parallelus</i>	115	Say 1837	SNR	
<i>Melitoma taurea</i>	107	(Say 1837)	SNR	
<i>Melissodes druriellus</i>	101	(Kirby 1802)	SNR	
<i>Bombus centralis</i>	100	Cresson 1864	G5	
<i>Bombus appositus</i>	100	Cresson 1878	G3	
<i>Triepeolus remigatus</i>	97	(Fabricius 1804)	SNR	
<i>Andrena asteris</i>	93	Robertson 1891	SNR	
<i>Lithurgopsis apicalis</i>	92	(Cresson 1875)	SNR	
<i>Agapostemon sericeus</i>	88	(Forster 1771)	G5	
<i>Lasioglossum coriaceum</i>	86	(Smith 1853)	G5	
<i>Holcopasites calliopsidis</i>	83	(Linsley 1943)	SNR	
<i>Dufourea monardae</i>	76	(Viereck 1924)	SNR	
<i>Ceratina strenua</i>	71	Smith 1879	SNR	
<i>Anthophora bomboides</i>	71	Kirby 1838	G5	
<i>Megachile mendica</i>	69	Cresson 1878	G5	
<i>Andrena crataegi</i>	66	Robertson 1893	G5	
<i>Lasioglossum imitatum</i>	62	(Smith 1853)	G5	
<i>Lasioglossum vierecki</i>	61	(Crawford 1904)	SNR	
<i>Ceratina calcarata</i>	61	Robertson 1900	G5	
<i>Chelostoma philadelphi</i>	60	(Robertson 1891)	SNR	
<i>Megachile inermis</i>	59	Provancher 1888	G5	
<i>Colletes latitarsis</i>	55	Robertson 1891	SNR	
<i>Bombus morrisoni</i>	55	Cresson 1878	G3	
<i>Bombus insularis</i>	54	(Smith 1861)	G3	
<i>Melissodes denticulatus</i>	51	Smith 1854	SNR	
<i>Nomia nortoni</i>	50	Cresson 1868	G5	

Table A.3—Continued

Bee Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Melissodes trinodis</i>	48	Robertson 1901	SNR	
<i>Lasioglossum zephyrus</i>	47	(Smith 1853)	G5	
<i>Anthophora walshii</i>	47	Cresson 1869	G4	
<i>Agapostemon splendens</i>	45	(Lepeletier 1841)	G5	
<i>Perdita perpallida</i>	40	Cockerell 1901	SNR	
<i>Triepeolus concavus</i>	40	(Cresson 1878)	SNR	
<i>Hylaeus mesillae</i>	40	(Cockerell 1896)	G5	
<i>Andrena aliciae</i>	37	Robertson 1891	SNR	
<i>Coelioxys modestus</i>	37	Smith 1854	SNR	
<i>Halictus tripartitus</i>	37	Cockerell 1895	G5	
<i>Nomada luteoloides</i>	36	Robertson 1895	SNR	
<i>Andrena cressonii</i>	36	Robertson 1891	G5	
<i>Andrena geranii</i>	35	Robertson 1891	SNR	
<i>Lasioglossum pilosum</i>	35	(Smith 1853)	G5	
<i>Bombus occidentalis</i>	35	Greene 1858	G3	
<i>Megachile fortis</i>	34	Cresson 1872	G2	
<i>Andrena distans</i>	33	Provancher 1888	SNR	
<i>Lasioglossum coeruleum</i>	33	(Robertson 1893)	SNR	
<i>Bombus bifarius</i>	33	Cresson 1878	G5	
<i>Colletes thoracicus</i>	32	Smith 1853	SNR	
<i>Eucera hamata</i>	31	(Bradley 1942)	SNR	
<i>Megachile montivaga</i>	31	Cresson 1878	G5	
<i>Bombus frigidus</i>	28	Smith 1854	G5	
<i>Megachile relativa</i>	28	Cresson 1878	G5	
<i>Brachymelecta californica</i>	26	(Cresson, 1878)	G5	
<i>Colletes compactus</i>	26	Cresson 1868	G5	
<i>Lasioglossum sisymbrii</i>	26	(Cockerell 1895)	G5	
<i>Andrena prunorum</i>	25	Cockerell 1896	G5	
<i>Hoplitis fulgida</i>	25	(Cresson 1864)	G5	
<i>Pseudoanthidium nanum</i>	23	(Mocsáry 1881)	SNR/Exotic	
<i>Dieunomia nevadensis</i>	23	(Cresson 1874)	G5	
<i>Chelostoma rapunculi</i>	22	(Lepeletier 1841)	SNR/Exotic	

Table A.3—Continued

Bee Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Megachile petulans</i>	22	Cresson 1878	G5	
<i>Megachile texana</i>	22	Cresson 1878	G5	
<i>Andrena nasonii</i>	21	Robertson 1895	G5	
<i>Anthidiellum notatum</i>	21	(Latreille 1809)	G5	
<i>Colletes simulans</i>	21	Cresson 1868	G5	
<i>Megachile centuncularis</i>	21	(Linnaeus 1758)	G5	
<i>Anthophora montana</i>	21	Cresson 1869	G4	
<i>Bombus sandersoni</i>	20	Franklin 1913	G5	
<i>Augochloropsis humeralis</i>	19	(Patton, 1879)	SNR	
<i>Augochloropsis viridula</i>	19	(Smith, 1853)	SNR	
<i>Melissodes comptoides</i>	19	Robertson 1898	SNR	
<i>Melissodes dentiventris</i>	19	Smith 1854	SNR	
<i>Andrena ziziae</i>	18	Robertson 1891	SNR	
<i>Cemolobus ipomoeae</i>	18	(Robertson 1891)	SNR	
<i>Diadasia enavata</i>	18	(Cresson 1872)	SNR	
<i>Bombus melanopygus</i>	18	Nylander, 1848	G5	
<i>Megachile inimica</i>	18	Cresson 1872	G5	
<i>Megachile melanophaea</i>	18	Smith 1853	G5	
<i>Megachile parallela</i>	18	Smith 1853	G5	
<i>Andrena miserabilis</i>	17	Cresson 1872	G5	
<i>Lasioglossum pectorale</i>	17	(Smith 1853)	G5	
<i>Megachile gemula</i>	17	Cresson 1878	G5	
<i>Nomada erigeronis</i>	16	Robertson 1897	SNR	
<i>Sphecodes davisii</i>	16	Robertson 1897	SNR	
<i>Megachile frigida</i>	16	Smith 1853	G5	
<i>Florilegus condignus</i>	15	(Cresson, 1878)	SNR	
<i>Andrena barbilabris</i>	15	(Kirby 1802)	G5	
<i>Megachile perihirta</i>	15	Cockerell 1898	G5	
<i>Megachile polcaris</i>	15	Say 1831	G5	
<i>Colletes aestivalis</i>	14	Patton, 1879	SNR	
<i>Epeolus lectoides</i>	14	Robertson 1901	SNR	

Table A.3—Continued

Bee Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Protandrena passiflorae</i>	14	(Robertson, 1902)	SNR	Name on NatureServe (<i>Psuedopanurgus passiflorae</i>)
<i>Hylaeus affinis</i>	14	(Smith 1853)	G5	
<i>Osmia georgica</i>	14	Cresson 1878	G5	
<i>Andrena nuda</i>	13	Robertson 1891	SNR	
<i>Megachile brevis</i>	13	Say 1837	G5	
<i>Coelioxys rufitarsis</i>	12	Smith 1854	SNR	
<i>Colletes aberrans</i>	12	Cockerell 1897	SNR	
<i>Lasioglossum texanum</i>	12	(Cresson, 1872)	SNR	
<i>Nomada articulata</i>	12	Smith 1854	SNR	
<i>Svastra atripes</i>	12	(Cresson 1872)	SNR	
<i>Andrena erythronii</i>	11	Robertson 1891	SNR	
<i>Epeolus scutellaris</i>	11	Say 1824	SNR	
<i>Melecta pacifica</i>	11	Cresson 1878	SNR	
<i>Nomada banksi</i>	11	Cockerell 1907	SNR	
<i>Nomada vegana</i>	11	Cockerell 1903	SNR	
<i>Perdita pallidipennis</i>	11	Graenicher, 1910	SNR	Name on NatureServe (<i>Perdita bequaerti</i>)
<i>Protandrena albitarsis</i>	11	(Cresson, 1872)	SNR	Name on NatureServe (<i>Psuedopanurgus albitarsis</i>)
<i>Protandrena andrenoides</i>	11	(Smith, 1853)	SNR	Name on NatureServe (<i>Psuedopanurgus andrenoides</i>)
<i>Protandrena compositarum</i>	11	(Robertson, 1893)	SNR	Name on NatureServe (<i>Psuedopanurgus compositarum</i>)
<i>Andrena accepta</i>	10	Viereck 1916	SNR	
<i>Andrena erythrogaster</i>	10	(Ashmead 1890)	SNR	
<i>Coelioxys octodentatus</i>	10	Say 1824	SNR	
<i>Melissodes agilis</i>	10	Cresson 1878	SNR	
<i>Perdita octomaculata</i>	10	(Say 1824)	SNR	
<i>Habropoda laboriosa</i>	10	(Fabricius 1804)	G5	
<i>Hylaeus hyalinatus</i>	9	Smith 1842	SNR/Exotic	
<i>Andrena integra</i>	9	Smith 1853	SNR	
<i>Calliopsis nebraskensis</i>	9	Crawford 1902	SNR	
<i>Nomada vineta</i>	9	Say 1837	SNR	
<i>Perdita halictoides</i>	9	Smith 1853	SNR	

Table A.3—Continued

Bee Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Sphecodes heraclei</i>	9	Robertson 1897	SNR	
<i>Triepeolus distinctus</i>	9	(Cresson 1878)	SNR	
<i>Triepeolus pectoralis</i>	9	(Robertson 1897)	SNR	
<i>Bombus mixtus</i>	9	Cresson 1878	G5	
<i>Lasioglossum nigroviride</i>	9	(Graenicher 1911)	G5	
<i>Lasioglossum quebecense</i>	9	(Crawford 1907)	G5	
<i>Hylaeus pictipes</i>	8	Nylander 1852	SNR/Exotic	
<i>Andrena andrenoides</i>	8	(Cresson 1878)	SNR	
<i>Andrena frigida</i>	8	Smith 1853	SNR	
<i>Augochloropsis metallica</i>	8	(Fabricius 1793)	SNR	
<i>Epeolus ainsliei</i>	8	Crawford, 1932	SNR	
<i>Stelis lateralis</i>	8	Cresson 1864	SNR	
<i>Anthophora californica</i>	8	Cresson 1869	G5	
<i>Anthophora urbana</i>	8	Cresson 1878	G5	
<i>Bombus flavifrons</i>	8	Cresson 1863	G5	
<i>Lasioglossum anomalum</i>	8	(Robertson, 1892)	G5	
<i>Brachymelecta interrupta</i>	8	(Cresson 1872)	G4	
<i>Andrena pruni</i>	7	Robertson 1891	SNR	
<i>Dianthidium curvatum</i>	7	(Smith 1854)	SNR	
<i>Dianthidium simile</i>	7	(Cresson 1864)	SNR	
<i>Hylaeus punctatus</i>	7	(Brullé, 1832)	SNR	
<i>Perdita albipennis</i>	7	Cresson 1868	SNR	
<i>Perdita gerhardi</i>	7	Viereck 1904	SNR	
<i>Protandrena labrosa</i>	7	(Robertson, 1895)	SNR	Name on NatureServe (<i>Psuedopanurgus labrosa</i>)
<i>Tetraloniella cressoniana</i>	7	Cockerell 1905	SNR	
<i>Triepeolus donatus</i>	7	(Smith 1854)	SNR	
<i>Andrena hippotes</i>	7	Robertson 1895	G5	
<i>Anthidium maculosum</i>	7	Cresson 1878	G5	
<i>Lasioglossum pictum</i>	7	(Crawford 1902)	G5	
<i>Andrena clarkella</i>	6	(Kirby 1802)	SNR	
<i>Andrena violae</i>	6	Robertson 1891	SNR	
<i>Coelioxys alternatus</i>	6	Say 1837	SNR	

