Michigan Statewide Bumble Bee and Habitat Surveys

Prepared By:
Logan Rowe, David Cuthrell, Daniel Earl, Summer Eckhardt, and Helen Enander
Michigan Natural Features Inventory
Michigan State University Extension
P.O. Box 30444
Lansing, MI 48909-7944

Prepared For:
United States Fish and Wildlife Service, Great Lakes Restoration Initiative

08/10/2023

MNFI Report No. 2023-21

Suggested Citation:

Rowe, L.M., D.L. Cuthrell, D.J. Earl, S.G. Eckhardt, H.D. Enander. 2023. Michigan Statewide Bumble Bee and Habitat Surveys. Michigan Natural Features Inventory Report No. 2023-21, Lansing, MI.

Cover: Yellow banded bumble bees (*Bombus terricola*) foraging from goldenrod in Michigan's Upper peninsula. August 2021. Photo by Logan Rowe.

Contents

List of Figures

List of Tables

Executive Summary

Michigan Natural Features Inventory (MNFI) received funding from the U.S. Fish and Wildlife Service (USFWS) via the Great Lakes Restoration Initiative to complete bumble bee community surveys across Michigan (Cooperative Agreement Award F20AC00228). The primary goals of this work were to: 1) assess potential locations for *Bombus affinis* in Michigan, 2) locate occurrences of state listed bumble bee species, and 3) complete standardized habitat assessments to accompany bumble bee community surveys. We also used the available data to construct habitat suitability models for state listed bumble bee species and to examine the environmental variables associated with species occurrence. This report details the methods and results of 2020-2022 bumble bee and habitat surveys throughout the state of Michigan.

We used a modified version of USFWS *B. affinis* survey protocol for unoccupied zones (USFWS Survey Protocols for the Rusty Patched Bumble Bee Version 2.2) to complete bumble bee community surveys and to determine the presence of *B. affinis* at suitable locations in Michigan. Surveys were 1-2 person hours, meander-based, and prioritized locations with high concentrations of blooming floral habitat. We generally used non-lethal techniques, but when identification confirmations were needed, we collected the specimen and completed identifications in the laboratory. To compliment bumble bee community surveys and gather site specific habitat and floral data, we completed *B. affinis* habitat assessment forms (Xerces 2017) for each survey. Surveys were completed during the months of July and August, from 2020-2022.

During the 3-year span of surveys, we completed a total of 189 surveys in 143 survey locations, resulting in 15,478 bumble bee records representing 16 unique species. The primary species encountered during surveys were common species (*B. impatiens*, n=5889; *B. ternarius*, n=2900; *B. vagans*, n=2196; *B. griseocollis*, n=1839; *B. bimaculatus*, n=1384) however we did document occurrences of multiple state listed species in Michigan (*B. terricola*, n=438; *B. borealis*, n=346; *B. auricomus*, n=166; *B. pensylvanicus*, n=13; *B. sandersoni*, n=6). We did not locate any populations of *B. affinis* in Michigan during these surveys.

Bumble bees were observed foraging on at least 135 different flowering plant species. The primary floral resources used by bumble bees during these survey events include *Centaurea stoebe*, n=7782; *Monarda fistulosa*, n=3495; *Solidago* sp., n=834; *Hypericum perforatum*, n=645; and *Eutrochium purpureum*, n=207. Multiple locations with *B. affinis* superfoods and known floral resources were documented.

The bumble bee community surveys completed in Michigan increase our knowledge of species distribution, relative abundance, floral resource use, and provide a baseline for identifying potential habitats for state listed bumble bee species. Furthermore, these surveys support the *B. affinis* recovery plan developed by the U.S. Fish and Wildlife Service by addressing multiple recovery actions for this species. While no *B. affinis* were located during these efforts, future survey work can prioritize high quality habitats capable of supporting *B. affinis* in Michigan.

Introduction

Bumble bees (Hymenoptera: Apidae: *Bombus*) are important pollinators of many naturally occurring and managed flowering plant communities. Multiple species of bumble bees across North America have experienced population declines and range contractions over the last few decades (Colla et al. 2012, Jacobson et al. 2018, Janousek et al. 2023). In Michigan, *B. affinis* (Rusty patched bumble bee) and *B. terricola* (Yellow banded bumble bee) are two species of bumble bees that historically occurred in relatively high abundances throughout the state but have experienced drastic declines in the last few decades (Husband et al. 1980, Wood et al. 2019, Rowe et al. 2019). Importantly, the declines associated with these species are not limited to Michigan, and each have experienced population and range decreases across historic distributions, primarily due to anthropogenic pressures such as increases in pesticide use, parasites and pathogens infections, and habitat loss (Cameron and Sadd, 2020). Based on contemporary survey efforts, the estimated statewide declines in distributions of these species in Michigan are 100% decline for *B. affinis* and 71% decline for *B. terricola* (Wood et al. 2019). *Bombus affinis* was last observed in Michigan in 1999. *Bombus terricola* currently occupies sparse habitats in northern Michigan, north of the floristic tension zone, where Laurentian Mixed Forest becomes increasingly more dominate.

In effort to mitigate loss of at-risk species of bumble bees, multiple federal and state level initiatives have been implemented to protect species of concern, as well as their associated habitats. In 2017, the United States Fish and Wildlife Service (USWFS) listed *B. affinis* as endangered under the Endangered Species Act (Smith et al. 2020). In Michigan, *B. affinis* is listed as State Endangered and *B. terricola* is listed as State Special Concern. Both are included as Species of Greatest Conservation Need in Michigan's Wildlife Action Plan (Derosier et al. 2015). Recent conservation status assessments (s-ranks) in the state have classified *B. affinis* and *B. terricola* as possible extirpated and imperiled-vulnerable, respectively (Rowe et al. 2019). Three additional species of bumble bees have received updated state statuses (*B. auricomus,* Black and gold bumble bee: State Special Concern; *B. borealis,* Northern amber bumble bee: State Special Concern, *B. sandersoni,* Sanderson's bumble bee: State Special Concern). One species, *B. pensylvanicus* (American bumble bee), is considered State Endangered as of 2023.

Dense patches of *Monarda fistulosa* serve as high-quality Bumble bee habitat in Southern Michigan.

Since listing *B. affinis* as endangered, the USFWS has developed a recovery plan for the species that incorporates representation, resiliency, and redundancy conservation principles to conserve populations and to increase the distribution of populations across the species' historic range. Since Michigan falls within the middle of the historic range of *B. affinis*, identifying extant populations of the species would aide in the overall recovery of the species across a broader geographic range. Furthermore, the Michigan Wildlife Action Plan recognizes that populations of at-risk species of bumble bees are intricately linked to the habitats which they occupy, and therefore describing components of a habitat with stable populations of *B. affinis* or *B. terricola* is critical to long term population viability. Considering the status of these species in Michigan, there is an immediate need to continue monitoring populations and associated habitats to understand shifts in statewide occupancy, habitat use, and the environmental or anthropogenic variables associated with declines. Gathering this information across the state provides a useful baseline for monitoring future population level changes and creates a framework for building targeted conservation initiatives to support populations of *B. affinis* and *B. terricola* and their associated habitats. Additionally, this baseline data provides valuable information on all species of *Bombus* so we can better detect population, or range declines in these seemingly "common" species, and provides valuable bumble bee habitat summaries at reference sites across the state.

In 2020-2022, the Michigan Natural Features Inventory (MNFI) completed statewide bumble bee surveys to improve knowledge of species distributions, identify associated floral resources, and evaluate habitats associated with at-risk species of bumble bees. While the primary goal was to discover new locations of *B. affinis* in the state, we completed full bumble bee community surveys to document species presence and community structure and relate this information to the available habitat. To inform future conservation efforts for bumble bee species of concern, we completed habitat suitability models for state listed species of bumble bees and identified the environmental variables associated with species occurrence in occupied habitats.

Bombus terricola foraging on *Eutrochium purpureum* in the upper peninsula of Michigan.

Methods

Site Selection

During the Fall of 2019, an initial list of survey sites was generated based on the availability of historic *B. affinis* occurrences in the state and locations for extant populations of *B. terricola* in northern Michigan. For *B. affinis*, we prioritized locations with historic *B. affinis* records, with the intent of resurveying these locations to determine *B. affinis* presence. For *B. terricola*, we prioritized locations with recent records of *B. terricola* (2010-*current*). Therefore, our primary objectives with selecting survey sites were to 1) re-evaluate historic locations of *B. affinis* in Michigan, and 2) initiate long-term population monitoring locations throughout the current range of *B. terricola* in Michigan. During this initial site selection process, we identified approximately 30 locations for *B. affinis* surveys, and 20 locations for *B. terricola* surveys in 2020. In the fall of 2020, and again in 2021, sites were re-evaluated based on the presence of state listed bumble species at surveyed sites and overall habitat quality. During each yearly reassessment, approximately 1/3 of sites were dropped and replaced with new sites based on the same criteria used during the initial site selection process. In each year, opportunistic survey locations were also selected and included approximately 40 locations over the 3-year survey period. These were generally sites with good habitat quality and an abundance of floral resources available.

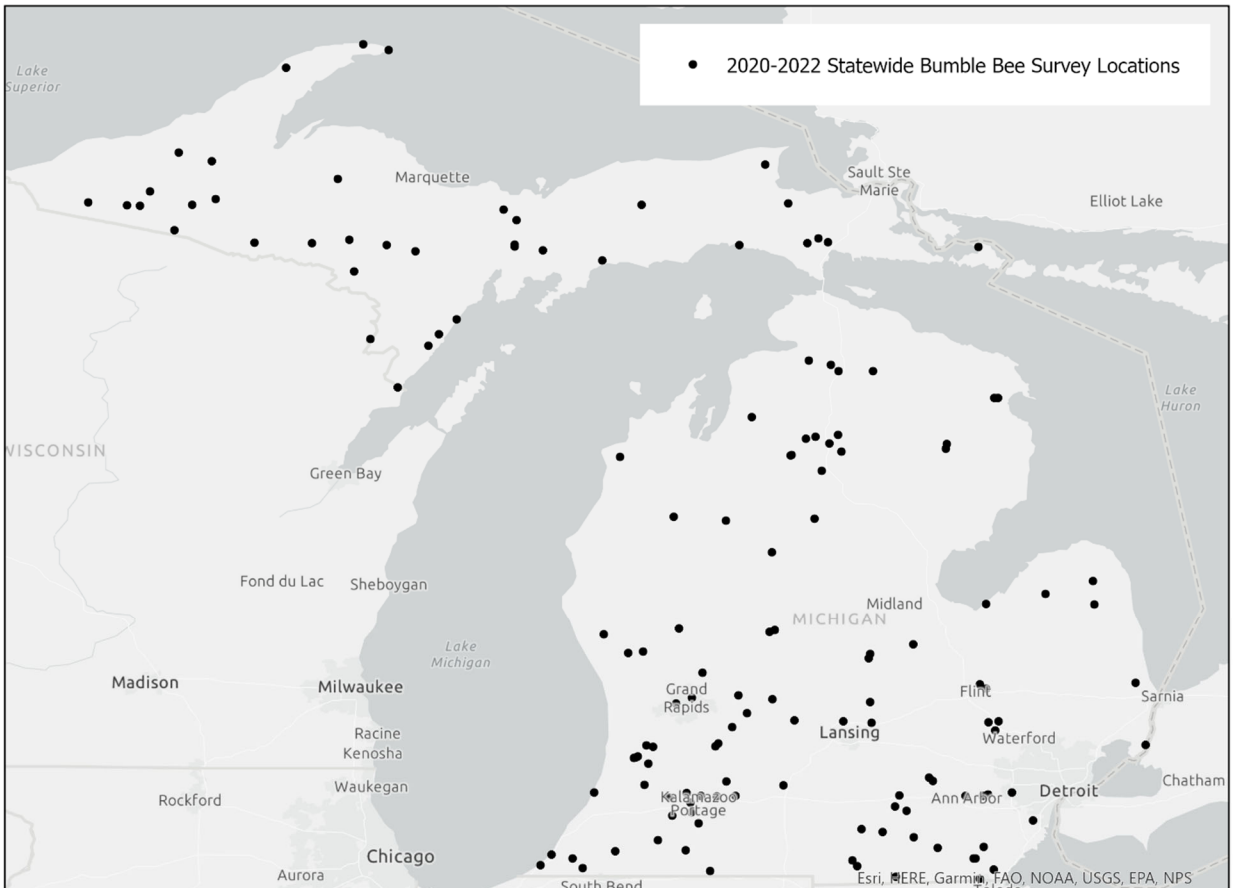

Figure 1. Locations of Bumble bee community and habitat surveys in Michigan from 2020-2022. Each site was surveyed at least once between 2020-2022.

Bumble Bee Community Surveys

We used a modified version of USFWS *B. affinis* survey protocol for unoccupied zones (USFWS Survey Protocols for the Rusty Patched Bumble Bee Version 2.2) to complete bumble bee community surveys at each survey location between 2020-2022. Each survey consisted of a 1–2-person hour bumble bee community survey (individual survey lengths depended on size of survey habitat and the availability of foraging resources). Surveyors walked meander paths through potential habitat, focusing survey efforts in areas of high concentrations of available flowering resources. We generally used non-lethal techniques, but when identification confirmations were needed, we collected the specimen and completed identifications in the laboratory. The purpose of this methodology was to document the relative abundance of each bumble bee species encountered. Therefore, for each bumble bee occurrence, we recorded the site, date, species (if known), GPS location, and floral resource association. In some instances, we were unable to identify the visited plant species, and so we recorded the lowest taxonomic level with high certainty. Bumble bee voucher specimen from each site were placed in vials with the same information and stored in a cooler for processing post-hoc. All bumble bee community surveys were conducted on days that had no rain, temperatures above 15^{o}C (60^{o}F), and when winds were ≤ 25 kph (15 mph). Bumble bee community surveys were completed between July 14th and August 21st in 2020, July 17th and August 18th in 2021, and July 15th and August 15th in 2022. We used ArcGIS Survey123 (ESRI 2020) to record all bumble bees and associated data during field surveys.