Table A.3—Continued

Bee Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Coelioxys sayi</i>	6	Robertson 1897	SNR	
<i>Colletes susannae</i>	6	Swenk 1925	SNR	
<i>Diadasia australis</i>	6	(Cresson, 1878)	SNR	Not found on NatureServe or IUCN; listed as SNR
<i>Lasioglossum gemmatum</i>	6	(Smith, 1853)	SNR	
<i>Tetraloniella albata</i>	6	Cresson 1872	SNR	
<i>Andrena alleghaniensis</i>	6	Viereck 1907	G5	
<i>Melissodes communis</i>	6	Cresson 1878	G5	
<i>Megachile frugalis</i>	6	Cresson 1872	G4	
<i>Epeolus autumnalis</i>	5	Robertson 1902	SNR	
<i>Lasioglossum pectinatum</i>	5	(Robertson 1890)	SNR	
<i>Nomada cuneata</i>	5	(Robertson 1903)	SNR	
<i>Nomada denticulata</i>	5	Robertson 1902	SNR	
<i>Perdita swenki</i>	5	Crawford, 1915	SNR	
<i>Protandrena cockerelli</i>	5	Dunning, 1897	SNR	
<i>Triepeolus cressonii</i>	5	(Robertson 1897)	SNR	
<i>Andrena rugosa</i>	5	Robertson 1891	G5	
<i>Lasioglossum cinctipes</i>	5	(Provancher 1888)	G5	
<i>Anthophora occidentalis</i>	5	Cresson 1869	G3	
<i>Andrena gardineri</i>	4	Cockerell 1906	SNR	
<i>Anthidiellum boreale</i>	4	(Robertson, 1902)	SNR	Not found on NatureServe or IUCN; listed as SNR
<i>Dufourea marginata</i>	4	(Cresson 1878)	SNR	
<i>Dufourea novaeangliae</i>	4	(Robertson 1897)	SNR	
<i>Epeolus minimus</i>	4	(Robertson 1902)	SNR	
<i>Nomada maculata</i>	4	Cresson, 1863	SNR	
<i>Nomada placida</i>	4	Cresson 1863	SNR	
<i>Protandrena rugosus</i>	4	Robertson, 1895	SNR	
<i>Stelis rudbeckiarum</i>	4	Cockerell, 1904	SNR	Not found on NatureServe or IUCN; listed as SNR
<i>Hylaeus basalis</i>	4	(Smith 1853)	G5	
<i>Osmia texana</i>	4	Cresson 1872	G5	
<i>Osmia ribifloris</i>	4	Cockerell 1900	G4	
<i>Megachile rugifrons</i>	4	(Smith 1854)	G2	

Table A.3—Continued

Bee Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Andrena carolina</i>	3	Viereck 1909	SNR	
<i>Andrena haynesi</i>	3	Cockerell 1914	SNR	
<i>Andrena parnassiae</i>	3	Cockerell, 1902	SNR	
<i>Andrena polemonii</i>	3	Robertson, 1891	SNR	
<i>Coelioxys germanus</i>	3	Cresson, 1878	SNR	
<i>Colletes validus</i>	3	Cresson, 1868	SNR	
<i>Diadasia diminuta</i>	3	(Cresson, 1878)	SNR	
<i>Epeolus pusillus</i>	3	Cresson 1864	SNR	
<i>Lasioglossum hartii</i>	3	(Robertson, 1892)	SNR	
<i>Macropis nuda</i>	3	(Provancher 1882)	SNR	
<i>Melissodes apicatus</i>	3	Lovell and Cockerell, 1906	SNR	
<i>Nomada texana</i>	3	Cresson 1872	SNR	
<i>Nomada tiftonensis</i>	3	Cockerell 1903	SNR	
<i>Perdita maculigera</i>	3	Cockerell 1896	SNR	
<i>Protandrena aethiops</i>	3	(Cresson, 1872)	SNR	Name on NatureServe (Psuedopanurgus aethiops)
<i>Protandrena bancrofti</i>	3	Dunning, 1897	SNR	
<i>Sphecodes aroniae</i>	3	Mitchell, 1960	SNR	
<i>Sphecodes ranunculi</i>	3	Robertson 1897	SNR	
<i>Agapostemon texanus</i>	3	Cresson 1872	G5	
<i>Andrena imitatrix</i>	3	Cresson, 1872	G5	
<i>Heriades carinata</i>	3	Cresson 1864	G5	
<i>Hoplitis producta</i>	3	(Cresson, 1864)	G5	
<i>Lasioglossum subviridatum</i>	3	(Cockerell 1938)	G5	
<i>Lasioglossum versatum</i>	3	(Robertson 1902)	G5	
<i>Xenoglossa strenua</i>	3	(Cresson 1878)	G5	
<i>Nomia universitatis</i>	3	Cockerell, 1908	G3	
<i>Andrena mariae</i>	2	Robertson 1891	SNR	
<i>Andrena obscuripennis</i>	2	Smith 1853	SNR	
<i>Calliopsis subalpina</i>	2	Cockerell 1894	SNR	
<i>Colletes andrewsi</i>	2	Cockerell, 1906	SNR	
<i>Diadasia ochracea</i>	2	(Cockerell 1903)	SNR	

Table A.3—Continued

Bee Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Dianthidium subrufulum</i>	2	Timberlake, 1943	SNR	Not found on NatureServe or IUCN; listed as SNR
<i>Dufourea maura</i>	2	(Cresson 1878)	SNR	
<i>Halictus farinosus</i>	2	Smith 1853	SNR	
<i>Hylaeus nelumbonis</i>	2	(Robertson 1890)	SNR	
<i>Lasioglossum nelumbonis</i>	2	(Robertson, 1890)	SNR	
<i>Melitoma grisella</i>	2	(Cockerell and Porter, 1899)	SNR	
<i>Nomada affabilis</i>	2	Cresson, 1878	SNR	
<i>Nomada imbricata</i>	2	Smith 1854	SNR	
<i>Nomada luteola</i>	2	Olivier, 1811	SNR	
<i>Nomada oblitterata</i>	2	Cresson 1863	SNR	
<i>Nomada rubicunda</i>	2	Olivier 1812	SNR	
<i>Nomada superba</i>	2	Cresson 1863	SNR	
<i>Nomada utahensis</i>	2	Moalif 1988	SNR	
<i>Nomada vicina</i>	2	Cresson 1863	SNR	
<i>Svastra petulca</i>	2	(Cresson, 1878)	SNR	
<i>Triepeolus oblitteratus</i>	2	Graenicher, 1911	SNR	
<i>Triepeolus simplex</i>	2	Robertson, 1903	SNR	
<i>Andrena lupinorum</i>	2	Cockerell, 1906	G5	
<i>Heriades leavitti</i>	2	Crawford 1913	G5	
<i>Hoplitis albifrons</i>	2	(Kirby, 1837)	G5	
<i>Hoplitis spoliata</i>	2	(Provancher 1888)	G5	
<i>Hylaeus annulatus</i>	2	(Linnaeus, 1758)	G5	
<i>Hylaeus verticalis</i>	2	(Cresson 1869)	G5	
<i>Lasioglossum bruneri</i>	2	(Crawford, 1902)	G5	
<i>Lasioglossum cressonii</i>	2	(Robertson 1890)	G5	
<i>Lasioglossum foxii</i>	2	(Robertson, 1895)	G5	
<i>Megachile addenda</i>	2	Cresson, 1878	G5	
<i>Megachile exilis</i>	2	Cresson 1872	G5	
<i>Megachile fidelis</i>	2	Cresson, 1878	G5	
<i>Osmia coloradensis</i>	2	Cresson 1878	G5	
<i>Osmia distincta</i>	2	Cresson 1864	G5	

Table A.3—Continued

Bee Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Osmia pumila</i>	2	Cresson 1864	G5	
<i>Anthophora ursina</i>	2	Cresson, 1869	G4	
<i>Megachile mucida</i>	2	Cresson, 1878	G4	
<i>Anthidium psoraleae</i>	2	Robertson 1902	G3	
<i>Andrena astragali</i>	1	Viereck and Cockerell, 1914	SNR	
<i>Andrena bisalicens</i>	1	Viereck 1908	SNR	
<i>Andrena bradleyi</i>	1	Viereck 1907	SNR	
<i>Andrena canadensis</i>	1	Dalla Torre, 1896	SNR	
<i>Andrena cerebrata</i>	1	Mitchell, 1960	SNR	
<i>Andrena chromotricha</i>	1	Cockerell, 1899	SNR	
<i>Andrena comoda</i>	1	Smith 1879	SNR	
<i>Andrena hiliaris</i>	1	Smith, 1853	SNR	
<i>Andrena krigiana</i>	1	Robertson, 1901	SNR	
<i>Andrena platyparia</i>	1	Robertson, 1895	SNR	
<i>Andrena quintilis</i>	1	Robertson, 1898	SNR	
<i>Andrena simplex</i>	1	Smith 1853	SNR	
<i>Andrena wilmattae</i>	1	Cockerell 1906	SNR	
<i>Calliopsis callops</i>	1	(Cockerell and Porter, 1899)	SNR	
<i>Centris caesalpiniae</i>	1	Cockerell 1897	SNR	
<i>Coelioxys hunteri</i>	1	Crawford 1914	SNR	
<i>Coelioxys sodalis</i>	1	Cresson, 1878	SNR	
<i>Colletes nudus</i>	1	Robertson, 1898	SNR	
<i>Colletes wilmattae</i>	1	Cockerell, 1904	SNR	
<i>Epeolus canadensis</i>	1	Mitchell, 1962	SNR	
<i>Epeolus novomexicanus</i>	1	Cockerell, 1912	SNR	
<i>Eucera dubitata</i>	1	(Cresson 1878)	SNR	
<i>Holcopasites heliopsis</i>	1	(Robertson, 1897)	SNR	
<i>Hylaeus sparsus</i>	1	(Cresson 1869)	SNR	
<i>Lasioglossum leucozonium</i>	1	(Schrank, 1781)	SNR	
<i>Lasioglossum lionotum</i>	1	(Sandhouse 1923)	SNR	
<i>Lasioglossum michiganense</i>	1	(Mitchell 1960)	SNR	

Table A.3—Continued

Bee Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Melissodes bidentis</i>	1	Cockerell, 1914	SNR	
<i>Melissodes subillatus</i>	1	LaBerge, 1961	SNR	
<i>Melissodes tepaneca</i>	1	Cresson, 1878	SNR	
<i>Melissodes vernoniae</i>	1	Robertson, 1902	SNR	
<i>Neolarra vigilans</i>	1	(Cockerell, 1895)	SNR	
<i>Nomada australis</i>	1	Mitchell 1962	SNR	
<i>Nomada besseyi</i>	1	Swenk, 1913	SNR	
<i>Nomada xanthura</i>	1	Cockerell 1908	SNR	
<i>Perdita bruneri</i>	1	Cockerell, 1897	SNR	
<i>Perdita cambarella</i>	1	Cockerell, 1897	SNR	
<i>Perdita coreopsidis</i>	1	Cockerell, 1906	SNR	
<i>Perdita kiowi</i>	1	Griswold 1988	SNR	
<i>Protandrena mexicanorum</i>	1	(Cockerell, 1896)	SNR	
<i>Protandrena porterae</i>	1	(Cockerell, 1900)	SNR	Not found on NatureServe or IUCN; listed as SNR
<i>Protandrena renimaculata</i>	1	(Cockerell, 1896)	SNR	Name on NatureServe (Psuedopanurgus renimaculata)
<i>Protandrena rudbeckiae</i>	1	(Robertson, 1895)	SNR	Name on NatureServe (Psuedopanurgus rudbeckiae)
<i>Sphecodes confertus</i>	1	Say, 1837	SNR	
<i>Sphecodes dichrous</i>	1	Smith 1853	SNR	
<i>Sphecodes pecosensis</i>	1	Cockerell, 1904	SNR	
<i>Stelis coarctatus</i>	1	Crawford, 1916	SNR	
<i>Tetraloniella spissa</i>	1	Cresson 1872	SNR	
<i>Trachusa dorsalis</i>	1	(Lepeletier, 1841)	SNR	
<i>Triepeolus helianthi</i>	1	(Robertson, 1897)	SNR	
<i>Triepeolus martini</i>	1	(Cockerell, 1900)	SNR	Not found on NatureServe or IUCN; listed as SNR
<i>Triepeolus michiganensis</i>	1	Mitchell, 1962	SNR	
<i>Triepeolus quadrifasciatus</i>	1	(Say, 1823)	SNR	
<i>Andrena nivalis</i>	1	Smith 1853	G5	
<i>Anthidium porterae</i>	1	Cockerell, 1900	G5	
<i>Ceratina dupla</i>	1	Say 1837	G5	
<i>Heriades variolosus</i>	1	(Cresson, 1872)	G5	
<i>Lasioglossum albipenne</i>	1	(Robertson, 1890)	G5	

Table A.3—Continued

Bee Species	#Observed	Taxonomic Authority	Conservation Rank	Notes
<i>Lasioglossum heterognathus</i>	1	(Mitchell, 1960)	G5	
<i>Lasioglossum hitchensi</i>	1	Gibbs 2012	G5	
<i>Lasioglossum lineatulum</i>	1	(Crawford 1906)	G5	
<i>Lasioglossum paraforbesii</i>	1	McGinley, 1986	G5	
<i>Lasioglossum pruinosum</i>	1	(Robertson, 1892)	G5	
<i>Lasioglossum versans</i>	1	(Lovell 1905)	G5	
<i>Osmia subfasciata</i>	1	Cresson, 1872	G5	
<i>Agapostemon angelicus</i>	1	Cockerell, 1924	G4	
<i>Megachile albitarsis</i>	1	Cresson 1872	G4	
<i>Megachile angularum</i>	1	Cockerell 1902	G4	
<i>Xenoglossa kansensis</i>	1	Cockerell, 1905	G4	
<i>Andrena mentzeliae</i>	1	Cockerell 1897	G2	

Total # Observation	221,370
Total # Species	383
# Species	
SNR	214
G5	139
G4	15
G3	11
G2	4
G1	0

Table A.4. Summary of iNaturalist bee and butterfly observations by city. Total number of 'research grade' butterfly and bee species observations, species detected, and city population (from US Census) were determined for selected cities in the North Central United States.

State	City	Population	# Butterfly Observations	Butterfly Species Documented	# Bee Observations	Bee Species Documented
CO	Aurora	386,261	1290	60	182	20
CO	Boulder	108,250	961	84	587	41
CO	Colorado Springs	478,961	1080	92	390	42
CO	Denver	715,522	977	50	1265	44
CO	Fort Collins	169,810	1224	67	932	50
IA	Ames	66,427	849	35	227	19
IA	Cedar Falls	40,713	113	26	172	20
IA	Cedar Rapids	137,710	254	34	190	20
IA	Davenport	101,724	162	26	314	22
IA	Iowa City	74,828	535	48	735	34
IL	Aurora	180,542	76	26	40	10
IL	Champaign	88,302	672	41	388	24
IL	Chicago	2,746,388	10521	72	3960	57
IL	Evanston	78,110	437	34	338	29
IL	Naperville	149,540	224	26	139	22
IL	Normal	52,736	251	32	188	15
IL	Springfield	114,394	201	41	106	16
IL	Urbana	38,336	911	51	625	34
IN	Bloomington	79,168	437	45	240	24
IN	Evansville	117,298	166	36	162	21
IN	Fort Wayne	263,886	309	34	227	18
IN	Indianapolis	887,642	2218	58	1311	43
IN	Muncie	65,194	134	25	97	11
IN	West Lafayette	44,595	771	43	576	20
KS	Kansas City	156,607	145	30	48	11
KS	Lawrence	94,934	1216	56	463	24
KS	Manhattan	54,100	231	46	89	16
KS	Overland Park	197,238	228	42	86	14

Table A.4—Continued

State	City	Population	# Butterfly Observations	Butterfly Species Documented	# Bee Observations	Bee Species Documented
KS	Topeka	126,587	261	41	66	14
KS	Wichita	397,532	937	67	215	20
KY	Bowling Green	72,294	410	54	231	27
KY	Frankfort	28,602	202	41	52	10
KY	Lexington-Fayette	325,330	3679	73	981	40
KY	Louisville	246,161	1070	55	683	37
MI	Ann Arbor	123,851	680	51	788	32
MI	Detroit	639,111	483	43	278	20
MI	East Lansing	47,741	166	33	282	44
MI	Grand Rapids	198,817	382	37	318	25
MI	Lansing	112,644	247	39	137	27
MI	Warren	139,387	256	21	130	20
MN	Mankato	44,488	209	29	198	28
MN	Minneapolis	429,954	2089	51	3976	75
MN	Rochester	121,395	393	44	249	26
MN	St. Paul	311,527	1404	55	5661	94
MO	Columbia	126,254	839	60	335	26
MO	Jefferson City	43,228	1880	76	332	33
MO	Kansas City	508,090	779	60	349	26
MO	Springfield	169,176	718	61	195	23
MO	St. Louis	301,578	2548	64	10327	61
ND	Bismarck	73,622	164	26	443	34
ND	Fargo	125,990	104	18	177	22
ND	Grand Forks	59,166	35	9	36	8
NE	Bellevue	64,176	187	35	79	14
NE	Kearney	33,790	45	24	34	12
NE	Lincoln	291,082	841	49	503	24
NE	Omaha	486,051	2384	59	1517	37
OH	Athens	23,849	226	36	116	14
OH	Cincinnati	309,317	2460	66	4000	48
OH	Cleveland	372,624	1002	45	678	53

Table A.4—Continued

State	City	Population	# Butterfly Observations	Butterfly Species Documented	# Bee Observations	Bee Species Documented
OH	Columbus	905,748	2741	61	2446	52
SD	Aberdeen	28,495	14	5	10	3
SD	Brookings	23,377	222	33	76	12
SD	Pierre	14,091	49	16	49	11
SD	Rapid City	74,703	51	20	47	9
SD	Sioux Falls	192,517	180	26	113	18
SD	Spearfish	12,193	11	10	5	3
SD	Vermillion	11,695	28	15	6	5
WI	Green Bay	107,395	212	34	154	26
WI	Madison	269,840	2170	57	2515	64
WI	Milwaukee	577,222	771	41	1456	33
WI	Oshkosh	66,816	35	14	30	12

Table A.5. Summary of sources of butterfly and bee occurrence data in GBIF. GBIF data was constrained to only include occurrences that were between January 1st, 2015 to December 31st, 2020 in the 14 states included in this study (GBIF 2023 and references therein; data accessed 05Jan2023).

Butterfly Data Sources	# Butterfly Records	% of total GBIF Observations	Bee Data Sources	# Bee Records	% of total GBIF Observations
Michigan State University A.J. Cook Arthropod Research Collection (iDigBIO SCAN)	100	0.070	Michigan State University - AJ Cook Arthropod Research collection (iDigBio SCAN)	3	0.005
Academy of Natural Sciences Entomology Collection LepNet (iDigBIO SCAN)	8	0.006	The Giant Resin Bee, <i>Megachile sculpturalis</i> Smith: New Distributional Records for the Mid- and Gulf-south USA (ADT)	1	0.002
BioDiversity4All	5	0.003	Auburn University Museum of Natural History Entomology (iDigBioSCAN)	1	0.002
Chicago Academy of Sciences (CHAS Entomology Collection)	4	0.003	Biodiversity4All	1	0.002
Colorado State University C.P. Gillette Museum of Arthropod Diversity	42	0.029	The Giant Resin Bee, <i>Megachile sculpturalis</i> Smith: New Distributional Records for the Mid- and Gulf-south USA (BBSL)	1	0.002
Estonian University of Life Sciences Insititue of Agricultural and Environmental Sciences Entomological Collections	24	0.017	Chicago Academy of Science (CHAS Entomology Collection)	1	0.002
Frost Entomological Museum (iDigBIO SCAN)	1	0.001	Colorado State University C.P. Gillette Museu of Arthropod Diversity	557	0.912
iNaturalist	108034	75.188	Cleveland Museum of Natural History, OH (CLEV)	44	0.072
Denver Botanic Gardens (iDigBIO SCAN)	22	0.015	Estonian University of Life Sciences Insititute of Agricultural and Environmental Sciences Entomological Collections	2	0.003
Luther College Entomological Research Collection (iDigBIO SCAN)	150	0.104	Denver Botanic Gardens Collection of Arthropods (iDigBio SCAN)	259	0.424
Mississippi State University Entomological Museum iDigBIO SCAN)	7	0.005	Field Museum of Natural History (Zoology) Insect, Arachnid and Myriapod Collection	44	0.072
Cleveland Museum of Natural History	1	0.001	iNaturalist	47731	78.119

Table A.5—Continued

Butterfly Data Sources	# Butterfly Records	% of total GBIF Observations	Bee Data Sources	# Bee Records	% of total GBIF Observations
New Mexico Museum of Natural History and Science	23	0.016	Illinois Natural History Survey Insect Collection	2446	4.003
New Mexico State Collection of Arthropods	1	0.001	Snow Entomological Museum Collection	2	0.003
International Barcode of Life	2	0.001	University of Kentucky Insect Collection (iDigBio SCAN)	285	0.466
The Lepidopterists' Society Season Summary	649	0.452	Luther Entomological Research Collection (iDigBio SCAN)	412	0.674
PollardBase	13879	9.659	Frost Entomological Museum (PSUC) (iDigBio SCAN)	5	0.008
University of California Davis R.M. Bohart Museum of Entomology (iDigBIO SCAN)	1	0.001	South Dakota State University, The Severin-McDaniel Insect Research Collection (iDigBio SCAN)	25	0.041
University of Minnesota Insect Collection (iDigBIO SCAN)	101	0.070	The Giant Resin Bee, <i>Megachile sculpturalis</i> Smith: New Distributional Records for the Mid- and Gulf-south USA (UAAM)	2	0.003
eButterfly	20,632	14.359	University of Michigan Museum of Zoology, Division of Insects	34	0.056
			USDA-ARS Pollinating Insects - Biology, Management and Systematics Research Unit	762	1.247
			Museum Records (BBSL)		
			USGS PWRC - Native Bee Inventory and Monitoring Lab (BIML)	5217	8.538
			University of Texas, Biodiversity Center, Entomology Collection (UTIC)	4	0.007
			The 'red-tailed' <i>Lasioglossum</i> (<i>Dialictus</i>) (Hymenoptera: Halictidae) of the western Nearctic (UMSP)	73	0.119
			Xerces Society - Bumble Bee Watch	3036	4.969
			The 'red-tailed' <i>Lasioglossum</i> (<i>Dialictus</i>) (Hymenoptera: Halictidae) of the western Nearctic (WMRE)	6	0.010

Table A.5—Continued

Butterfly Data Sources	# Butterfly Records	% of total GBIF Observations	Bee Data Sources	# Bee Records	% of total GBIF Observations
			International Barcode of Life project (iBOL)	146	0.239
Total GBIF Observations	143,686		Total GBIF Observations	61,100	
# observations directly downloaded from iNaturalist		155,096	# observations directly downloaded from iNaturalist		67,525
# iNaturalist Observations in GBIF		108,034	# iNaturalist observations in GBIF		47,731
# iNat Observations missing from GBIF		47,062	# iNat Observations missing from GBIF		19,794

Table A.6. Summary of identifiers for a subset of genera. The genera *Andrena*, *Bombus*, and *Lasioglossum* had 100 observations haphazardly chosen from our regional dataset to be evaluated for identifier qualification. The top four identifiers with the highest taxonomic expertise were included unless there were two or more taxonomic experts identifying the observation. When this was the case some novice users were not recorded in this table.