Floral Community Surveys

To accompany field-based survey efforts, we completed a *B. affinis* habitat assessment form (Xerces 2017) for each site. These assessments incorporate 5 main sections to evaluate the suitability of a landscape for *B. affinis* (Section 1: Regional and Landscape Features, Section 2: Site Features, Section 3: Foraging Habitat, Section 4: Nesting and Overwintering Habitat, Section 5: Pesticide and Management Practices). Since we were unable to accurately describe a survey site's history of pesticide and management practices, we left this section blank during site level evaluations. Based on the criteria set in these sections, each site received a numerical score on a scale of 1-135 points to describe the overall habitat quality and suitability for rare bumble bees (specifically *B. affinis*). For sites that we visited multiple years, we completed the form once per year. To assess the average habitat scores for sites with Michigan state listed species, we only used habitat scores for sites where that species is expected to occur in Michigan (i.e., we only included southern Michigan site scores for species found in southern Michigan). For *B. auricomus*, *B. pensylvanicus*, and *B. sandersoni*, we included a total of 86 site level habitat scores for each comparison. For *B. borealis* and *B. terricola*, we included a total of 56 site level habitat scores.

Data Summary and Analysis

We summarized all bumble bee occurrence data by applicable site and year combination(s) and provide the abundance of each bumble bee species documented during survey events at each site. To assess floral use by state listed bumble bees in Michigan, we generated a rank abundance of plant species floral visits by these species. Similarly, we summarized all floral abundance data to identify primary floral resources visited by bumble bees between mid-July and mid-August, which is the timeframe of peak bumble bee abundance during the foraging season in Michigan. Survey sites were ranked using the calculated habitat scores based on the Rusty patched bumble bee habitat assessment form to identify locations in Michigan most suitable for supporting a population of *B. affinis*.

For state listed species of bumble bees (*B. affinis*, *B. auricomus*, *B. borealis*, *B. pensylvanicus,* and *B. terricola*), we constructed habitat suitability models (HSMs) and identified the environmental variables associated with species occurrence in occupied habitats. Habitat suitability models were created with the maximum entropy algorithm (Maxent ver. 3.4.4k) (Phillips et al. 2006), a presence-only modeling method. High resolution (GPS) presence locations of state listed bumble bee species for the years 2012-2022 were selected and spatially thinned, retaining only occurrences that were at least a distance of 1 km apart to avoid potential spatial autocorrelation bias. Maxent requires approximately 10,000 pseudo-absence or background locations, and these were generated randomly within a 2 km distance of any *Bombus* location to correct for geographic sampling bias. From over 150 environmental variables describing climate, landcover (at multiple spatial scales), terrain and derivatives, geology, and hydrology, we chose a set that were deemed ecologically and biologically relevant to the species. Variables were further reduced by eliminating those correlated at > 0.7 (Pearson correlation coefficient), keeping the variable that explained the most percent deviance to the response in a univariate GAM. Seven state-wide environmental predictor variables for *B. terricola* and *B. borealis*, and eight variables for *B. auricomus* and *B. pensylvanicus* at the extent of Michigan's lower peninsula remained after variable reduction. The R package MaxentVariableSelection (Jueterbock et al. 2016) was used to identify the most important combination of predictor variables and feature types across a range of regularization multiplier values (1 to 4 by 0.5 increments), while avoiding model overfitting and complexity. Each possible model was run with ten-fold cross-validation of test and training sets. Model evaluation was based on the test AUC, the area under the receiver-operator curve (Fielding and Bell, 1997). AUC is expressed on a 0-1 scale with 0.5 indicating a model that is equivalent to random. We chose AUC because it evaluates model performance over all possible thresholds. A threshold is a subjective choice that converts the continuous suitability model output to binary predictions of suitable/unsuitable habitat. To understand the relationship of environmental variables in the final model to habitat suitability we generated variable response curves when 1) all other variables are held at their mean, and 2) as single variable predictors, where all other variables have been removed.

Since no contemporary records for *B. affinis* exist in Michigan, we used records from other states with *B. affinis* occurrences to inform the model for this species. *Bombus affinis* occurrence records were obtained from Illinois, Indiana, Minnesota, and Wisconsin through a NatureServe data request submitted in Spring 2023. Using natural heritage quality data sources ensures that the occurrence data has been vetted prior to use in models. A similar process to spatially thin and correct for geographic sampling bias was applied to the *B. affinis* occurrence dataset. A total of 390 occurrences were used to construct the habitat suitability model (153 from Illinois, 1 from Indiana, 102 from Minnesota, and 134 from Wisconsin). Similar to extant state listed species in Michigan, we assessed a set of environmental variables deemed ecologically and biologically relevant to *B. affinis*. In addition, we only incorporated environmental variables with a spatial extant that covers Illinois, Indiana, Michigan, Minnesota, and Wisconsin. The National Land Cover Database (NLCD) (Dewitz and USGS 2021) is produced for the conterminous United States and has 15 land cover classes plus a separate imperviousness dataset. NLCD Tree Canopy Cover (Yang et al. 2018) was also included. Bioclimatic climate variables (https://www.worldclim.org/data/bioclim.html) derived from monthly temperature values for a 30-year window were readily available (Auer and Natureserve, 2016). We selected environmental variables based on boxplots of presence location values and background location values. Three Bioclimatic environmental variables were selected for modeling, as well as land cover class, and percent of agricultural cropland and percent of developed landcover at multiple spatial scales. Variable reduction

was performed in a similar manner as the other *Bombus* species. The model was trained on the final set of the four state environmental layers and presence locations. Then the model was projected to the geographic extent of Michigan using a set of the same environmental layers. Projection is the process of training a species distribution model on one set of environmental variables and applying it to another set of environmental variables at a different geographic extent or a future climate scenario.

Results

Bumble Bee Surveys

Between 2022-2022, we completed a total of 189 surveys in 143 locations, resulting in 15,478 bumble bee records representing 16 unique species. The most frequently encountered species during these surveys was *B. impatiens* (n=5889), followed by *B. ternarius* (n=2900) and *B. vagans* (n=2196). For state listed species, we documented 166 occurrences of *B. auricomus* (18 sites, 13% of sites surveyed), 346 occurrences of *B. borealis* (37 sites, 26% of sites surveyed), 13 occurrences of *B. pensylvanicus* (4 sites, 3% of sites surveyed), 6 occurrences of *B. sandersoni* (6 sites, 4% of sites surveyed), and 438 occurrences of *B. terricola* (48 sites, 34% of sites surveyed) (Table 1, Table 2). We did not document *B. affinis* at any survey location in Michigan between 2020-2022. The mean number of bumble bees documented per survey was 108.3. When we split the survey sites by northern and southern Michigan (using the floristic tension zone as a determining factor), we observed differences in the relative abundance of species occupying survey locations (Figure 2). South of the floristic tension zone, *B. impatiens* (59%) and *B. griseocollis* (16%) were the primary species documented, while north of the tension zone, *B. ternarius* (35%) and *B. vagans* (25%) were the primary species documented.

Bombus auricomus foraging from *Monarda fistulosa*.

Table 1. Scientific and common names, conservation status, and the total number of each bumble bee species documented during Michigan surveys in 2020-2022.

Bumble Bee Species	Common Name	Global Rank	State Rank	State Status	Record Count 2020-2022			
					2020	2021	2022	Total
Bombus affinis	Rusty patched	G2	SH	SE	0	0	0	0
Bombus auricomus	Black and gold	G5	S2	SC	44	97	25	166
Bombus bimaculatus	Two spotted	G5	S4	-	409	559	416	1384
Bombus borealis	Northern amber	G4	S3	SC	117	97	132	346
Bombus citrinus	Lemon cuckoo	G4	S3	-	7	36	52	95
Bombus fervidus	Golden northern	G3	S3	-	26	57	28	111
Bombus flavidus	Fernald cuckoo	G5	SNR	-	3	0	9	12
Bombus griseocollis	Brown belted	G5	S5	-	606	534	689	1829
Bombus impatiens	Common eastern	G5	S5	-	1233	2713	1943	5889
Bombus insularis	Indiscriminate cuckoo	G3	SNR	-	0	1	0	1
Bombus pensylvanicus	American	G3	S1	SE	10	1	2	13
Bombus perplexus	Perplexing	G5	S3	-	22	28	27	77
Bombus rufocinctus	Red belted	G5	S3	-	3	15	6	15
Bombus sandersoni	Sanderson's	G5	S2	SC	4	2	0	6
Bombus ternarius	Tri-colored	G5	S4	-	1050	978	872	2900
Bombus terricola	Yellow banded	G3	S2	SC	317	37	84	438
Bombus vagans	Half-black	G4	S4	-	624	867	705	2196
Total					**4475**	**6022**	**4990**	**15478**

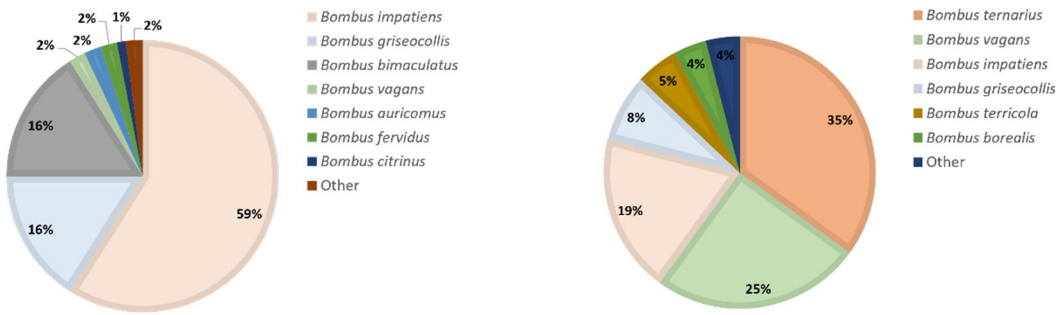

Figure 2. Generalized bumble bee communities south (left) and north (right) of the floristic tension zone in Michigan.

Table 2. The number of survey events and occurrences of each bumble bee species for each site surveyed between 2020-2022 in Michigan.

Site ID	X Cor.	Y Cor.	Number of Surveys	*Bombus auricomus*	*Bombus bimaculatus*	*Bombus borealis*	*Bombus citrinus*	*Bombus fervidus*	*Bombus flavidus*	*Bombus griseocollis*	*Bombus impatiens*	*Bombus insularis*	*Bombus pensylvanicus*	*Bombus perplexus*	*Bombus rufocinctus*	*Bombus sandersoni*	*Bombus ternarius*	*Bombus terricola*	*Bombus vagans*	Grand Total
Site 1	[redacted]	[redacted]	1	-	3	-	-	-	-	26	35	-	-	-	-	-	-	-	-	64
Site 2	[redacted]	[redacted]	1	1	1	-	-	-	-	-	5	-	-	-	-	-	-	-	-	7
Site 3	[redacted]	[redacted]	1	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	4
Site 4	[redacted]	[redacted]	1	-	11	-	-	-	-	11	30	-	-	-	-	-	-	-	-	52
Site 5	[redacted]	[redacted]	2	4	2-	-	1	5	-	37	36	-	-	3	-	-	-	-	8	114
Site 6	[redacted]	[redacted]	2	-	5	-	5	2	-	2	19	-	-	1	-	-	-	-	1	35
Site 7	[redacted]	[redacted]	1	-	-	-	-	-	-	-	22	-	-	-	-	-	-	-	-	22
Site 8	[redacted]	[redacted]	1	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	2	4
Site 9	[redacted]	[redacted]	1	-	-	-	-	-	-	9	4	-	-	-	-	-	-	-	-	13
Site 10	[redacted]	[redacted]	1	-	1	-	-	-	-	25	9	-	-	-	-	-	-	-	3	38
Site 11	[redacted]	[redacted]	1	-	1	-	-	4	-	4	1	-	1	-	-	-	-	-	15	26
Site 12	[redacted]	[redacted]	2	1	11	-	9	-	-	21	56	-	-	-	-	-	-	-	3	101
Site 13	[redacted]	[redacted]	1	-	-	-	-	1	-	14	24	-	-	-	-	-	-	-	-	39
Site 14	[redacted]	[redacted]	2	27	63	-	1	1	-	28	36	-	-	6	-	-	-	-	9	171
Site 15	[redacted]	[redacted]	2	-	2	-	-	1	-	2	30	-	-	-	-	-	-	-	2	37
Site 16	[redacted]	[redacted]	3	-	5	-	-	-	-	16	43	-	1	-	-	-	-	-	-	65
Site 17	[redacted]	[redacted]	2	54	18	-	-	4	-	2-	69	-	-	11	-	-	-	-	8	184
Site 18	[redacted]	[redacted]	2	-	9	-	-	1	-	16	88	-	-	-	-	-	-	-	5	119
Site 19	[redacted]	[redacted]	1	-	-	-	-	-	-	1	10	-	-	-	-	-	-	-	1	12
Site 20	[redacted]	[redacted]	2	1	7	-	1	4	-	4	64	-	-	-	-	-	-	-	3	84
Site 21	[redacted]	[redacted]	1	-	-	-	9	-	-	1	6	-	-	-	-	-	-	-	1	17
Site 22	[redacted]	[redacted]	1	-	13	-	-	-	-	18	10	-	-	1	-	-	-	-	7	49
Site 23	[redacted]	[redacted]	1	-	4	-	8	8	-	8	16	-	-	-	-	-	-	-	8	52

Site ID	X Cor.	Y Cor.	Number of Surveys	*Bombus auricomus*	*Bombus bimaculatus*	*Bombus borealis*	*Bombus citrinus*	*Bombus fervidus*	*Bombus flavidus*	*Bombus griseocollis*	*Bombus impatiens*	*Bombus insularis*	*Bombus pensylvanicus*	*Bombus perplexus*	*Bombus rufocinctus*	*Bombus sandersoni*	*Bombus ternarius*	*Bombus terricola*	*Bombus vagans*	Grand Total
Site 24	[redacted]	[redacted]	1	-	3	-	-	-	-	1	1	-	-	-	-	-	-	-	-	5
Site 25	[redacted]	[redacted]	2	18	39	-	-	5	-	10	51	-	-	-	-	-	-	-	7	130
Site 26	[redacted]	[redacted]	1	2-	8	-	-	-	-	117	34	-	-	-	-	-	-	-	1	180
Site 27	[redacted]	[redacted]	1	-	2-	-	-	-	-	38	83	-	-	-	-	-	-	-	-	141
Site 28	[redacted]	[redacted]	1	-	-	-	5	2	-	21	52	-	-	-	-	-	-	-	1	81
Site 29	[redacted]	[redacted]	1	-	-	-	5	2	-	3	58	-	-	-	-	-	-	-	3	71
Site 30	[redacted]	[redacted]	1	-	-	-	-	2	-	11	63	-	-	-	-	-	-	-	-	76
Site 31	[redacted]	[redacted]	1	-	-	-	24	-	-	21	55	-	-	-	-	-	-	-	-	100
Site 32	[redacted]	[redacted]	3	-	31	-	-	6	-	25	312	-	-	4	-	-	-	-	3	381
Site 33	[redacted]	[redacted]	2	-	4	-	2	3	-	2	11	-	-	-	-	-	-	-	1	23
Site 34	[redacted]	[redacted]	1	-	2	-	-	-	-	14	172	-	-	-	-	-	-	-	-	188
Site 35	[redacted]	[redacted]	2	4	22	-	-	2	-	26	60	-	-	-	-	-	-	-	2	116
Site 36	[redacted]	[redacted]	2	3	33	-	-	5	-	29	172	-	-	-	-	-	-	-	1	243
Site 37	[redacted]	[redacted]	1	-	23	-	-	3	-	33	25	-	-	-	-	-	-	-	-	84
Site 38	[redacted]	[redacted]	2	-	16	-	1	-	-	31	22	-	-	-	-	-	-	-	-	70
Site 39	[redacted]	[redacted]	1	8	23	-	-	8	-	11	45	-	-	-	-	-	-	-	-	95
Site 40	[redacted]	[redacted]	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Site 41	[redacted]	[redacted]	1	-	18	-	-	-	-	28	103	-	-	-	-	-	-	-	2	151
Site 42	[redacted]	[redacted]	1	-	12	-	-	-	-	-	9	-	-	-	-	-	-	-	1	22
Site 43	[redacted]	[redacted]	2	1	30	-	-	-	-	45	345	-	-	-	-	-	-	-	-	421
Site 44	[redacted]	[redacted]	2	-	12	-	3	-	-	72	99	-	-	-	-	-	-	-	-	186
Site 45	[redacted]	[redacted]	1	-	4	-	-	-	-	4	1	-	-	-	-	-	-	-	-	9
Site 46	[redacted]	[redacted]	2	-	23	-	-	-	-	14	22	-	-	-	-	-	-	-	-	59
Site 47	[redacted]	[redacted]	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Site 48	[redacted]	[redacted]	1	-	17	-	-	-	-	2-	67	-	-	-	-	-	-	-	1	105

Site ID	X Cor.	Y Cor.	Number of Surveys	*Bombus auricomus*	*Bombus bimaculatus*	*Bombus borealis*	*Bombus citrinus*	*Bombus fervidus*	*Bombus flavidus*	*Bombus griseocollis*	*Bombus impatiens*	*Bombus insularis*	*Bombus pensylvanicus*	*Bombus perplexus*	*Bombus rufocinctus*	*Bombus sandersoni*	*Bombus ternarius*	*Bombus terricola*	*Bombus vagans*	Grand Total
Site 49	[redacted]	[redacted]	1	-	47	-	-	-	-	14	-	-	-	-	-	-	-	-	-	61
Site 50	[redacted]	[redacted]	1	-	6	-	-	-	-	15	11	-	-	-	-	-	-	-	-	32
Site 51	[redacted]	[redacted]	1	-	-	-	1	-	-	21	23	-	-	-	-	-	-	-	-	45
Site 52	[redacted]	[redacted]	1	-	21	-	-	1	-	11	3	-	-	-	-	-	-	-	1	37
Site 53	[redacted]	[redacted]	1	-	17	-	-	-	-	4	37	-	-	-	-	-	-	-	-	58
Site 54	[redacted]	[redacted]	1	-	8	-	1	2	-	-	154	-	-	-	-	-	-	-	1	166
Site 55	[redacted]	[redacted]	2	-	5	-	1	-	-	4	121	-	-	-	-	-	-	-	-	131
Site 56	[redacted]	[redacted]	1	-	12	-	2	-	-	9	64	-	-	-	-	-	-	-	-	87
Site 57	[redacted]	[redacted]	1	-	5	-	-	2	-	3	69	-	-	-	-	-	-	-	-	79
Site 58	[redacted]	[redacted]	1	-	2	-	-	-	-	2	28	-	-	1	-	-	-	-	-	33
Site 59	[redacted]	[redacted]	1	-	21	-	-	-	-	5	11	-	-	-	-	-	-	-	-	37
Site 60	[redacted]	[redacted]	1	6	33	-	1	-	-	4	42	-	-	-	-	-	-	-	4	90
Site 61	[redacted]	[redacted]	1	-	24	-	-	7	-	2	19	-	-	-	-	-	-	-	7	59
Site 62	[redacted]	[redacted]	1	-	1	-	-	3	-	3	108	-	-	-	-	-	-	-	1	116
Site 63	[redacted]	[redacted]	2	-	15	-	-	5	-	2	71	-	-	1	-	-	-	-	-	94
Site 64	[redacted]	[redacted]	1	1	-	-	-	4	-	2	153	-	-	-	-	-	-	-	-	160
Site 65	[redacted]	[redacted]	1	-	2	-	-	-	-	5	64	-	-	-	-	-	-	-	-	71
Site 66	[redacted]	[redacted]	2	2	90	-	1	-	-	9	82	-	-	-	-	-	-	-	27	211
Site 67	[redacted]	[redacted]	2	-	86	-	1	2	-	1-	60	-	-	1	-	-	-	-	1	161
Site 68	[redacted]	[redacted]	1	-	7	-	-	2	-	3	3	-	-	-	-	-	-	-	1	16
Site 69	[redacted]	[redacted]	1	-	4	-	-	-	-	4	17	-	-	-	-	-	-	-	1	26
Site 70	[redacted]	[redacted]	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
Site 71	[redacted]	[redacted]	1	-	-	-	1	1	-	3	108	-	-	-	1	-	-	-	7	121
Site 72	[redacted]	[redacted]	2	1-	75	1	1	8	-	48	134	-	-	-	-	-	-	-	2	279
Site 73	[redacted]	[redacted]	1	-	6	-	-	-	-	41	15	-	-	-	-	-	-	1	-	63

Site ID	X Cor.	Y Cor.	Number of Surveys	*Bombus auricomus*	*Bombus bimaculatus*	*Bombus borealis*	*Bombus citrinus*	*Bombus fervidus*	*Bombus flavidus*	*Bombus griseocollis*	*Bombus impatiens*	*Bombus insularis*	*Bombus pensylvanicus*	*Bombus perplexus*	*Bombus rufocinctus*	*Bombus sandersoni*	*Bombus ternarius*	*Bombus terricola*	*Bombus vagans*	Grand Total
Site 74	[redacted]	[redacted]	1	-	58	-	-	-	-	7	17	-	1	-	-	-	-	1	1	85
Site 75	[redacted]	[redacted]	1	-	-	-	-	-	-	6	7	-	-	-	-	-	-	-	-	13
Site 76	[redacted]	[redacted]	1	-	3	-	-	-	-	2	2	-	-	-	-	-	-	-	1	8
Site 77	[redacted]	[redacted]	1	4	2	-	-	-	-	2	7	-	-	-	-	-	-	-	1	16
Site 78	[redacted]	[redacted]	1	1	7	-	-	-	-	14	27	-	-	-	-	-	-	1	-	50
Site 79	[redacted]	[redacted]	3	-	50	-	-	2	-	33	127	-	10	-	-	-	-	4	8	234
Site 80	[redacted]	[redacted]	1	-	-	-	3	-	-	8	72	-	-	-	-	-	-	-	2	85
Site 81	[redacted]	[redacted]	1	-	-	1	-	1	-	1	8	-	-	-	-	-	-	-	1	12
Site 82	[redacted]	[redacted]	1	-	2	-	-	-	-	-	50	-	-	-	2	-	-	-	-	54
Site 83	[redacted]	[redacted]	1	-	2	-	-	-	-	-	46	-	-	-	-	-	-	-	1	49
Site 84	[redacted]	[redacted]	1	-	12	-	-	-	-	54	32	-	-	-	-	-	14	-	-	112
Site 85	[redacted]	[redacted]	1	-	1	-	-	1	-	1	47	-	-	-	-	-	4	1	-	55
Site 86	[redacted]	[redacted]	1	-	-	-	-	-	-	4	6	-	-	-	-	-	3	-	4	17
Site 87	[redacted]	[redacted]	1	-	36	2	-	-	-	19	8	-	-	2	-	-	-	3	-	70
Site 88	[redacted]	[redacted]	1	-	14	-	-	-	-	37	25	-	-	-	-	-	1	-	1	78
Site 89	[redacted]	[redacted]	1	-	38	1	-	-	-	26	25	-	-	-	-	-	-	-	18	108
Site 90	[redacted]	[redacted]	1	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	1	4
Site 91	[redacted]	[redacted]	1	-	2	-	-	-	1	3	9	-	-	-	-	-	23	1	10	49
Site 92	[redacted]	[redacted]	1	-	-	-	-	-	-	-	-	-	-	-	-	-	8	-	-	8
Site 93	[redacted]	[redacted]	1	-	3	-	-	-	-	18	42	-	-	-	-	-	23	2	-	88
Site 94	[redacted]	[redacted]	1	-	2	-	-	-	-	3	80	-	-	-	-	-	12	1	-	98
Site 95	[redacted]	[redacted]	1	-	8	-	-	-	-	1	2	-	-	1	-	-	-	-	-	12
Site 96	[redacted]	[redacted]	1	-	4	-	-	-	-	-	2	-	-	-	-	-	11	1	2	20
Site 97	[redacted]	[redacted]	1	-	18	-	-	-	-	2	10	-	-	1	-	-	1	4	9	45
Site 98	[redacted]	[redacted]	1	-	-	-	-	-	-	4	-	-	-	-	-	-	2	-	1	7

Site ID	X Cor.	Y Cor.	Number of Surveys	*Bombus auricomus*	*Bombus bimaculatus*	*Bombus borealis*	*Bombus citrinus*	*Bombus fervidus*	*Bombus flavidus*	*Bombus griseocollis*	*Bombus impatiens*	*Bombus insularis*	*Bombus pensylvanicus*	*Bombus perplexus*	*Bombus rufocinctus*	*Bombus sandersoni*	*Bombus ternarius*	*Bombus terricola*	*Bombus vagans*	Grand Total
Site 99	[redacted]	[redacted]	1	-	2	7	-	-	-	7	24	-	-	-	-	-	-	1	41	
Site 100	[redacted]	[redacted]	1	-	1	1	1	-	-	12	24	-	-	-	-	-	5	-	1	45
Site 101	[redacted]	[redacted]	1	-	12	-	-	-	-	18	31	-	-	-	-	-	24	-	-	85
Site 102	[redacted]	[redacted]	1	-	-	-	2	-	-	4	30	-	-	-	4	-	-	-	11	51
Site 103	[redacted]	[redacted]	1	-	-	5	-	-	-	6	198	-	-	-	-	-	31	-	11	251
Site 104	[redacted]	[redacted]	1	-	3	-	-	-	-	4	65	-	-	-	-	-	-	5	8	85
Site 105	[redacted]	[redacted]	1	-	3	5	-	-	-	6	68	-	-	-	-	-	11	2	38	133
Site 106	[redacted]	[redacted]	1	-	-	-	-	-	-	-	10	-	-	-	-	-	-	1	4	15
Site 107	[redacted]	[redacted]	1	-	1	5	-	-	-	8	78	-	-	-	-	-	66	1	9	168
Site 108	[redacted]	[redacted]	2	-	-	13	-	-	-	40	88	-	-	-	-	-	19	2	196	358
Site 109	[redacted]	[redacted]	2	-	-	3	2	-	3	47	92	-	-	-	-	-	315	8	154	624
Site 110	[redacted]	[redacted]	2	-	-	2	-	-	-	78	179	-	-	-	2	-	28	1	177	467
Site 111	[redacted]	[redacted]	2	-	2	14	-	-	-	9	19	-	-	-	-	-	45	2	137	228
Site 112	[redacted]	[redacted]	2	-	31	53	-	-	-	1	86	-	-	-	-	1	78	1	121	372
Site 113	[redacted]	[redacted]	1	-	-	12	-	-	-	1	-	-	-	-	1	-	24	5	29	72
Site 114	[redacted]	[redacted]	2	-	-	2	-	-	-	1	-	-	-	4	-	-	205	12	92	316
Site 115	[redacted]	[redacted]	1	-	2	-	-	-	-	1	-	-	-	-	-	-	10	-	2	15
Site 116	[redacted]	[redacted]	1	-	-	1	-	-	-	2	3	-	-	-	-	1	12	3	2	24
Site 117	[redacted]	[redacted]	1	-	-	-	-	-	-	1	-	-	-	-	-	1	-	2	6	10
Site 118	[redacted]	[redacted]	1	-	-	14	-	-	-	1-	4	-	-	-	-	-	153	12	23	216
Site 119	[redacted]	[redacted]	2	-	-	29	-	-	-	5	4	-	-	1	-	-	125	12	16	192
Site 120	[redacted]	[redacted]	3	-	21	4	1	-	-	3	13	-	-	1	-	-	13	21	213	290
Site 121	[redacted]	[redacted]	3	-	1	14	1	-	1	21	9	1	-	14	-	1	218	16	176	473
Site 122	[redacted]	[redacted]	3	-	3	5	1	-	1	9	37	-	-	-	13	1	49	5	30	154
Site 123	[redacted]	[redacted]	3	-	16	20	-	-	-	98	9	-	-	2	-	-	75	47	38	305