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Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Andrena</i>	12358998	https://www.inaturalist.org/observations/12358998	1	2	Taxonomist	Trusted Identifier	Trusted Identifier	Novice
<i>Lasioglossum</i>	17766706	https://www.inaturalist.org/observations/17766706	1	3	Novice	Trusted Identifier	Taxonomist	Trusted Identifier
<i>Andrena</i>	27091125	https://www.inaturalist.org/observations/27091125	1	2	Novice	Novice	Trusted Identifier	Taxonomist
<i>Lasioglossum</i>	41734723	https://www.inaturalist.org/observations/41734723	1	2	Novice	Taxonomist	Trusted Identifier	Novice
<i>Andrena</i>	22170950	https://www.inaturalist.org/observations/22170950	1	2	Trusted Identifier	Taxonomist	Trusted Identifier	Novice
<i>Lasioglossum</i>	203344	https://www.inaturalist.org/observations/35296782	1	2	Taxonomist	Novice	Trusted Identifier	Novice
<i>Lasioglossum</i>	2683034	http://www.inaturalist.org/observations/2683034	1	3	Novice	Taxonomist	Trusted Identifier	Trusted Identifier
<i>Bombus</i>	53897591	https://www.inaturalist.org/observations/53897591	2	4	Trusted Identifier	Taxonomist	Trusted Identifier	Taxonomist

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Andrena</i>	15582820	https://www.inaturalist.org/observations/15582820	1	2	Novice	Novice	Trusted Identifier	Taxonomist
<i>Lasioglossum</i>	97215435	https://www.inaturalist.org/observations/97215435	1	2	Novice	Taxonomist	Trusted Identifier	Novice
<i>Lasioglossum</i>	21278946	https://www.inaturalist.org/observations/21278946	1	2	Novice	Novice	Taxonomist	Novice
<i>Lasioglossum</i>	34587654	https://www.inaturalist.org/observations/34587654	1	2	Taxonomist	Trusted Identifier	Novice	Trusted Identifier
<i>Lasioglossum</i>	17083765	https://www.inaturalist.org/observations/17083765	1	2	Taxonomist	Novice	Novice	Trusted Identifier
<i>Andrena</i>	60563902	https://www.inaturalist.org/observations/60563902	1	2	Novice	Novice	Taxonomist	Trusted Identifier
<i>Andrena</i>	6153213	https://www.inaturalist.org/observations/6153213	1	2	Novice	Novice	Taxonomist	Trusted Identifier
<i>Lasioglossum</i>	67028675	https://www.inaturalist.org/observations/67028675	1	3	Trusted Identifier	Taxonomist	Novice	Trusted Identifier
<i>Lasioglossum</i>	65083588	https://www.inaturalist.org/observations/65083588	1	3	Novice	Taxonomist	Trusted Identifier	Trusted Identifier
<i>Lasioglossum</i>	65083589	https://www.inaturalist.org/observations/65083589	1	3	Novice	Taxonomist	Trusted Identifier	Trusted Identifier

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Andrena</i>	13241410	https://www.inaturalist.org/observations/13241410	2	3	Taxonomist	Taxonomist	Novice	Trusted Identifier
<i>Andrena</i>	25895502	https://www.inaturalist.org/observations/25895502	1	3	Trusted Identifier	Trusted Identifier	Taxonomist	Novice
<i>Andrena</i>	40732184	https://www.inaturalist.org/observations/40732184	1	1	Novice	Taxonomist	Novice	Novice
<i>Lasioglossum</i>	13223527	https://www.inaturalist.org/observations/13223527	2	2	Taxonomist	Taxonomist	Novice	Trusted Identifier
<i>Lasioglossum</i>	34509559	https://www.inaturalist.org/observations/34509559	1	2	Trusted Identifier	Taxonomist	Novice	Novice
<i>Bombus</i>	5232167	https://www.inaturalist.org/observations/5232167	2	4	Taxonomist	Trusted Identifier	Taxonomist	
<i>Andrena</i>	15320355	https://www.inaturalist.org/observations/15320355	1	1	Novice	Taxonomist	Novice	
<i>Lasioglossum</i>	67913362	https://www.inaturalist.org/observations/67913362	1	2	Novice	Taxonomist	Trusted Identifier	
<i>Bombus</i>	189905359	https://www.inaturalist.org/observations/189905359	0	2	Trusted Identifier	Novice	Trusted Identifier	
<i>Bombus</i>	204515015	https://www.inaturalist.org/observations/204515015	0	1	Novice	Novice	Trusted Identifier	

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Bombus</i>	35621679	https://www.inaturalist.org/observations/35621679	1	3	Taxonomist	Trusted Identifier	Trusted Identifier	
<i>Bombus</i>	195693340	https://www.inaturalist.org/observations/195693340	0	3	Trusted Identifier	Trusted Identifier	Trusted Identifier	
<i>Bombus</i>	189018657	https://www.inaturalist.org/observations/189018657	1	3	Taxonomist	Trusted Identifier	Trusted Identifier	
<i>Andrena</i>	57849548	https://www.inaturalist.org/observations/57849548	1	1	Novice	Taxonomist	Trusted Identifier	
<i>Lasioglossum</i>	51313475	https://www.inaturalist.org/observations/51313475	1	2	Taxonomist	Trusted Identifier	Novice	
<i>Andrena</i>	127730	https://www.inaturalist.org/observations/117518933	0	0	Novice	Novice	Novice	
<i>Andrena</i>	9023567	https://www.inaturalist.org/observations/9023567	1	2	Trusted Identifier	Taxonomist	Trusted Identifier	
<i>Andrena</i>	51436325	https://www.inaturalist.org/observations/51436325	1	1	Novice	Taxonomist	Novice	
<i>Bombus</i>	85780271	https://www.inaturalist.org/observations/85780271	0	1	Trusted Identifier	Novice	Novice	
<i>Andrena</i>	41398873	https://www.inaturalist.org/observations/41398873	0	1	Novice	Trusted Identifier	Novice	

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Bombus</i>	84119830	https://www.inaturalist.org/observations/84119830	0	1	Trusted Identifier	Novice	Novice	
<i>Andrena</i>	13568158	https://www.inaturalist.org/observations/13568158	1	1	Novice	Taxonomist	Novice	
<i>Lasioglossum</i>	12781135	https://www.inaturalist.org/observations/12781135	1	2	Novice	Taxonomist	Trusted Identifier	
<i>Bombus</i>	1497146	http://www.inaturalist.org/observations/1497146	2	3	Taxonomist	Taxonomist	Trusted Identifier	
<i>Bombus</i>	55358963	https://www.inaturalist.org/observations/55358963	0	2	Trusted Identifier	Novice	Novice	
<i>Lasioglossum</i>	56708395	https://www.inaturalist.org/observations/56708395	1	2	Novice	Taxonomist	Trusted Identifier	
<i>Lasioglossum</i>	9044073	https://www.inaturalist.org/observations/9044073	2	3	Trusted Identifier	Taxonomist	Taxonomist	
<i>Lasioglossum</i>	9054559	https://www.inaturalist.org/observations/9054559	2	3	Trusted Identifier	Taxonomist	Taxonomist	
<i>Lasioglossum</i>	86826	https://www.inaturalist.org/observations/167422640	2	3	Trusted Identifier	Taxonomist	Taxonomist	
<i>Andrena</i>	31308393	https://www.inaturalist.org/observations/31308393	1	2	Novice	Trusted Identifier	Taxonomist	

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Andrena</i>	218161	https://www.inaturalist.org/observations/96530905	1	1	Novice	Novice	Taxonomist	
<i>Bombus</i>	145231922	https://www.inaturalist.org/observations/145231922	1	2	Novice	Trusted Identifier	Taxonomist	
<i>Andrena</i>	46888662	https://www.inaturalist.org/observations/46888662	1	1	Novice	Novice	Taxonomist	
<i>Andrena</i>	26212080	https://www.inaturalist.org/observations/26212080	1	2	Novice	Trusted Identifier	Taxonomist	
<i>Lasioglossum</i>	26054	https://www.inaturalist.org/observations/170219140	1	1	Novice	Taxonomist	Novice	
<i>Bombus</i>	131901977	https://www.inaturalist.org/observations/131901977	0	1	Novice	Trusted Identifier	Novice	
<i>Bombus</i>	14963773	https://www.inaturalist.org/observations/14963773	1	1	Taxonomist	Novice	Novice	
<i>Bombus</i>	55804630	https://www.inaturalist.org/observations/55804630	0	2	Trusted Identifier	Trusted Identifier	Novice	
<i>Bombus</i>	83432009	https://www.inaturalist.org/observations/83432009	1	2	Trusted Identifier	Taxonomist	Novice	
<i>Bombus</i>	60708948	https://www.inaturalist.org/observations/60708948	1	2	Trusted Identifier	Taxonomist	Novice	

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Bombus</i>	28933622	https://www.inaturalist.org/observations/28933622	0	1	Trusted Identifier	Novice	Novice	
<i>Bombus</i>	171782452	https://www.inaturalist.org/observations/171782452	0	0	Novice	Novice	Novice	
<i>Bombus</i>	29382391	https://www.inaturalist.org/observations/29382391	0	1	Novice	Trusted Identifier	Novice	
<i>Bombus</i>	134359942	https://www.inaturalist.org/observations/134359942	0	2	Trusted Identifier	Trusted Identifier	Novice	
<i>Bombus</i>	180537601	https://www.inaturalist.org/observations/180537601	0	2	Trusted Identifier	Trusted Identifier	Novice	
<i>Bombus</i>	123875827	https://www.inaturalist.org/observations/123875827	0	2	Trusted Identifier	Trusted Identifier	Novice	
<i>Bombus</i>	54438209	https://www.inaturalist.org/observations/54438209	1	2	Taxonomist	Trusted Identifier	Novice	
<i>Bombus</i>	105482272	https://www.inaturalist.org/observations/105482272	0	2	Trusted Identifier	Trusted Identifier	Novice	
<i>Bombus</i>	13897119	https://www.inaturalist.org/observations/13897119	0	1	Novice	Trusted Identifier	Novice	
<i>Bombus</i>	6164864	https://www.inaturalist.org/observations/6164864	0	1	Trusted Identifier	Novice	Novice	