Site ID	X Cor.	Y Cor.	Number of Surveys	*Bombus auricomus*	*Bombus bimaculatus*	*Bombus borealis*	*Bombus citrinus*	*Bombus fervidus*	*Bombus flavidus*	*Bombus griseocollis*	*Bombus impatiens*	*Bombus insularis*	*Bombus pensylvanicus*	*Bombus perplexus*	*Bombus rufocinctus*	*Bombus sandersoni*	*Bombus ternarius*	*Bombus terricola*	*Bombus vagans*	Grand Total
Site 124	[redacted]	[redacted]	1	-	-	19	-	-	-	2	-	-	-	-	-	-	42	4	27	94
Site 125	[redacted]	[redacted]	1	-	-	5	-	-	-	13	-	-	-	-	-	-	9	2	45	74
Site 126	[redacted]	[redacted]	1	-	-	-	-	-	3	-	-	-	-	1-	-	-	53	2	2	70
Site 127	[redacted]	[redacted]	1	-	-	4	-	-	-	6	-	-	-	-	-	-	19	50	2	81
Site 128	[redacted]	[redacted]	1	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	1	3
Site 129	[redacted]	[redacted]	1	-	-	4	-	-	-	-	-	-	-	1	-	-	88	16	40	149
Site 130	[redacted]	[redacted]	1	-	-	8	-	-	-	20	51	-	-	1	-	-	40	18	14	152
Site 131	[redacted]	[redacted]	2	-	-	-	-	1	-	22	2	-	-	-	-	-	108	8	3	144
Site 132	[redacted]	[redacted]	1	-	-	9	-	-	3	-	-	-	-	1	-	-	51	2	36	102
Site 133	[redacted]	[redacted]	2	-	20	2	-	-	-	17	3	-	-	1	-	1	89	32	24	189
Site 134	[redacted]	[redacted]	1	-	-	8	-	-	-	1	14	-	-	1	-	-	125	4	67	220
Site 135	[redacted]	[redacted]	2	-	-	43	-	-	-	24	21	-	-	3	-	-	296	22	58	467
Site 136	[redacted]	[redacted]	1	-	-	14	-	-	-	2	4	-	-	1	-	-	19	4	65	109
Site 137	[redacted]	[redacted]	1	-	1	2	-	-	-	1	1	-	-	1	-	-	55	24	13	98
Site 138	[redacted]	[redacted]	2	-	-	-	-	-	-	1	-	-	-	1	-	-	144	57	6	209
Site 139	[redacted]	[redacted]	1	-	-	6	-	-	-	-	13	-	-	-	-	-	58	11	56	144
Site 140	[redacted]	[redacted]	1	-	-	2	-	-	-	12	121	-	-	-	-	-	2	1	13	151
Site 141	[redacted]	[redacted]	1	-	-	6	-	-	-	8	54	-	-	-	1	-	36	-	10	115
Site 142	[redacted]	[redacted]	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
Site 143	[redacted]	[redacted]	1	-	-	-	-	-	-	-	2	-	-	1	-	-	57	2	6	68

Floral Resource Use

We documented bumble bees foraging from at least 136 different plant species during surveys from 2020-2022 (Table 3). The most commonly used plant species was *Centaurea stoebe* (spotted knapweed, n=7782), followed by *Monarda fistulosa* (wild bergamot, n=3495), *Hypericum perforatum* (St. John's wort, n=645) and *Solidago canadensis* (Canada goldenrod, n=394). *Bombus auricomus* was documented foraging from 7 plant species but almost exclusively from *M. fistulosa* (149 occurrences, 91% of records) (Figure 3). Similarly, approximately 50% of *B. fervidus* occurrences were on *M. fistulosa*, despite visiting 16 different plant species. Half of the record *B. pensylvanicus* occurrences were documented on *Aureolaria pedicularia* (fern-leaf false foxglove), and this species visited 6 plant species in total (Figure 5). *Bombus borealis*, *B. sandersoni* and *B. terricola* were each documented using *C. stoebe* to a higher degree than other plant species (*B. borealis*: 65% of records, 21 plant species visited; *B. sandersoni*: 83% of records, 2 plant species visited; *B. terricola*: 62% of records, 27 plant species visited) (Figure 4, Figure 6, Figure 7).

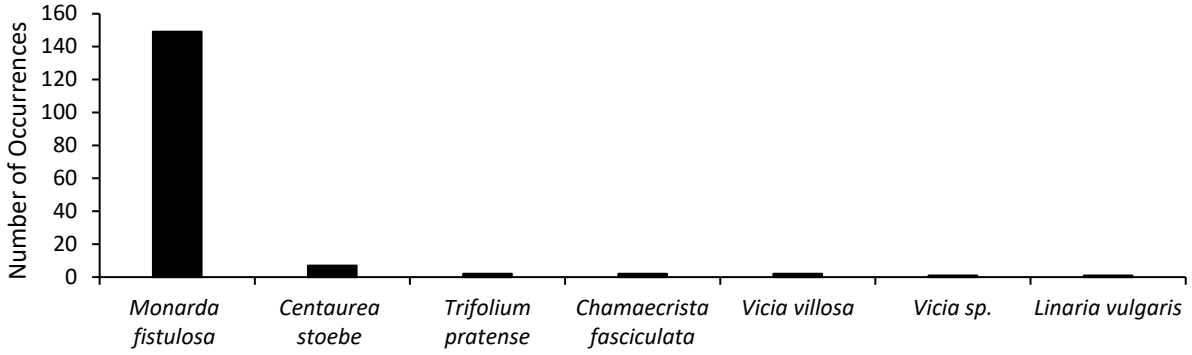

Figure 3. Primary floral resources used by *B. auricomus* in Michigan during surveys between 2020-2022.

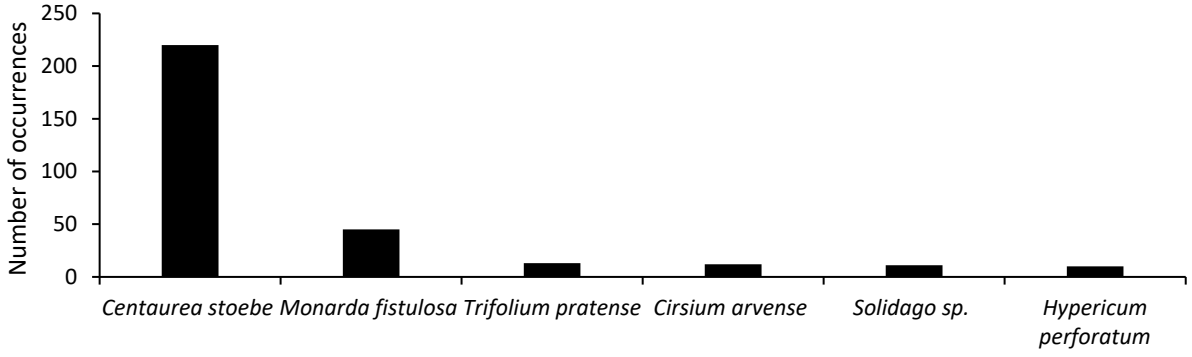

Figure 4. Primary floral resources used by *B. borealis* in Michigan during surveys between 2020-2022.

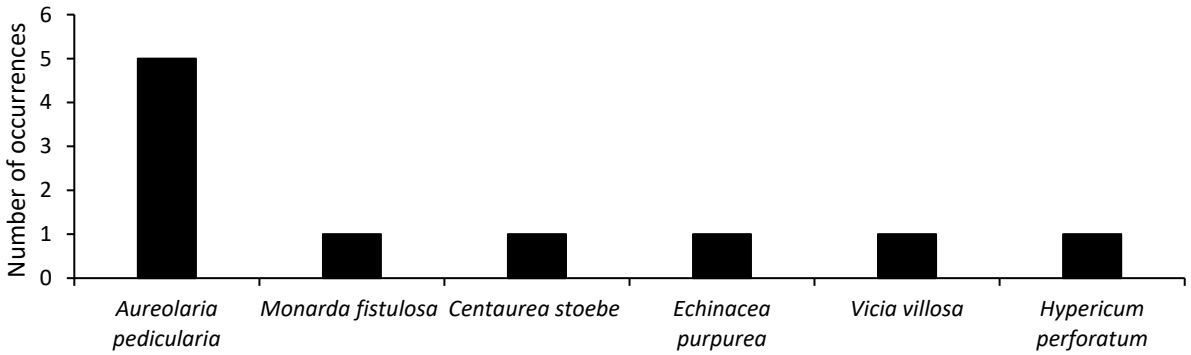

Figure 5. Primary floral resources used by *B. pensylvanicus* in Michigan during surveys between 2020-2022.

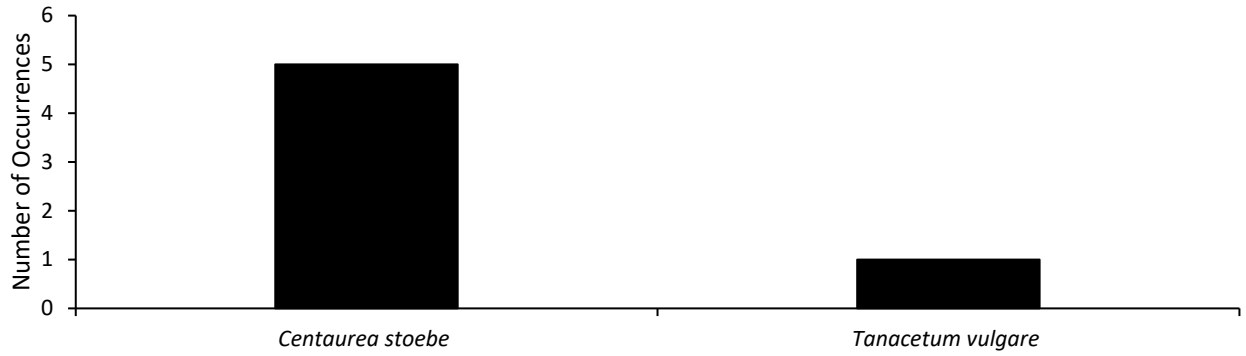

Figure 6. Primary floral resources used by *B. sandersoni* in Michigan during surveys between 2020-2022.

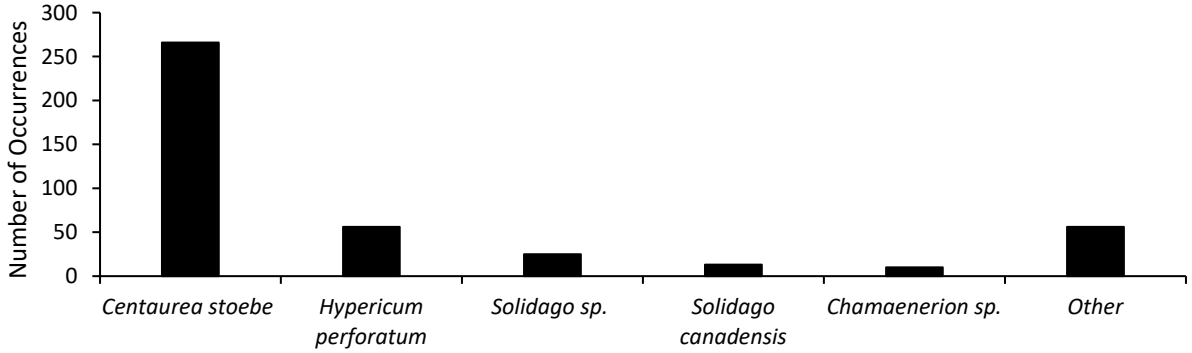

Figure 7. Primary floral resources used by *B. terricola* in Michigan during surveys between 2020-2022.

Table 3. Total number of occurrences for each bumble bee species on each plant species in Michigan during surveys between 2020-2022.

Plant Species	*Bombus auricomus*	*Bombus bimaculatus*	*Bombus borealis*	*Bombus citrinus*	*Bombus fervidus*	*Bombus flavidus*	*Bombus griseocollis*	*Bombus impatiens*	*Bombus insularis*	*Bombus pensylvanicus*	*Bombus perplexus*	*Bombus rufocinctus*	*Bombus sandersoni*	*Bombus ternarius*	*Bombus terricola*	*Bombus vagans*	Total
Centaurea stoebe	7	238	220	32	12	6	822	2730	-	1	35	6	5	1940	266	1462	7782
Monarda fistulosa	149	878	45	11	54	-	597	1380	-	1	17	3	-	21	1	338	3495
Hypericum perforatum	-	79	10	-	-	-	65	103	-	1	3	1	-	262	56	65	645
Solidago sp.	-	5	11	2	-	1	5	145	-	-	1	-	-	197	25	47	439
Solidago canadensis	-	1	2	-	-	-	13	165	-	-	-	3	-	156	13	41	394
Eutrochium purpureum	-	-	6	4	-	-	5	161	-	-	1	-	-	21	2	7	207
Securigera varia	-	34	1	-	1	-	25	50	-	-	-	-	-	-	-	14	125
Hypericum prolificum	-	17	-	-	-	-	20	67	-	-	-	-	-	-	-	1	105
Tanacetum vulgare	-	-	-	-	-	-	4	18	-	-	-	9	1	56	4	9	101
Lythrum salicaria	-	6	-	-	-	-	1	83	-	-	-	-	-	-	-	11	101
Silphium perfoliatum	-	-	-	22	-	-	21	56	-	-	-	-	-	-	-	-	99
Eupatorium perfoliatum	-	-	1	3	-	1	8	58	-	-	-	-	-	16	3	1	91
Aureolaria pedicularia	-	-	-	-	1	-	5	77	-	5	-	-	-	-	-	-	88
Dipsacus sp.	-	7	-	-	1	-	28	48	-	-	-	-	-	-	-	-	84
Echinacea purpurea	-	1	-	-	7	-	12	47	-	1	6	-	-	-	-	9	83
Cirsium arvense	-	-	12	1	1	-	-	12	1	-	1	-	-	19	2	32	81
Cirsium vulgare	-	8	2	9	7	1	7	22	-	-	1	-	-	1	-	23	81
Spiraea alba	-	6	-	-	-	-	7	51	-	-	-	-	-	9	1	1	75
Daucus carota	-	2	1	-	-	-	2	37	-	-	-	-	-	24	6	1	73
Lotus corniculatus	-	1	2	-	1	-	2	25	-	-	-	-	-	18	2	22	73
Vicia sp.	1	9	5	-	-	-	11	6	-	-	-	-	-	23	-	11	66
Liatris spicata	-	12	-	-	-	-	30	11	-	-	-	-	-	-	-	7	60
Verbena sp.	-	13	-	-	-	-	7	34	-	-	-	-	-	3	-	3	60

Trifolium pratense	2	11	13	1	9	-	3	5	-	-	-	-	-	3	-	10	57
Chamaecrista fasciculata	2	-	-	-	-	-	1	50	-	-	-	-	-	-	-	-	53
Asclepias syriaca	-	-	2	-	-	3	3	2	-	-	7	1	-	20	4	1	43
Pycnanthemum virginianum	-	4	-	-	-	-	12	21	-	-	1	-	-	-	-	5	43
Ratibida pinnata	-	4	-	-	-	-	17	14	-	-	1	-	-	-	-	-	36
Vicia villosa	2	1	-	-	4	-	2	1	-	1	-	-	-	1	-	19	31
Helianthus strumosus	-	1	-	-	1	-	1	27	-	-	-	-	-	-	-	-	30
Chamaenerion angustifolium	-	-	-	-	-	-	-	3	-	-	-	-	-	11	4	11	29
Monarda punctata	-	1	-	-	-	-	15	13	-	-	-	-	-	-	-	-	29
Verbena hastata	-	-	-	-	-	-	-	26	-	-	-	-	-	-	-	2	28
Liatris sp.	-	-	1	-	2	-	6	7	-	-	-	-	-	-	4	5	25
Doellingeria umbellata	-	-	-	-	-	-	1	11	-	-	-	-	-	11	1	1	25
Melilotus albus	-	-	-	-	-	-	1	6	-	-	-	-	-	9	3	2	21
Lespedeza capitata	-	-	-	-	-	-	-	18	-	-	-	-	-	-	-	1	19
Rudbeckia hirta	-	2	-	-	-	-	6	8	-	-	-	-	-	1	1	-	18
Solanum carolinense	-	1	-	-	-	-	-	17	-	-	-	-	-	-	-	-	18
Silphium terebinthinaceum	-	-	-	2	-	-	1	15	-	-	-	-	-	-	-	-	18
Trifolium repens	-	1	-	-	-	-	-	9	-	-	-	-	-	7	-	1	18
Cirsium sp.	-	1	-	-	-	-	2	14	-	-	-	-	-	-	-	-	17
Linaria vulgaris	1	-	-	-	4	-	1	7	-	-	-	-	-	-	-	3	16
Dasiphora fruticosa	-	4	-	-	-	-	3	3	-	-	-	-	-	5	-	1	16
Euthamia graminifolia	-	-	-	-	-	-	-	5	-	-	-	-	-	6	1	-	12
Chamaenerion sp.	-	-	-	-	-	-	-	-	-	-	1	-	-	-	10	-	11
Cirsium canadensis	-	2	-	-	-	-	1	8	-	-	-	-	-	-	-	-	11
Liatris aspera	-	-	-	-	-	-	-	8	-	-	-	-	-	-	2	-	10
Asclepias incarnata	-	1	-	-	-	-	8	1	-	-	-	-	-	-	-	-	10
Dipsacus laciniatus	-	2	-	-	-	-	4	3	-	-	-	-	-	-	-	-	9
Verbena stricta	-	-	-	-	-	-	-	6	-	-	-	-	-	-	-	3	9
Verbascum sp.	-	-	-	-	-	-	-	1	-	-	-	-	-	-	7	-	8
Vernonia sp.	-	-	-	5	-	-	-	3	-	-	-	-	-	-	-	-	8
Lamium sp.	-	-	2	-	1	-	-	-	-	-	-	-	-	2	-	3	8
Achillea millefolium	-	2	-	-	-	-	-	4	-	-	-	-	-	2	-	-	8

Cichorium intybus	-	-	-	-	-	-	-	6	-	-	-	-	-	1	-	1	8
Dipsacus fullonum	-	-	-	-	-	-	1	7	-	-	-	-	-	-	-	-	8
Lupinus perennis	-	3	-	-	-	-	4	1	-	-	-	-	-	-	-	-	8
Oenothera sp.	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	4	8
Cynanchum sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	7
Epilobium coloratum	-	-	-	-	-	-	-	7	-	-	-	-	-	-	-	-	7
Potentilla sp.	-	-	-	-	-	-	1	6	-	-	-	-	-	-	-	-	7
Sonchus arvensis	-	-	-	-	-	-	-	7	-	-	-	-	-	-	-	-	7
Symphotrichum sp.	-	1	-	-	-	-	-	1	-	-	-	-	-	5	-	-	7
Desmodium sp.	-	1	-	-	-	-	1	4	-	-	-	-	-	-	-	-	6
Helianthus sp.	-	-	-	-	-	-	-	3	-	-	-	-	-	-	1	1	5
Veronicastrum virginicum	-	-	-	-	-	-	1	3	-	-	-	-	-	-	-	1	5
Helenium autumnale	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	5
Mentha sp.	-	2	-	-	-	-	-	2	-	-	-	-	-	1	-	-	5
Rosa sp.	-	-	-	-	-	-	-	1	-	-	-	-	-	-	3	-	4
Helianthus divaricatus	-	1	-	-	-	-	1	1	-	-	-	-	-	-	-	1	4
Senna hebecarpa	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	4
Silene latifolia	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	3	4
Verbesina alternifolia	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	4
Vernonia fasciculata	-	1	-	-	-	-	-	3	-	-	-	-	-	-	-	-	4
Arctium minus	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	3
Betonica officinalis	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	2	3
Coreopsis tripteris	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	3
Desmodium canadense	-	-	-	-	-	-	2	1	-	-	-	-	-	-	-	-	3
Oenothera biennis	-	-	-	-	-	-	1	2	-	-	-	-	-	-	-	-	3
Potentilla norvegica	-	-	-	-	-	-	-	1	-	-	-	-	-	2	-	-	3
Prunella vulgaris	-	-	1	-	-	-	-	2	-	-	-	-	-	-	-	-	3
Silphium sp.	-	-	-	1	-	-	-	2	-	-	-	-	-	-	-	-	3
Trifolium sp.	-	1	1	-	-	-	-	-	-	-	-	-	-	1	-	-	3
Pteridium sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	2
Clinopodium vulgare	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	2
Asclepias tuberosa	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	2

Capsella bursa-pastoris	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	2
Cirsium discolor	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	2
Cirsium palustre	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	2
Creopsis tripteris	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	2
Helianthus mollis	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	2
Heliopsis helianrhodes	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	2
Hypericum sp.	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Impatiens capensis	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	2
Melilotus officinalis	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	2
Salvia yangii	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	2
Silphium integrifolium	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	2
Teucrium canadense	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Trifolium hybridum	-	-	1	-	-	-	-	-	-	-	-	-	-	1	-	-	2
Verbascum thapsus	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-	2
Euphorbia esula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
Silphium laciniatum	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1
Agrimonia parviflora	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Alium sp.	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Allium canadense	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Ambrosia artemisiifolia	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1
Asclepias viridiflora	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1
Berteroa incana	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Calystegia sepium	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Carduus nutans	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Cephalanthus occidentalis	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Chelone glabra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
Erigeron annuus	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Erigeron canadensis	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1
Erigeron strigosus	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1
Eryngium yuccifolium	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Euphorbia corollata	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Euphrasia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1

Gymnosperma glutinosum	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1
Hieracium aurantiacum	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1
Lespedeza virginica	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Leucanthemum vulgare	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Lotus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1
Mentha arvensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
Oligoneuron rigidum	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Pilosella caespitosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
Pinus sp.	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Sagittaria latifolia	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Silene vulgaris	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Solidago speciosa	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Sonchus sp.	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Symphyotrichum novae-angliae	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Symphyotrichum oolentangiense	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
Vaccinium angustifolium	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Verbena urticifolia	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1
Vicia cracca	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1

Habitat Evaluations

Bumble bee sampling areas varied in overall habitat quality across the state. In southern Michigan, survey locations were a mix of grasslands, prairie restorations, woodland edges, old fields, and some right-of-way habitats. A mixture of private and public lands were surveyed. In northern Michigan, most survey locations were forest openings, right-of-way habitats, or urban parks located near smaller cities.

On average, survey sites contained just over 11 flowering plant species per survey. However, a few sites greatly exceeded this average (Site 35: 28 blooming plant species, Site 62: 27 blooming plant species, Site 15: 26 blooming plant species) (Figure 8a). The total assessment scores for survey sites varied from 18 to 102 out of a possible 135 points (Figure 8b). The mean site score of all survey locations in Michigan was 66/135. Site 28 received the highest habitat assessment score among all surveys 2020-2022, with a score of 102/135. Sites with *B. terricola* had an average habitat assessment score of 64.8, compared to 49.1 for sites lacking *B. terricola*. This trend of higher habitat assessment scores with populations of state listed bumble bees was generally consistent across species assessed (Table 4).

High quality habitat in southern Michigan contains a diverse assortment of native flowering forbs and bunch grasses.

Table 4. Summary of habitat assessment scores for state listed bumble bees in Michigan.

Species	Total Sites Assessed	Number of Sites with Species	Average Habitat Assessment Score of Sites with Species	Average Assessment Score of Sites Lacking Species
B. auricomus	86	18	74.4	65.6
B. borealis	56	37	66.9	51.7
B. pensylvanicus	86	4	77.3	67
B. sandersoni	56	6	66.2	50.6
B. terricola	56	48	64.8	49.1