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Bombus</i>	59480257	https://www.inaturalist.org/observations/59480257	0	1	Trusted Identifier	Novice	Novice	
<i>Bombus</i>	183047368	https://www.inaturalist.org/observations/183047368	1	2	Trusted Identifier	Taxonomist	Novice	
<i>Bombus</i>	106875726	https://www.inaturalist.org/observations/106875726	1	2	Trusted Identifier	Taxonomist	Novice	
<i>Lasioglossum</i>	9043899	https://www.inaturalist.org/observations/9043899	1	2	Taxonomist	Trusted Identifier	Novice	
<i>Bombus</i>	54525743	https://www.inaturalist.org/observations/54525743	0	0	Novice	Novice	Novice	
<i>Lasioglossum</i>	41800303	https://www.inaturalist.org/observations/41800303	1	2	Taxonomist	Trusted Identifier	Novice	
<i>Lasioglossum</i>	23087094	https://www.inaturalist.org/observations/23087094	1	2	Taxonomist	Novice	Trusted Identifier	
<i>Bombus</i>	60137360	https://www.inaturalist.org/observations/60137360	1	2	Taxonomist	Novice	Trusted Identifier	
<i>Lasioglossum</i>	214226	https://www.inaturalist.org/observations/86070527	0	2	Novice	Trusted Identifier	Trusted Identifier	
<i>Andrena</i>	9464079	https://www.inaturalist.org/observations/9464079	1	2	Taxonomist	Trusted Identifier	Novice	

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Andrena</i>	109016	https://www.inaturalist.org/observations/13871144	1	1	Novice	Taxonomist	Trusted Identifier	
<i>Lasioglossum</i>	23567	https://www.inaturalist.org/observations/100783918	1	1	Novice	Taxonomist	Novice	
<i>Lasioglossum</i>	81706	https://www.inaturalist.org/observations/137353486	0	0	Novice	Novice	Novice	
<i>Bombus</i>	195877442	https://www.inaturalist.org/observations/195877442	0	3	Trusted Identifier	Trusted Identifier	Trusted Identifier	
<i>Bombus</i>	30908584	https://www.inaturalist.org/observations/30908584	0	1	Novice	Novice	Trusted Identifier	
<i>Bombus</i>	90351421	https://www.inaturalist.org/observations/90351421	0	3	Trusted Identifier	Trusted Identifier	Trusted Identifier	
<i>Bombus</i>	17556741	https://www.inaturalist.org/observations/17556741	1	3	Taxonomist	Trusted Identifier	Trusted Identifier	
<i>Bombus</i>	89843530	https://www.inaturalist.org/observations/89843530	1	3	Taxonomist	Trusted Identifier	Trusted Identifier	
<i>Andrena</i>	57987863	https://www.inaturalist.org/observations/57987863	1	1	Novice	Taxonomist	Novice	
<i>Andrena</i>	169351	https://www.inaturalist.org/observations/96322267	1	1	Taxonomist	Novice	Novice	

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Lasioglossum</i>	211728	https://www.inaturalist.org/observations/72047599	0	1	Novice	Trusted Identifier	Novice	
<i>Lasioglossum</i>	27281807	https://www.inaturalist.org/observations/27281807	1	2	Taxonomist	Novice	Novice	
<i>Bombus</i>	21984519	https://www.inaturalist.org/observations/21984519	0	2	Trusted Identifier	Trusted Identifier	Trusted Identifier	
<i>Lasioglossum</i>	197956	https://www.inaturalist.org/observations/17083765	1	2	Taxonomist	Novice	Trusted Identifier	
<i>Andrena</i>	71241426	https://www.inaturalist.org/observations/71241426	1	2	Taxonomist	Novice	Trusted Identifier	
<i>Andrena</i>	20241953	https://www.inaturalist.org/observations/20241953	1	2	Novice	Taxonomist	Trusted Identifier	
<i>Bombus</i>	70220405	https://www.inaturalist.org/observations/70220405	1	3	Trusted Identifier	Taxonomist	Trusted Identifier	
<i>Bombus</i>	57695012	https://www.inaturalist.org/observations/57695012	1	3	Trusted Identifier	Taxonomist	Trusted Identifier	
<i>Lasioglossum</i>	68219529	https://www.inaturalist.org/observations/68219529	1	2	Novice	Taxonomist	Trusted Identifier	
<i>Lasioglossum</i>	24918787	https://www.inaturalist.org/observations/24918787	2	3	Taxonomist	Taxonomist	Trusted Identifier	

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Andrena</i>	59976582	https://www.inaturalist.org/observations/59976582	1	2	Taxonomist	Novice	Trusted Identifier	
<i>Lasioglossum</i>	35069025	https://www.inaturalist.org/observations/35069025	1	2	Taxonomist	Novice	Trusted Identifier	
<i>Lasioglossum</i>	30299737	https://www.inaturalist.org/observations/30299737	1	2	Taxonomist	Novice	Trusted Identifier	
<i>Bombus</i>	1527744	http://www.inaturalist.org/observations/1527744	1	3	Taxonomist	Trusted Identifier	Trusted Identifier	
<i>Lasioglossum</i>	17234466	https://www.inaturalist.org/observations/17234466	1	2	Taxonomist	Novice	Trusted Identifier	
<i>Andrena</i>	4133310	http://www.inaturalist.org/observations/4133310	1	1	Novice	Taxonomist	Novice	
<i>Andrena</i>	114533	https://www.inaturalist.org/observations/47413974	1	3	Taxonomist	Trusted Identifier	Trusted Identifier	
<i>Andrena</i>	34251661	https://www.inaturalist.org/observations/34251661	1	1	Novice	Taxonomist	Novice	
<i>Bombus</i>	133137756	https://www.inaturalist.org/observations/133137756	0	1	Trusted Identifier	Novice	Novice	
<i>Bombus</i>	28706876	https://www.inaturalist.org/observations/28706876	0	0	Novice	Novice	Novice	