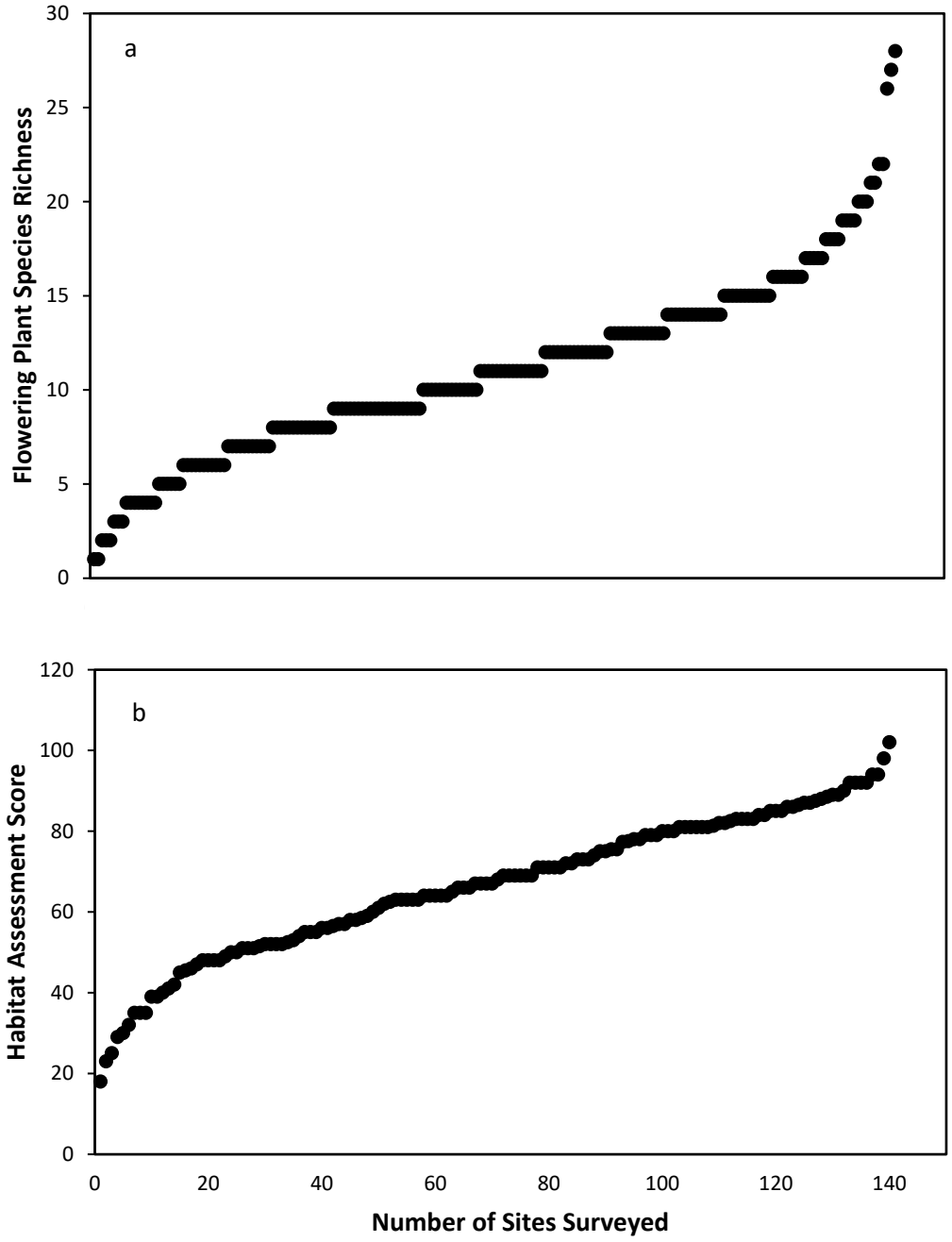

Figure 8. Scores for flowering plant species richness (a) and habitat assessments (b) at each survey location in Michigan during surveys between 2020-2022.

Habitat Suitability Models for State Listed Species

Habitat suitability models were constructed for *B. auricomus* (Figure 10), *B. borealis* (Figure 11), *B. pensylvanicus* (Figure 12), and *B. terricola* (Figure 13) in Michigan. Max temperature of the warmest month was positively correlated with habitat suitability for *B. auricomus* and *B. pensylvanicus*, while negatively correlated with habitat suitability for *B. borealis* and *B. terricola*. For *B. auricomus*, the most important covariate for habitat suitability was mean grassland cover within a 300-meter radius. Mean upland and wetland forest cover within a 300-meter radius was positively correlated with habitat suitability for *B. borealis*, *B. pensylvanicus*, and *B. terricola*, while negatively correlated with habitat suitability for *B. auricomus* (Table 5).

For *B. affinis*, the most effective single variable for predicting the distribution of occurrence data is mean annual temperature (% contribution = 69.5, permuation importance= 60.4). Figure 9 below shows that the mean annual temperature of about 8.5 degrees C is optimal for *B. affinis* presence, with a range from 5-11 degrees C. Mean annual temperature is calculated as mean of all the monthly mean temperatures in years 1981-2014. Each monthly mean temperature is the mean of that month's maximum and minimum temperature.

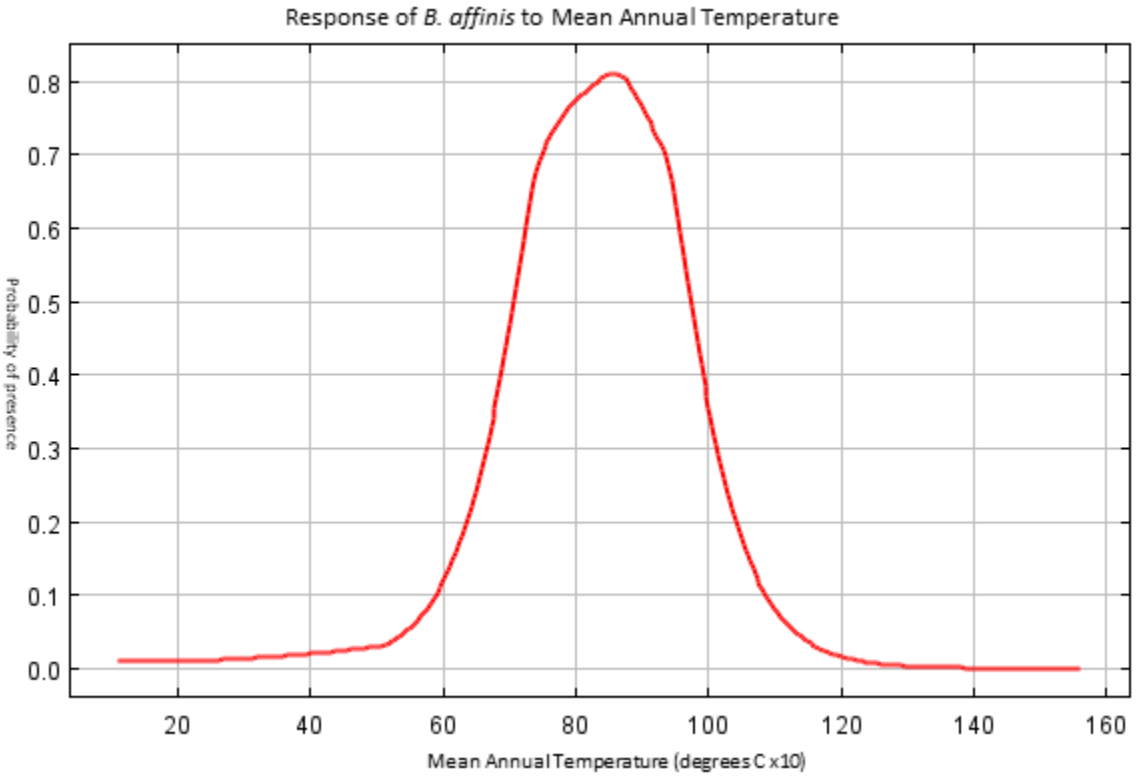

Figure 9. Relationship between probability of presence and mean annual temperature for *B. affinis* occurrences in the geographic region where occurrence data exists for the species.

The variables “cropland” and “developed land” (at 300-meter radius) were both negatively correlated with habitat suitability, although their percent contribution and permutation importance values were generally lower in the model output (nlcd developed 300m: % contribution = 11, permutation importance = 9.2; nlcd crop 300m: % contribution = 3.4, permutation importance = 15.2)

Table 5. Model statistics and covariates associated with occurrences of extant state listed bumble bee species in Michigan.

Modeled Species	Full model AUC	Covariates*	Relationship	% Contribution	Permutation importance
B. auricomus	0.8300	gr100	(-)	53	45.3
		mxtpwrmmth	(+)	32	32.6
		for10	(-)	15.1	22.1
B. borealis	0.8070	mxtpwrmmth	(-)	60.3	63.9
		for10	(+)	32.2	29
		crop100	(+)	7.5	7.1
B. pensylvanicus	0.7890	for10	(-)	52.6	70.3
		mxtpwrmmth	(+)	47.4	29.7
B. terricola	0.8350	mxtpwrmmth	(-)	60.9	67.4
		uopen10	(+)	24.7	17.2
		for10	(+)	8	10.6
		develop100	(-)	6.3	4.9

* **crop100**: mean agricultural crops within a 3000-meter radius, **develop100**: mean developed land within a 3000-meter radius, **for10**: mean upland and wetland forest cover within a 300-meter radius, **gr100**: mean grassland cover within a 3000-meter radius, **mxtpwrmmnth**: max temperature of the warmest month, **uopen10**: mean open (herbaceous grassland and shrub) upland cover within a 300-meter radius.

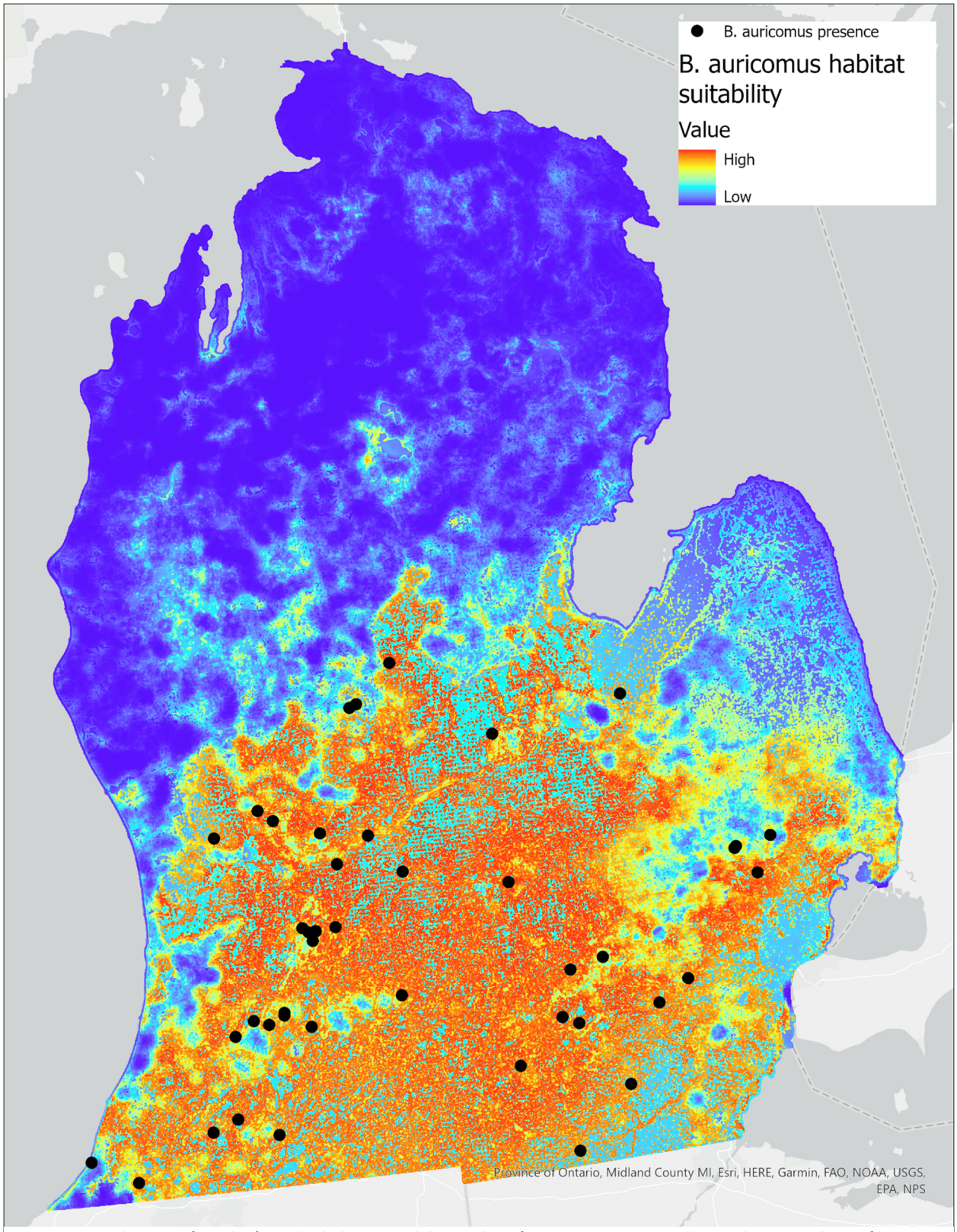

Figure 10. Visualization of results from the habitat suitability analysis for *B. auricomus* in Michigan along a gradient of low to high suitability.

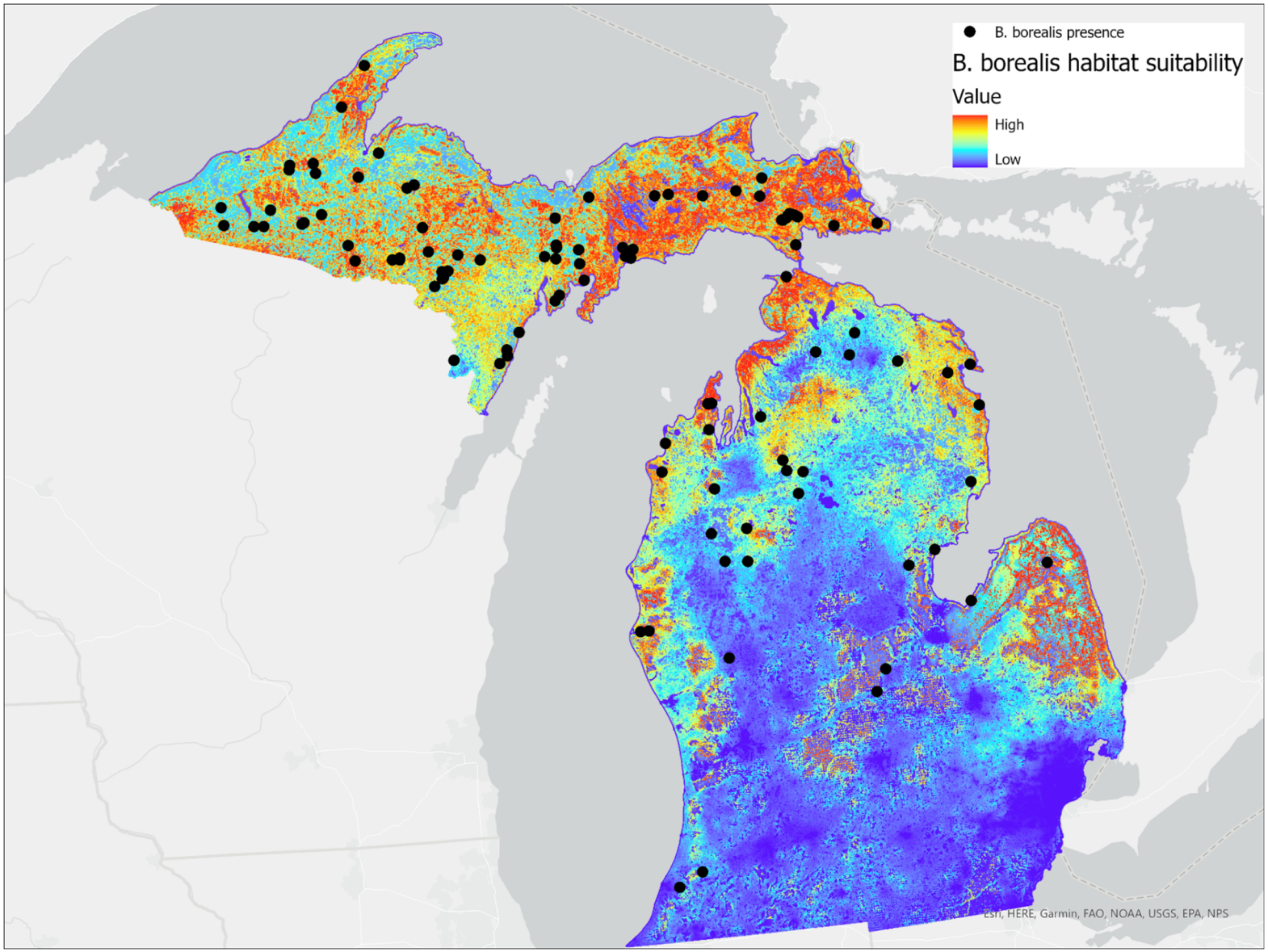

Figure 11. Visualization of results from the habitat suitability analysis for *B. borealis* in Michigan along a gradient of low to high suitability.

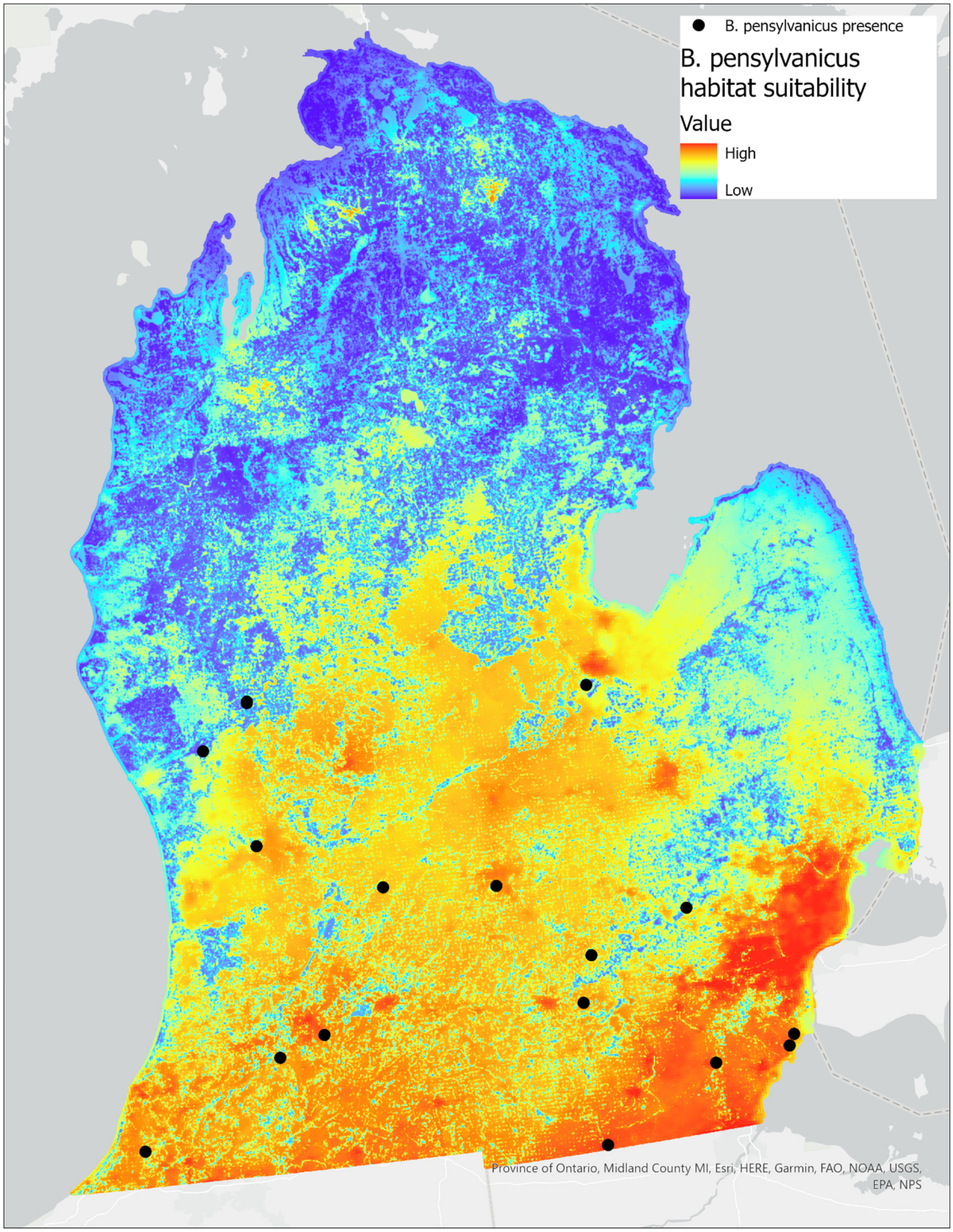

Figure 12. Visualization of results from the habitat suitability analysis for *B. pensylvanicus* in Michigan along a gradient of low to high suitability.

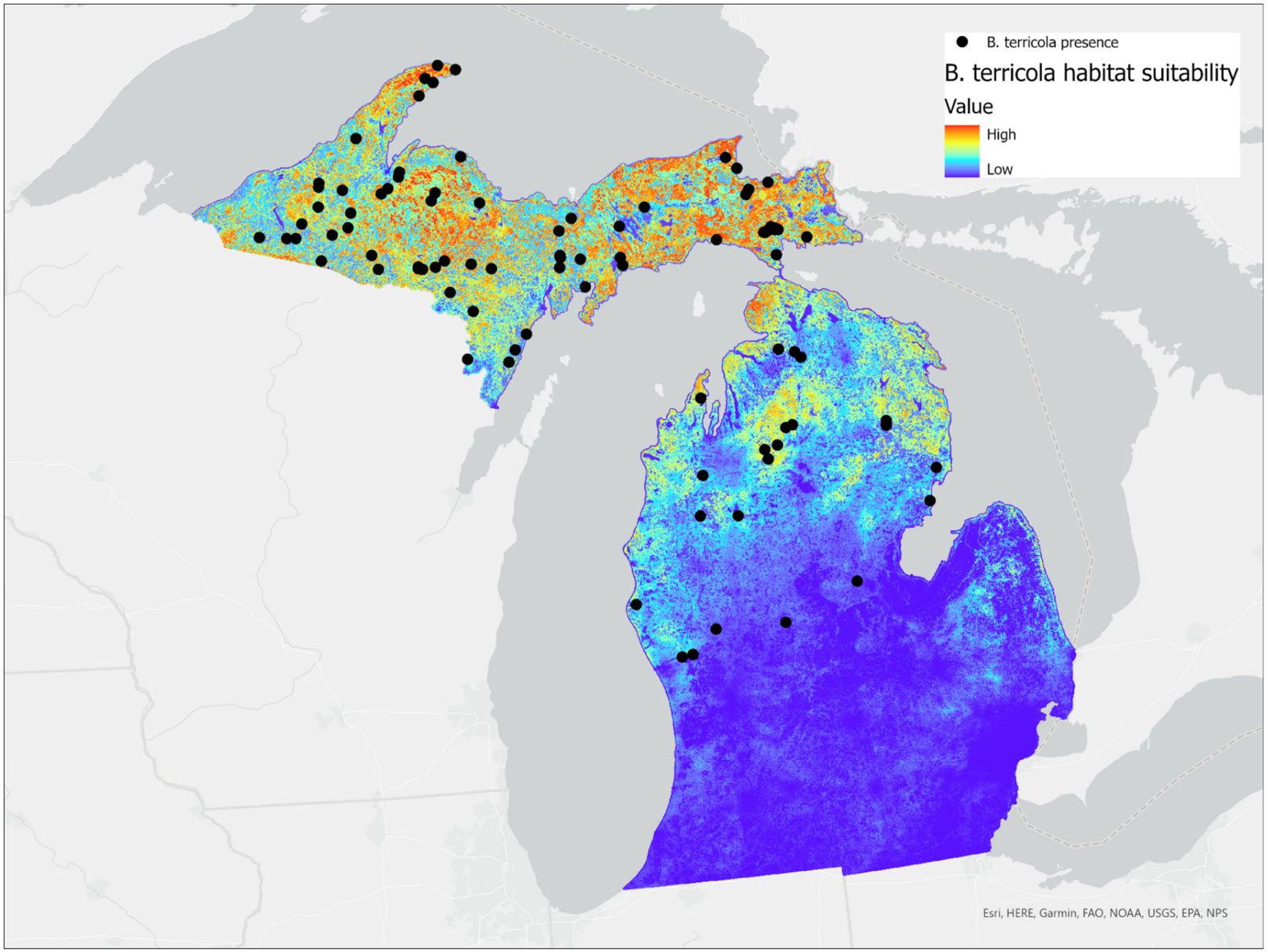

Figure 13. Visualization of results from the habitat suitability analysis for *B. terricola* in Michigan along a gradient of low to high suitability.

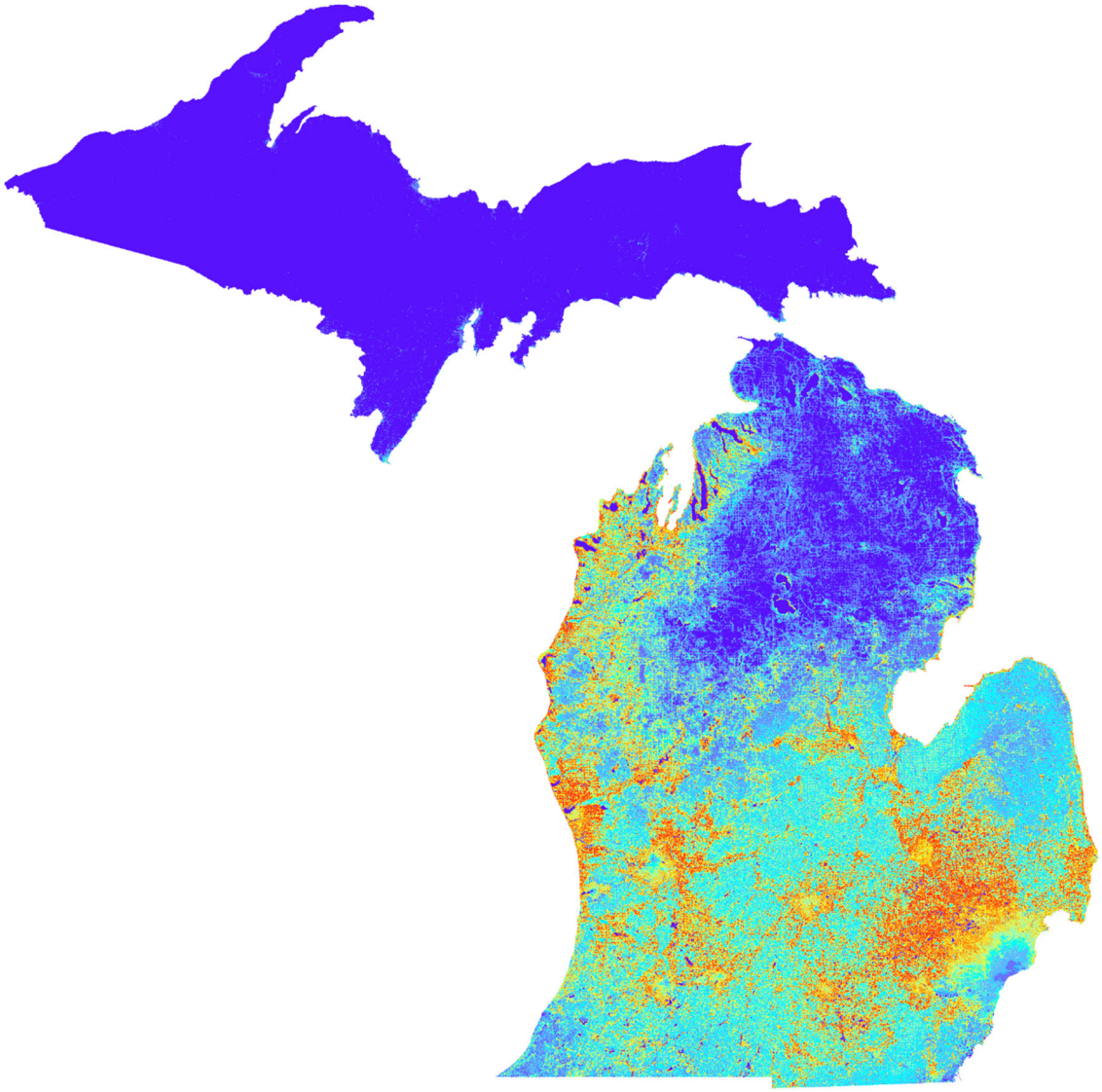

Figure 14. Visualization of results from the habitat suitability analysis for *B. affinis* in Michigan along a gradient of low to high suitability.