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Bombus</i>	192937631	https://www.inaturalist.org/observations/192937631	0	2	Trusted Identifier	Novice	Novice	
<i>Bombus</i>	132466748	https://www.inaturalist.org/observations/132466748	1	2	Novice	Trusted Identifier	Taxonomist	
<i>Bombus</i>	35792038	https://www.inaturalist.org/observations/35792038	2	3	Taxonomist	Trusted Identifier	Taxonomist	
<i>Andrena</i>	79855921	https://www.inaturalist.org/observations/79855921	1	1	Taxonomist	Novice		
<i>Andrena</i>	43158691	https://www.inaturalist.org/observations/43158691	0	1	Trusted Identifier	Novice		
<i>Lasioglossum</i>	58161609	https://www.inaturalist.org/observations/58161609	1	1	Taxonomist	Novice		
<i>Lasioglossum</i>	34719505	https://www.inaturalist.org/observations/34719505	1	1	Taxonomist	Novice		
<i>Lasioglossum</i>	66198	https://www.inaturalist.org/observations/118513930	0	1	Trusted Identifier	Novice		
<i>Bombus</i>	187141297	https://www.inaturalist.org/observations/187141297	0	1	Novice	Trusted Identifier		
<i>Andrena</i>	128213	https://www.inaturalist.org/observations/121764731	1	2	Taxonomist	Trusted Identifier		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Andrena</i>	10173	https://www.inaturalist.org/observations/164237134	0	1	Novice	Trusted Identifier		
<i>Bombus</i>	16933193	https://www.inaturalist.org/observations/16933193	0	2	Trusted Identifier	Trusted Identifier		
<i>Lasioglossum</i>	40876	https://www.inaturalist.org/observations/52411832	0	1	Novice	Trusted Identifier		
<i>Andrena</i>	46683053	https://www.inaturalist.org/observations/46683053	1	1	Taxonomist	Novice		
<i>Lasioglossum</i>	185956	https://www.inaturalist.org/observations/186745845	0	1	Trusted Identifier	Novice		
<i>Andrena</i>	57795	https://www.inaturalist.org/observations/90582140	1	2	Taxonomist	Novice		
<i>Lasioglossum</i>	32027702	https://www.inaturalist.org/observations/32027702	1	1	Taxonomist	Novice		
<i>Lasioglossum</i>	47068213	https://www.inaturalist.org/observations/47068213	1	1	Taxonomist	Novice		
<i>Lasioglossum</i>	16674870	https://www.inaturalist.org/observations/16674870	1	1	Taxonomist	Novice		
<i>Andrena</i>	43651789	https://www.inaturalist.org/observations/43651789	1	1	Taxonomist	Novice		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Bombus</i>	59725838	https://www.inaturalist.org/observations/59725838	0	1	Trusted Identifier	Novice		
<i>Andrena</i>	29567	https://www.inaturalist.org/observations/13502847	1	1	Taxonomist	Novice		
<i>Andrena</i>	44511526	https://www.inaturalist.org/observations/44511526	0	1	Novice	Trusted Identifier		
<i>Andrena</i>	12013790	https://www.inaturalist.org/observations/12013790	1	2	Taxonomist	Trusted Identifier		
<i>Andrena</i>	108485	https://www.inaturalist.org/observations/9464016	1	2	Taxonomist	Trusted Identifier		
<i>Andrena</i>	108311	https://www.inaturalist.org/observations/9017570	1	2	Taxonomist	Trusted Identifier		
<i>Andrena</i>	110649	https://www.inaturalist.org/observations/19645265	1	2	Taxonomist	Trusted Identifier		
<i>Lasioglossum</i>	19601177	https://www.inaturalist.org/observations/19601177	1	2	Taxonomist	Trusted Identifier		
<i>Andrena</i>	43498257	https://www.inaturalist.org/observations/43498257	1	1	Taxonomist	Novice		
<i>Lasioglossum</i>	2905	https://www.inaturalist.org/observations/37651226	1	1	Taxonomist	Novice		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Andrena</i>	205230	https://www.inaturalist.org/observations/51038800	1	1	Taxonomist	Novice		
<i>Lasioglossum</i>	11603362	https://www.inaturalist.org/observations/11603362	1	1	Novice	Taxonomist		
<i>Lasioglossum</i>	19625047	https://www.inaturalist.org/observations/19625047	1	1	Novice	Taxonomist		
<i>Bombus</i>	57163544	https://www.inaturalist.org/observations/57163544	1	1	Novice	Taxonomist		
<i>Lasioglossum</i>	113287	https://www.inaturalist.org/observations/31311673	1	1	Novice	Taxonomist		
<i>Andrena</i>	228812	https://www.inaturalist.org/observations/171137526	1	1	Novice	Taxonomist		
<i>Lasioglossum</i>	1882	https://www.inaturalist.org/observations/27281807	1	2	Trusted Identifier	Taxonomist		
<i>Andrena</i>	22106818	https://www.inaturalist.org/observations/22106818	1	1	Novice	Taxonomist		
<i>Andrena</i>	235849	https://www.inaturalist.org/observations/196364724	1	1	Novice	Taxonomist		
<i>Andrena</i>	71005	https://www.inaturalist.org/observations/127059449	1	1	Novice	Taxonomist		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Andrena</i>	67803	https://www.inaturalist.org/observations/122770189	1	1	Novice	Taxonomist		
<i>Andrena</i>	180002	https://www.inaturalist.org/observations/169837950	1	1	Novice	Taxonomist		
<i>Andrena</i>	47546131	https://www.inaturalist.org/observations/47546131	1	1	Novice	Taxonomist		
<i>Andrena</i>	229598	https://www.inaturalist.org/observations/173180679	1	1	Novice	Taxonomist		
<i>Bombus</i>	54225157	https://www.inaturalist.org/observations/54225157	1	2	Trusted Identifier	Taxonomist		
<i>Bombus</i>	83922973	https://www.inaturalist.org/observations/83922973	1	1	Novice	Taxonomist		
<i>Andrena</i>	9047637	https://www.inaturalist.org/observations/9047637	1	2	Trusted Identifier	Taxonomist		
<i>Andrena</i>	12870887	https://www.inaturalist.org/observations/12870887	1	2	Trusted Identifier	Taxonomist		
<i>Lasioglossum</i>	13651049	https://www.inaturalist.org/observations/13651049	1	2	Trusted Identifier	Taxonomist		
<i>Andrena</i>	46447820	https://www.inaturalist.org/observations/46447820	1	1	Novice	Taxonomist		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Andrena</i>	45932797	https://www.inaturalist.org/observations/45932797	1	1	Novice	Taxonomist		
<i>Andrena</i>	77519515	https://www.inaturalist.org/observations/77519515	1	1	Novice	Taxonomist		
<i>Andrena</i>	14434062	https://www.inaturalist.org/observations/14434062	1	2	Trusted Identifier	Taxonomist		
<i>Andrena</i>	10498809	https://www.inaturalist.org/observations/10498809	1	2	Trusted Identifier	Taxonomist		
<i>Andrena</i>	9011532	https://www.inaturalist.org/observations/9011532	1	2	Trusted Identifier	Taxonomist		
<i>Andrena</i>	20246183	https://www.inaturalist.org/observations/20246183	1	2	Trusted Identifier	Taxonomist		
<i>Lasioglossum</i>	14434072	https://www.inaturalist.org/observations/14434072	1	2	Trusted Identifier	Taxonomist		
<i>Lasioglossum</i>	15035247	https://www.inaturalist.org/observations/15035247	1	2	Trusted Identifier	Taxonomist		
<i>Lasioglossum</i>	196488	https://www.inaturalist.org/observations/14434072	1	2	Trusted Identifier	Taxonomist		
<i>Lasioglossum</i>	50723	https://www.inaturalist.org/observations/82054424	1	1	Novice	Taxonomist		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Lasioglossum</i>	78769293	https://www.inaturalist.org/observations/78769293	1	1	Novice	Taxonomist		
<i>Andrena</i>	9344779	https://www.inaturalist.org/observations/9344779	1	1	Novice	Taxonomist		
<i>Andrena</i>	32482	https://www.inaturalist.org/observations/24777203	1	1	Novice	Taxonomist		
<i>Andrena</i>	119960	https://www.inaturalist.org/observations/57492813	1	1	Novice	Taxonomist		
<i>Lasioglossum</i>	2760541	http://www.inaturalist.org/observations/2760541	1	1	Novice	Taxonomist		
<i>Andrena</i>	135564	https://www.inaturalist.org/observations/154883807	1	1	Novice	Taxonomist		
<i>Andrena</i>	129153	https://www.inaturalist.org/observations/125812819	1	1	Novice	Taxonomist		
<i>Andrena</i>	128588	https://www.inaturalist.org/observations/123547386	1	1	Novice	Taxonomist		
<i>Lasioglossum</i>	129098	https://www.inaturalist.org/observations/125654579	1	1	Novice	Taxonomist		
<i>Lasioglossum</i>	137206	https://www.inaturalist.org/observations/171219858	1	1	Novice	Taxonomist		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Lasioglossum</i>	135224	https://www.inaturalist.org/observations/140887236	1	1	Novice	Taxonomist		
<i>Lasioglossum</i>	133108	https://www.inaturalist.org/observations/131622812	1	1	Novice	Taxonomist		
<i>Andrena</i>	218201	https://www.inaturalist.org/observations/96638414	1	1	Novice	Taxonomist		
<i>Andrena</i>	81239	https://www.inaturalist.org/observations/136727694	1	1	Novice	Taxonomist		
<i>Andrena</i>	32318	https://www.inaturalist.org/observations/22472498	1	2	Trusted Identifier	Taxonomist		
<i>Bombus</i>	42026946	https://www.inaturalist.org/observations/42026946	1	2	Trusted Identifier	Taxonomist		
<i>Bombus</i>	53780137	https://www.inaturalist.org/observations/53780137	1	2	Trusted Identifier	Taxonomist		
<i>Bombus</i>	60079463	https://www.inaturalist.org/observations/60079463	1	2	Trusted Identifier	Taxonomist		
<i>Andrena</i>	91549	https://www.inaturalist.org/observations/173878784	1	1	Novice	Taxonomist		
<i>Andrena</i>	190264	https://www.inaturalist.org/observations/169471900	1	1	Novice	Taxonomist		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Andrena</i>	47794028	https://www.inaturalist.org/observations/47794028	1	1	Novice	Taxonomist		
<i>Andrena</i>	139735	https://www.inaturalist.org/observations/176228558	1	1	Novice	Taxonomist		
<i>Lasioglossum</i>	5238145	https://www.inaturalist.org/observations/5238145	1	1	Novice	Taxonomist		
<i>Andrena</i>	94414	https://www.inaturalist.org/observations/176138466	1	1	Novice	Taxonomist		
<i>Andrena</i>	194608	https://www.inaturalist.org/observations/8282378	1	1	Novice	Taxonomist		
<i>Andrena</i>	25421	https://www.inaturalist.org/observations/152587854	1	1	Novice	Taxonomist		
<i>Andrena</i>	41724061	https://www.inaturalist.org/observations/41724061	1	1	Novice	Taxonomist		
<i>Andrena</i>	62089	https://www.inaturalist.org/observations/96022014	1	2	Trusted Identifier	Taxonomist		
<i>Andrena</i>	51292	https://www.inaturalist.org/observations/83465002	1	1	Novice	Taxonomist		
<i>Lasioglossum</i>	226208	https://www.inaturalist.org/observations/141104172	1	1	Novice	Taxonomist		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Andrena</i>	64709	https://www.inaturalist.org/observations/106056497	1	1	Taxonomist	Novice		
<i>Andrena</i>	169566	https://www.inaturalist.org/observations/96624689	1	2	Taxonomist	Trusted Identifier		
<i>Andrena</i>	119818855	https://www.inaturalist.org/observations/119818855	0	2	Trusted Identifier	Trusted Identifier		
<i>Andrena</i>	22565	https://www.inaturalist.org/observations/72218548	1	1	Taxonomist	Novice		
<i>Andrena</i>	10552721	https://www.inaturalist.org/observations/10552721	1	1	Taxonomist	Novice		
<i>Bombus</i>	131401071	https://www.inaturalist.org/observations/131401071	0	1	Trusted Identifier	Novice		
<i>Lasioglossum</i>	37713641	https://www.inaturalist.org/observations/37713641	0	1	Trusted Identifier	Novice		
<i>Lasioglossum</i>	62644800	https://www.inaturalist.org/observations/62644800	0	1	Trusted Identifier	Novice		
<i>Lasioglossum</i>	52611	https://www.inaturalist.org/observations/85755920	0	1	Trusted Identifier	Novice		
<i>Lasioglossum</i>	161188	https://www.inaturalist.org/observations/85662010	0	1	Trusted Identifier	Novice		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Andrena</i>	143883	https://www.inaturalist.org/observations/194924091	1	1	Taxonomist	Novice		
<i>Bombus</i>	12523159	https://www.inaturalist.org/observations/12523159	1	1	Taxonomist	Novice		
<i>Bombus</i>	64151948	https://www.inaturalist.org/observations/64151948	1	1	Taxonomist	Novice		
<i>Bombus</i>	90723568	https://www.inaturalist.org/observations/90723568	0	1	Trusted Identifier	Novice		
<i>Bombus</i>	85979875	https://www.inaturalist.org/observations/85979875	0	1	Trusted Identifier	Novice		
<i>Bombus</i>	130991924	https://www.inaturalist.org/observations/130991924	0	1	Trusted Identifier	Novice		
<i>Bombus</i>	171300530	https://www.inaturalist.org/observations/171300530	0	0	Novice	Novice		
<i>Lasioglossum</i>	104876	https://www.inaturalist.org/observations/187197041	0	0	Novice	Novice		
<i>Lasioglossum</i>	20889	https://www.inaturalist.org/observations/184233583	0	0	Novice	Novice		
<i>Lasioglossum</i>	205307	https://www.inaturalist.org/observations/51313475	1	2	Taxonomist	Trusted Identifier		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Lasioglossum</i>	203948	https://www.inaturalist.org/observations/42724723	1	2	Taxonomist	Trusted Identifier		
<i>Lasioglossum</i>	128495	https://www.inaturalist.org/observations/123117030	0	1	Novice	Trusted Identifier		
<i>Lasioglossum</i>	217429	https://www.inaturalist.org/observations/93615414	0	2	Trusted Identifier	Trusted Identifier		
<i>Lasioglossum</i>	35088602	https://www.inaturalist.org/observations/35088602	1	1	Taxonomist	Novice		
<i>Lasioglossum</i>	14942714	https://www.inaturalist.org/observations/14942714	1	1	Taxonomist	Novice		
<i>Andrena</i>	224659	https://www.inaturalist.org/observations/134122883	1	1	Taxonomist	Novice		
<i>Lasioglossum</i>	100568	https://www.inaturalist.org/observations/181482581	0	0	Novice	Novice		
<i>Bombus</i>	4671632	http://www.inaturalist.org/observations/4671632	1	1	Taxonomist	Novice		
<i>Lasioglossum</i>	99238	https://www.inaturalist.org/observations/180221721	0	0	Novice	Novice		
<i>Lasioglossum</i>	128975	https://www.inaturalist.org/observations/125307078	1	1	Taxonomist	Novice		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Lasioglossum</i>	218629	https://www.inaturalist.org/observations/98766186	1	1	Taxonomist	Novice		
<i>Lasioglossum</i>	109980	https://www.inaturalist.org/observations/16055834	1	1	Taxonomist	Novice		
<i>Lasioglossum</i>	135303	https://www.inaturalist.org/observations/142767946	1	1	Taxonomist	Novice		
<i>Lasioglossum</i>	226279	https://www.inaturalist.org/observations/141423331	1	1	Taxonomist	Novice		
<i>Lasioglossum</i>	100746	https://www.inaturalist.org/observations/181734216	0	0	Novice	Novice		
<i>Lasioglossum</i>	79248	https://www.inaturalist.org/observations/134659833	0	0	Novice	Novice		
<i>Lasioglossum</i>	66343	https://www.inaturalist.org/observations/119149477	0	0	Novice	Novice		
<i>Lasioglossum</i>	143059	https://www.inaturalist.org/observations/184139185	1	1	Taxonomist	Novice		
<i>Lasioglossum</i>	43314791	https://www.inaturalist.org/observations/43314791	1	1	Taxonomist	Novice		
<i>Andrena</i>	135438	https://www.inaturalist.org/observations/145795995	0	0	Novice	Novice		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Bombus</i>	128525092	https://www.inaturalist.org/observations/128525092	0	2	Trusted Identifier	Trusted Identifier		
<i>Bombus</i>	82086426	https://www.inaturalist.org/observations/82086426	0	1	Novice	Trusted Identifier		
<i>Bombus</i>	16410351	https://www.inaturalist.org/observations/16410351	0	2	Trusted Identifier	Trusted Identifier		
<i>Bombus</i>	14969740	https://www.inaturalist.org/observations/14969740	0	2	Trusted Identifier	Trusted Identifier		
<i>Bombus</i>	86187008	https://www.inaturalist.org/observations/86187008	0	2	Trusted Identifier	Trusted Identifier		
<i>Andrena</i>	53552994	https://www.inaturalist.org/observations/53552994	1	2	Taxonomist	Trusted Identifier		
<i>Andrena</i>	6321	https://www.inaturalist.org/observations/89872652	1	2	Taxonomist	Trusted Identifier		
<i>Andrena</i>	41563	https://www.inaturalist.org/observations/53552994	1	2	Taxonomist	Trusted Identifier		
<i>Bombus</i>	12382173	https://www.inaturalist.org/observations/12382173	1	2	Taxonomist	Trusted Identifier		
<i>Bombus</i>	15458948	https://www.inaturalist.org/observations/15458948	1	2	Taxonomist	Trusted Identifier		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Bombus</i>	16083798	https://www.inaturalist.org/observations/16083798	1	2	Taxonomist	Trusted Identifier		
<i>Bombus</i>	29001494	https://www.inaturalist.org/observations/29001494	1	2	Taxonomist	Trusted Identifier		
<i>Bombus</i>	31645335	https://www.inaturalist.org/observations/31645335	1	2	Taxonomist	Trusted Identifier		
<i>Bombus</i>	57970864	https://www.inaturalist.org/observations/57970864	1	2	Taxonomist	Trusted Identifier		
<i>Bombus</i>	52217393	https://www.inaturalist.org/observations/52217393	1	2	Taxonomist	Trusted Identifier		
<i>Bombus</i>	45796982	https://www.inaturalist.org/observations/45796982	1	2	Taxonomist	Trusted Identifier		
<i>Bombus</i>	62823079	https://www.inaturalist.org/observations/62823079	1	2	Taxonomist	Trusted Identifier		
<i>Bombus</i>	33604781	https://www.inaturalist.org/observations/33604781	0	1	Novice	Trusted Identifier		
<i>Bombus</i>	15785142	https://www.inaturalist.org/observations/15785142	0	2	Trusted Identifier	Trusted Identifier		
<i>Bombus</i>	62999507	https://www.inaturalist.org/observations/62999507	0	2	Trusted Identifier	Trusted Identifier		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Bombus</i>	181918488	https://www.inaturalist.org/observations/181918488	0	1	Novice	Trusted Identifier		
<i>Bombus</i>	91640860	https://www.inaturalist.org/observations/91640860	0	2	Trusted Identifier	Trusted Identifier		
<i>Bombus</i>	86055992	https://www.inaturalist.org/observations/86055992	0	2	Trusted Identifier	Trusted Identifier		
<i>Bombus</i>	88572418	https://www.inaturalist.org/observations/88572418	0	1	Novice	Trusted Identifier		
<i>Bombus</i>	86244604	https://www.inaturalist.org/observations/86244604	0	2	Trusted Identifier	Trusted Identifier		
<i>Bombus</i>	84889685	https://www.inaturalist.org/observations/84889685	0	2	Trusted Identifier	Trusted Identifier		
<i>Bombus</i>	86123303	https://www.inaturalist.org/observations/86123303	1	2	Taxonomist	Trusted Identifier		
<i>Lasioglossum</i>	4164710	http://www.inaturalist.org/observations/4164710	1	1	Taxonomist	Novice		
<i>Bombus</i>	130550045	https://www.inaturalist.org/observations/130550045	0	1	Trusted Identifier	Novice		
<i>Andrena</i>	32705757	https://www.inaturalist.org/observations/32705757	1	1	Taxonomist	Novice		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Bombus</i>	38004731	https://www.inaturalist.org/observations/38004731	1	1	Taxonomist	Novice		
<i>Lasioglossum</i>	34643327	https://www.inaturalist.org/observations/34643327	0	1	Novice	Novice		
<i>Andrena</i>	199424	https://www.inaturalist.org/observations/26905123	1	2	Taxonomist	Trusted Identifier		
<i>Bombus</i>	30790660	https://www.inaturalist.org/observations/30790660	1	2	Taxonomist	Trusted Identifier		
<i>Lasioglossum</i>	19632	https://www.inaturalist.org/observations/101178508	1	2	Taxonomist	Trusted Identifier		
<i>Andrena</i>	42769	https://www.inaturalist.org/observations/54952237	1	1	Taxonomist	Novice		
<i>Andrena</i>	42769	https://www.inaturalist.org/observations/54952237	1	1	Taxonomist	Novice		
<i>Andrena</i>	5704396	https://www.inaturalist.org/observations/5704396	1	1	Taxonomist	Novice		
<i>Andrena</i>	191283	https://www.inaturalist.org/observations/27448107	1	2	Taxonomist	Trusted Identifier		
<i>Lasioglossum</i>	64181	https://www.inaturalist.org/observations/102113242	1	1	Taxonomist	Novice		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Lasioglossum</i>	34582229	https://www.inaturalist.org/observations/34582229	0	0	Novice	Novice		
<i>Lasioglossum</i>	22253302	https://www.inaturalist.org/observations/22253302	0	0	Novice	Novice		
<i>Bombus</i>	175021011	https://www.inaturalist.org/observations/175021011	0	0	Novice	Novice		
<i>Bombus</i>	16113284	https://www.inaturalist.org/observations/16113284	0	0	Novice	Novice		
<i>Bombus</i>	26777621	https://www.inaturalist.org/observations/26777621	0	1	Trusted Identifier	Novice		
<i>Andrena</i>	212447	https://www.inaturalist.org/observations/79095372	1	1	Novice	Taxonomist		
<i>Bombus</i>	15756622	https://www.inaturalist.org/observations/15756622	1	2	Trusted Identifier	Taxonomist		
<i>Bombus</i>	13565656	https://www.inaturalist.org/observations/13565656	1	1	Novice	Taxonomist		
<i>Lasioglossum</i>	114099	https://www.inaturalist.org/observations/37713641	1	2	Trusted Identifier	Taxonomist		
<i>Bombus</i>	8055046	https://www.inaturalist.org/observations/8055046	2	2	Taxonomist	Taxonomist		

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Bombus</i>	30458570	https://www.inaturalist.org/observations/30458570	2	2	Taxonomist	Taxonomist		
<i>Bombus</i>	33244494	https://www.inaturalist.org/observations/33244494	2	2	Taxonomist	Taxonomist		
<i>Bombus</i>	58468131	https://www.inaturalist.org/observations/58468131	2	2	Taxonomist	Taxonomist		
<i>Lasioglossum</i>	170057246	https://www.inaturalist.org/observations/170057246	1	1	Novice	Taxonomist		
<i>Bombus</i>	183789097	https://www.inaturalist.org/observations/183789097	1	2	Trusted Identifier	Taxonomist		
<i>Lasioglossum</i>	2905	https://www.inaturalist.org/observations/37651226	1	1	Taxonomist			
<i>Lasioglossum</i>	39291	https://www.inaturalist.org/observations/48288399	1	1	Taxonomist			
<i>Lasioglossum</i>	61066	https://www.inaturalist.org/observations/94365720	1	1	Taxonomist			
<i>Lasioglossum</i>	25219	https://www.inaturalist.org/observations/138569206	1	1	Taxonomist			
<i>Lasioglossum</i>	50	http://www.inaturalist.org/observations/3273686	1	1	Taxonomist			

Table A.6—Continued

Bee Genus	Observation id	Url	# Taxonomist IDs	# Trusted IDs	ID Level 1	ID Level 2	ID Level 3	ID Level 4
<i>Lasioglossum</i>	111087	https://www.inaturalist.org/observations/26409642	1	1	Taxonomist			

Table A.7. Summary of identifiers for all bee species with only one observation documented on iNaturalist included in the dataset. If a taxonomic expert identified a bee only this identifier was listed. When a non-taxonomist identifier or known trusted identifier identified a bee multiple users were listed. (Identifier information was accessed in April 2024).

Bee Species	Identifier	Notes
<i>Agapostemon angelicus</i>	Zach Portman	Pinned specimen
<i>Andrena astragali</i>	John Ascher	
<i>Andrena bisalicens</i>	John Ascher	
<i>Andrena bradleyi</i>	John Ascher	
<i>Andrena canadensis</i>		Two PhD students
<i>Andrena cerebrata</i>	John Ascher/Nina Fogel	
<i>Andrena chromotricha</i>		PhD student researcher
<i>Andrena commoda</i>	John Ascher	
<i>Andrena hiliaris</i>	John Ascher	
<i>Andrena krigiana</i>	John Ascher	
<i>Andrena mentzeliae</i>	John Ascher	
<i>Andrena nivalis</i>	John Ascher	
<i>Andrena platyparia</i>	John Ascher	Pinned specimen
<i>Andrena quintilis</i>	John Ascher, Zach Portman	
<i>Andrena simplex</i>	John Ascher	Pinned specimen
<i>Andrena wilmattae</i>	John Ascher	
<i>Anthidium porterae</i>	John Ascher	
<i>Calliopsis callops</i>	John Ascher	
<i>Centris caesalpiniae</i>	John Ascher	
<i>Ceratina dupla</i>	Mellisa Spring	Post Doc researcher
<i>Coelioxys hunteri</i>	John Ascher	
<i>Coelioxys sodalis</i>	Jason Gibbs	
<i>Colletes nudus</i>	John Ascher	
<i>Colletes wilmattae</i>	Jason Gibbs	
<i>Epeolus canadensis</i>	John Ascher	
<i>Epeolus novomexicanus</i>	John Ascher	
<i>Eucera dubitata</i>	John Ascher	Pinned specimen
<i>Heriades variolosus</i>	Laura Rericha-Anchor	ID by Amy Moorehouse in lab
<i>Holcopasites heliopsis</i>	John Ascher	New state record
<i>Hylaeus sparsus</i>	John Ascher	
<i>Lasioglossum albipenne</i>		Post Doc at York
<i>Lasioglossum heterognathus</i>	John Ascher, Jason Gibbs	Pinned specimen
<i>Lasioglossum hitchensi</i>	John Ascher, James Hung	
<i>Lasioglossum leucozonium</i>	Michelle Orcut	

Table A.7—Continued

Bee Species	Identifier	Notes
<i>Lasioglossum lineatulum</i>	Jason Gibbs	
<i>Lasioglossum lionotum</i>	John Ascher, Jason Gibbs	
<i>Lasioglossum michiganense</i>	Jason Gibbs	
<i>Lasioglossum paraforbesii</i>	Jason Gibbs	
<i>Lasioglossum pruinosum</i>	John Ascher	
<i>Lasioglossum versans</i>	Jason Gibbs	
<i>Megachile albitarsis</i>	John Ascher	
<i>Megachile angelarum</i>	John Ascher	
<i>Melissodes bidentis</i>	John Ascher	
<i>Melissodes subillatus</i>	John Ascher	
<i>Melissodes tepaneca</i>	John Ascher	
<i>Melissodes vernoniae</i>	Wilson	Taxonomist grad student
<i>Neolarra vigilans</i>	John Ascher	
<i>Nomada australis</i>	John Ascher	Pinned specimen
<i>Nomada besseyi</i>	John Ascher	
<i>Nomada xanthura</i>	John Ascher	
<i>Osmia subfasciata</i>	John Ascher	Pinned specimen
<i>Perdita bruneri</i>	John Ascher, Zach Portman	Pinned specimen
<i>Perdita cambarella</i>	John Ascher, Zach Portman	
<i>Perdita coreopsidis</i>	John Ascher	
<i>Perdita kiowi</i>	John Ascher	
<i>Protandrena mexicanorum</i>	John Ascher	
<i>Protandrena porterae</i>	Steve Robinson	
<i>Protandrena renimaculata</i>	John Ascher	Pinned specimen
<i>Protandrena rudbeckiae</i>	Jason Gibbs	
<i>Sphecodes confertus</i>	Jason Gibbs	
<i>Sphecodes dichrous</i>	John Ascher, Jason Gibbs	
<i>Sphecodes pecosensis</i>	John Ascher, Jason Gibbs	
<i>Stelis coarctatus</i>	John Ascher	
<i>Tetraloniella spissa</i>	John Ascher	Pinned specimen
<i>Trachusa dorsalis</i>	John Ascher	Pinned specimen
<i>Triepeolus helianthi</i>	John Ascher	
<i>Triepeolus martini</i>	John Ascher	
<i>Triepeolus michiganensis</i>	Tonuferko	Member of the Packer Lab
<i>Triepeolus quadrifasciatus</i>	John Ascher	
<i>Xenoglossa kansensis</i>	John Ascher	

APPENDIX B
SUPPLEMENTAL MATERIAL FOR CHAPTER 3

List B.1. Flowering plants observed at the wetland habitat located in the Oakland University Biological Preserve.

<i>Achillea millefolium</i>	<i>Impatiens capensis</i>	<i>Solidago altissima/canadensis</i>
<i>Agrimonia gryposepala</i>	<i>Iris versicolor</i>	<i>Solidago gigantea</i>
<i>Agrimonia parviflora</i>	<i>Leucanthemum vulgare</i>	<i>Solidago juncea</i>
<i>Apocynum cannabinum</i>	<i>Liatris spicata</i>	<i>Solidago nemoralis</i>
<i>Asclepias incarnata</i>	<i>Lobelia siphilitica</i>	<i>Stachys palustris</i>
<i>Asclepias syriaca</i>	<i>Lobelia spicata</i>	<i>Symphotrichum novae-angliae</i>
<i>Cerastium fontanum</i>	<i>Lotus corniculatus</i>	<i>Symphyotrichum laeve</i>
<i>Chelone glabra</i>	<i>Lycopus americanus</i>	<i>Symphyotrichum lateriflorum</i>
<i>Cicuta maculata</i>	<i>Lysimachia ciliata</i>	<i>Symphyotrichum oolentangiense</i>
<i>Cirsium arvense</i>	<i>Lysimachia quadriflora</i>	<i>Symphyotrichum pilosum</i>
<i>Cirsium discolor</i>	<i>Medicago lupulina</i>	<i>Trifolium hybridum</i>
<i>Dasiphora fruticosa</i>	<i>Melilotus albus</i>	<i>Trifolium pratense</i>
<i>Daucus carota</i>	<i>Mimulus ringens</i>	<i>Trifolium repens</i>
<i>Desmodium canadense</i>	<i>Monarda fistulosa</i>	<i>Verbena hastata</i>
<i>Dianthus armeria</i>	<i>Oenothera biennis</i>	<i>Verbena urticifolia</i>
<i>Dipsacus sylvestris</i>	<i>Oxalis corniculata</i>	<i>Vicia tetrasperma</i>
<i>Doellingeria umbellata</i>	<i>Oxalis dillenii</i>	<i>Zizia aurea</i>
<i>Epilobium coloratum</i>	<i>Oxalis stricta</i>	
<i>Epilobium hirsutum</i>	<i>Penstemon digitalis</i>	
<i>Erigeron annuus</i>	<i>Persicaria maculosa</i>	
<i>Erigeron philadelphicus</i>	<i>Persicaria virginiana</i>	
<i>Erigeron strigosus</i>	<i>Plantago lanceolata</i>	
<i>Eupatorium perfoliatum</i>	<i>Potentilla recta</i>	
<i>Euthamia graminifolia</i>	<i>Potentilla simplex</i>	
<i>Eutrochium maculatum</i>	<i>Prunella vulgaris</i>	
<i>Galium album</i>	<i>Pycnanthemum virginianum</i>	
<i>Galium asprellum</i>	<i>Ranunculus sceleratus</i>	
<i>Galium boreale</i>	<i>Ranunculus acris</i>	
<i>Galium mollugo</i>	<i>Rosa multiflora</i>	
<i>Geum aleppicum</i>	<i>Rosa palustris</i>	
<i>Geum canadense</i>	<i>Rubus flagellaris</i>	
<i>Hackelia virginiana</i>	<i>Rudbeckia hirta</i>	
<i>Hieracium lachenalii</i>	<i>Rumex crispus</i>	
<i>Hypericum perforatum</i>	<i>Securigera varia</i>	
<i>Hypericum prolificum</i>	<i>Sisyrinchium spp</i>	

List B.2. Bee observed at the wetland habitat located in the Oakland University Biological Preserve.

<i>Andrena helianthi</i>	<i>Hylaeus leptocephalus</i>
<i>Andrena nubecula</i>	<i>Hylaeus mesillae</i>
<i>Andrena placata</i>	<i>Hylaeus modestus</i>
<i>Andrena robertsonii</i>	<i>Lasioglossum admirandum</i>
<i>Andrena wilkella</i>	<i>Lasioglossum anomalum</i>
<i>Anthophora terminalis</i>	<i>Lasioglossum atwoodi</i>
<i>Apis mellifera</i>	<i>Lasioglossum callidum</i>
<i>Augochlora pura</i>	<i>Lasioglossum coeruleum</i>
<i>Augochlorella aurata</i>	<i>Lasioglossum coriaceum</i>
<i>Augochloropsis viridula</i>	<i>Lasioglossum hitchensi</i>
<i>Bombus bimaculatus</i>	<i>Lasioglossum illinoense</i>
<i>Bombus citrinus</i>	<i>Lasioglossum laevissimum</i>
<i>Bombus griseocollis</i>	<i>Lasioglossum leucozonium</i>
<i>Bombus impatiens</i>	<i>Lasioglossum lineatulum</i>
<i>Bombus rufocinctus</i>	<i>Lasioglossum nr.laevissimum</i>
<i>Bombus vagans</i>	<i>Lasioglossum pilosum</i>
<i>Calliopsis andreniformis</i>	<i>Lasioglossum subviridatum</i>
<i>Calliopsis nebraskensis</i>	<i>Lasioglossum timothyi</i>
<i>Ceratina mikmaqi</i>	<i>Lasioglossum versatum</i>
<i>Ceratina calcarata</i>	<i>Megachile campanulae</i>
<i>Ceratina dulpa</i>	<i>Megachile exilis</i>
<i>Ceratina strenua</i>	<i>Megachile mendica</i>
<i>Coelioxys porterae</i>	<i>Megachile petulans</i>
<i>Halictus confusus</i>	<i>Megachile relativa</i>
<i>Halictus ligatus</i>	<i>Megachile texana</i>
<i>Halictus rubicundus</i>	<i>Melissodes subillatus</i>
<i>Heriades carinata</i>	<i>Osmia pumila</i>
<i>Hoplitis pilosifrons</i>	<i>Xylocopa virginia</i>
<i>Hylaeus annulatus</i>	

APPENDIX C
SUPPLEMENTAL MATERIAL FOR CHAPTER 4

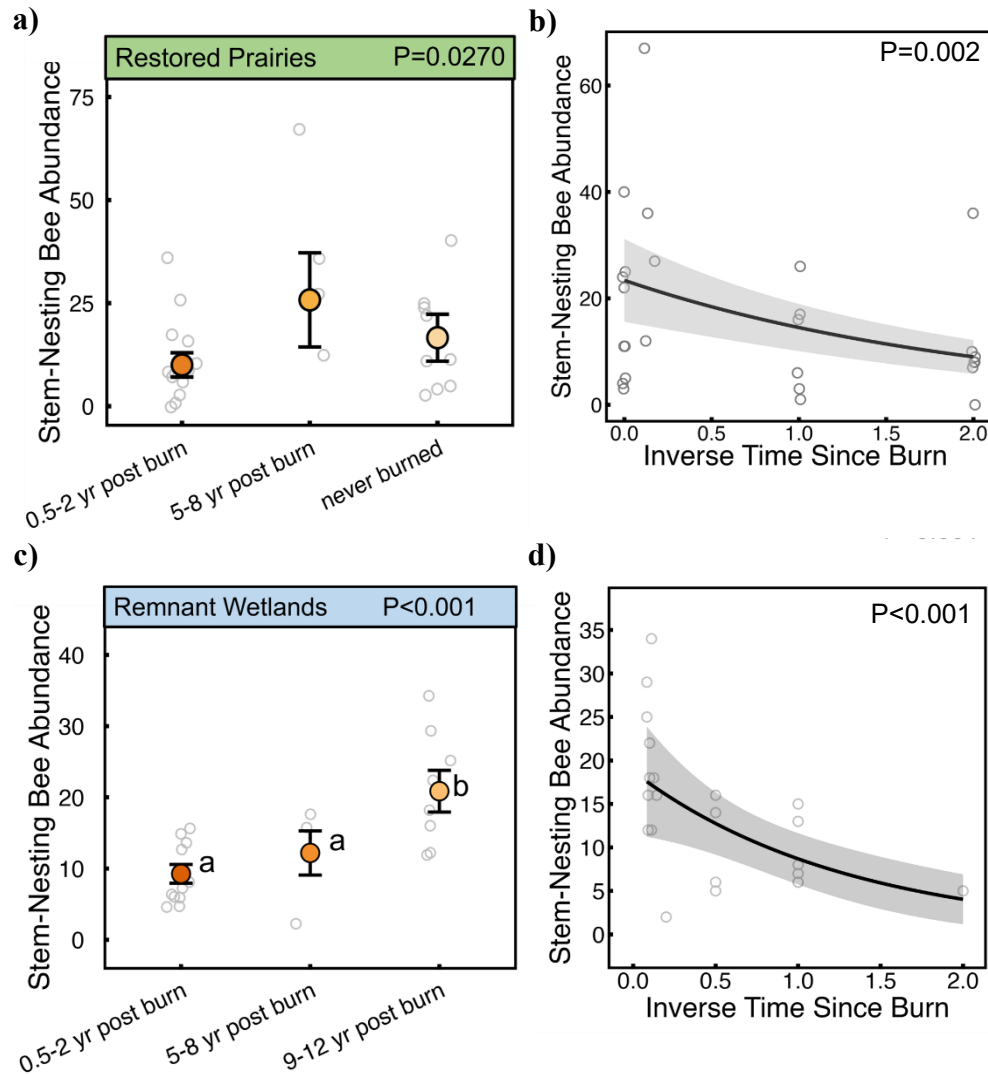


Figure C.1. Summary of differences in stem-nesting bee abundance across categorical and continuous variables. Orange circles show estimated marginal means with ± 1 SE for a) restored prairie stem-nesting bee abundance and c) remnant wetland stem-nesting bee abundance. Gray circles indicate raw means. Different letters associated with time since burn categories within each panel indicate significant differences ($p < 0.05$). Model predicted abundance for b) restored prairie stem-nesting bee abundance and d) remnant wetland stem-nesting bee abundance across inverse time since burn are indicated by solid black lines with 95% confidence intervals in shaded regions. Points represent raw observed abundance data. Separate models were created to assess abundance for each habitat type.

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