Discussion

Between 2020-2022, MNFI completed 189 bumble bee surveys in 143 survey locations, resulting in 15,478 bumble bee records representing 16 unique species. While most records were of common species, numerous occurrences of state listed species were documented, including 166 *B. auricomus*, 346 *B. borealis*, 13 *B. pensylvanicus*, 6 *B. sandersoni*, and 438 *B. terricola*. Many of these occurrences represent previously undocumented populations of rare bumble bees in Michigan. Notably, statewide surveys demonstrate that Michigan's bumble bee communities shift along a longitudinal gradient, where bumble bee communities north of the floristic tension zone are unique when compared to communities south of the zone (See Figure 14). Here, a noticeable shift in forest community type, as well as associated ground level forb species, may be associated with bumble bee species composition, particularly the presence of state listed species. For example, *B. terricola* is generally found north of this zone, while *B. auricomus* and *B. pensylvanicus* are generally found south of this zone. Therefore, habitat assessments at each survey location serve as crucial starting points to identifying habitat characteristics associated with bumble bee species of concern, which may have specific requirements for supporting populations.

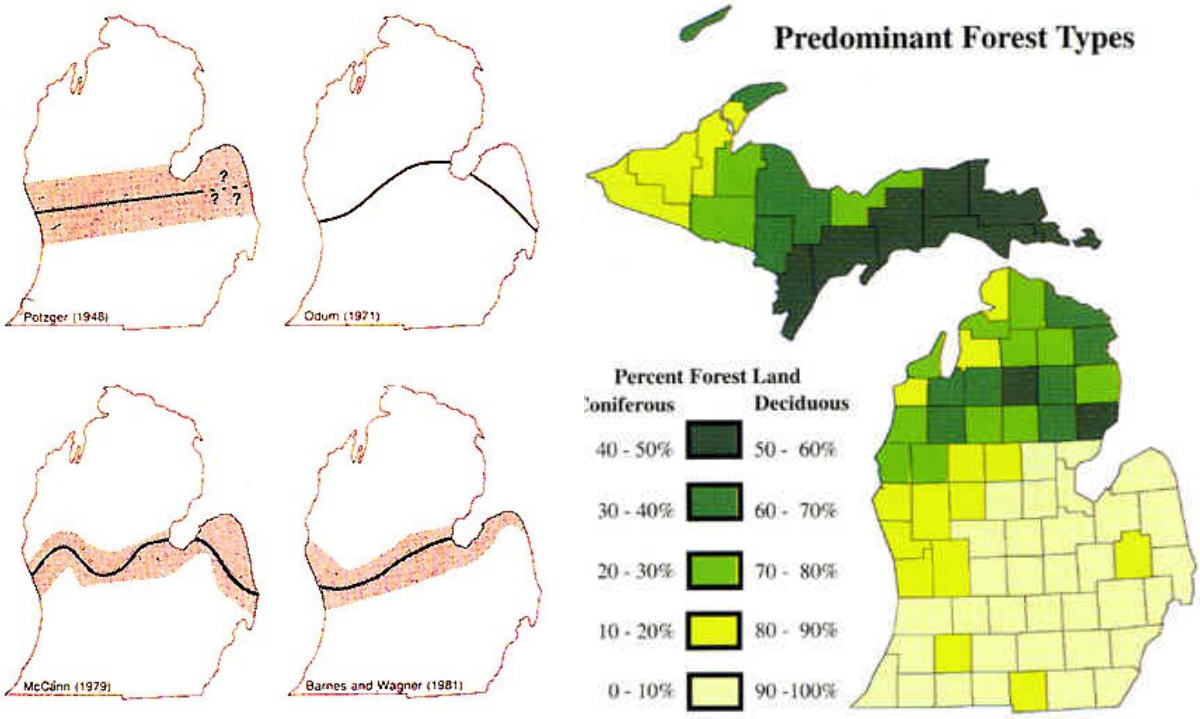

Figure 15. Floristic tension zone running through the middle of Michigan's southern peninsula separates the primary forested habitat types associated with the northern and southern regions of the state. Maps developed by Wayne Kiefer, Central Michigan University.

With these surveys, we were able to document the primary floral resources used by bumble bees in Michigan in July and August. One interesting find was the strong associated that *B. auricomus* and *B. fervidus* both had with *M. fistulosa*, with 91% and 50% of occurrences from this plant species, respectfully. Nearly all survey areas where these species were found in southern Michigan had at least some *M. fistulosa* in bloom, even if the bee was not actively foraging from it at the point of documentation. Many locations north of the floristic tension zone have significant populations of *C. stoebe*, a highly invasive species (Blair and Hufbauer, 2010), that seems to currently play an important role in providing pollen and nectar resources to populations of bumble bees. This creates a conservation conundrum, where habitat restoration that incorporates native wildflowers into land management programs must account for this association and provide significant co-blooming resources to offset the effect that removal of spotted knapweed may have on populations of at-risk bumble bees.

The associated habitat assessments for each survey site provide insights to overall habitat quality of landscape across Michigan that are suitable for bumble bees. We anticipate that the habitat level data collected alongside the bumble bee community data will be a valuable starting point in working with land managers to implement decisions that support bumble bees in these areas. For example, depending on the current abundance and richness of native wildflower species that are present at a site, plant species selection for habitat management can be optimized to incorporate additional resources the create a more diverse habitat with resources available at all life stages. Alternatively, data may suggest that nesting resources may be a limiting factor in supporting populations of rare species. In these cases, land managers may be able to increase the ground level nesting resources by adjusting burn programs or incorporating more native bunch grasses into programs to improve nest site availability.

By constructing habitat suitability models for state listed bumble bee species, we provide researchers and conservation scientists maps to 1) develop conservation priorities that target overlapping at-risk bumble bee species, and 2) begin identifying landscapes, within species' expected ranges in Michigan, to protect and improve suitable habitats. Furthermore, by mapping suitable habitat across Michigan based on predictive environmental variables, we can use the information to identify un-surveyed habitats that have higher probabilities of state listed species occurrence. This is particularly important when locating and conducting on-the-ground surveys for a species when time and funding is limited. As climate change, as well as human development, continue to put pressures on at-risk bumble bee species, identifying approaches to mitigate these stressors will become increasingly needed to support long-term population viability.

Bombus affinis was last observed in Michigan in 1999, despite being well within the historic range of this species. Similarly, the species seems to be extirpated from Ohio and Indiana, minimizing the routes the species may take to re-establish populations within the state. Interestingly, *B. affinis* seems to be occupying habitats along a longitudinal gradient west of lake Michigan, in Wisconsin, which contains many reasonably similar habitats as Michigan. Furthermore, results of the habitat suitability analysis suggest that probability of occurrence is strongly associated to mean annual temperate, demonstrating that this species is adapted to temperate climate, such as those within the great lakes basin. Therefore, it's plausible that suitable habitats exist in Michigan despite documented occurrence. There are two general conclusions we can make from this information: 1) adequate pollen, nectar, and nesting resource availability which connects Michigan with extant populations of the species needs to be adopted in order to ensure species re-introduction to the state and 2) habitats within Michigan should continue to be managed to maintain ecological integrity and include *B. affinis* super foods and nesting

needs. To meet the goals of *B. affinis* recovery across the US, collaborative efforts between states within the historic range will be required. As efforts to increase the spatial range of suitable habitat withing the Great Lakes region continue, populations of *B. affinis* may expand through connected habitats and re-integrate into bumble bee communities in Michigan.

Conclusion and Future Research Needs

Despite not locating any populations of *B. affinis* in Michigan, statewide surveys provided valuable information for bumble bee conservation in the state. The documentation of robust bumble bee communities, which include the presence of state listed species, provides a framework for identifying and conserving the habitats and floral resources which species are associated with. The habitat assessments provide an initial evaluation of bumble bee habitats across the state, improve our understanding of realized habitat availability in relation to bumble bee presence, and create a baseline for improving habitat management to protect rare species. Future work should incorporate a more robust approach to surveying habitat quality, as we were only able to visit a site once per year, limiting our understanding of total floral resource availability. Spring and/or fall surveys at many of these sites are needed to document resource availability at critical early and late life stages of at-risk bumble bees.

In Michigan, future work to support the *B. affinis* recovery plan should prioritize continuing bumble bee survey efforts, particularly in locations informed by habitat suitability modeling efforts. Since multiple locations of state listed bumble bee species have been identified, improving habitat management in these areas will ensure that populations persist. Particular attention should be paid to those habitats containing state listed species which have similar distributions as *B. affinis*, such as *B. auricomus* and *B. pensylvanicus*. Collaboration and communication between states within the historic range of *B. affinis* will be needed to assist in the expansion of *B. affinis* to locations throughout its historic range.

Michigan Nature Association Newaygo Prairie. Surveyed during each year 2020-2022. Remains the only site in Michigan with documented occurrences of both *B. pensylvanicus* and *B. terricola*.

Acknowledgements

This project was funded by the United States Fish and Wildlife Service through a Great Lakes Restoration Initiative Cooperative Agreement Award F20AC00228. Thank you to the field technicians that assisted in data collection: Nicole Bailey, Courtney Ross, Molly Fava and multiple Huron Pines Americorp members. Access to many of these survey sites would not have been possible without the assistance of project partners: The Nature Conservancy of Michigan, Michigan DNR, United States Fish and Wildlife Service, Southwest Michigan Land Conservancy, Michigan Nature Association, and many additional public and private land managers. Ashley Adkins, Deborah Richardson, Sarah Carter, and Brian Klatt provided administrative assistance.

Literature Cited

Blair, A. C., & Hufbauer, R. A. (2010). Hybridization and invasion: one of North America's most devastating invasive plants shows evidence for a history of interspecific hybridization. *Evolutionary Applications*, *3*(1), 40-51.

Cameron, S. A., & Sadd, B. M. (2020). Global trends in bumble bee health. *Annual review of entomology*, *65*, 209-232.

Colla, S. R., Gadallah, F., Richardson, L., Wagner, D., & Gall, L. (2012). Assessing declines of North American bumble bees (*Bombus* spp.) using museum specimens. *Biodiversity and Conservation*, *21*, 3585-3595.

Dewitz, J., and U.S. Geological Survey (2021. National Land Cover Database (NLCD) 2019 Products (ver. 2.0, June 2021): U.S. Geological Survey data rel)ease, https://doi.org/10.5066/P9KZCM54

Derosier, A.L., S.K. Hanshue, K.E. Wehrly, J.K. Farkas, and M.J. Nichols. 2015. Michigan's Wildlife Action Plan. Michigan Department of Natural Resources, Lansing, MI. available online at: http://www.michigan.gov/dnrwildlifeaction

ESRI 2020. ArcGIS Survey123: Version 2.08. Redlands, CA: Environmental Systems Research Institute.

Fielding, A.H., & Bell, J.F. (1997). A Review of Methods for the Assessment of Prediction Errors in Conservation Presence/Absence Models. Environmental Conservation 24(1): 38–49.

Husband, R. W., Fischer, R. L., & Porter, T. W. (1980). Description and biology of bumblebees (Hymenoptera: Apidae) in Michigan. *Great Lakes Entomologist*, *13*(4), 225-239.

Jacobson, M. M., Tucker, E. M., Mathiasson, M. E., & Rehan, S. M. (2018). Decline of bumble bees in northeastern North America, with special focus on *Bombus terricola*. *Biological Conservation*, *217*, 437-445.

Janousek, W. M., Douglas, M. R., Cannings, S., Clément, M. A., Delphia, C. M., Everett, J. G., ... & Graves, T. A. (2023). Recent and future declines of a historically widespread pollinator linked to climate, land cover, and pesticides. *Proceedings of the National Academy of Sciences*, *120*(5), e2211223120.

Jueterbock, A., Smolina, I., Coyer, J. A., & Hoarau, G. (2016). The fate of the Arctic seaweed Fucus distichus under climate change: an ecological niche modeling approach. *Ecology and Evolution*, *6*(6), 1712-1724.

Phillips, S.J., Anderson, R. P. & Schapire, R.E. (2006). Maximum entropy modeling of species geographic distributions. Ecological Modelling, 190, 231-259.

Rowe, L. M., Cuthrell, D. L., & Enander, H. D. (2019) Assessing Bumble Bee Diversity, Distribution, and Status for the Michigan Wildlife Action Plan. Michigan Natural Features Inventory Report No. 2019-33.

Smith, T. A., Strange, J. P., Evans, E. C., Sadd, B. M., Steiner, J. C., Mola, J. M., Traylor-Holzer, K. (eds.). 2020. Rusty patched bumble bee, *Bombus affinis*, ex situ assessment and planning workshop: final report. IUCN SSC Conservation Planning Specialist Group, Apple Valley, MN. https://wildlifepreservation.ca/2016/wp-content/uploads/2021/01/RPBB-Ex-Situ-Assessment-Final-Report.pdf

Wood, T. J., Gibbs, J., Graham, K. K., & Isaacs, R. (2019). Narrow pollen diets are associated with declining Midwestern bumble bee species. *Ecology*, *100*(6), e02697.

Yang, L., et al. 2018. A new generation of the United States National Land Cover Database: Requirements, research priorities, design, and implementation strategies. ISPRS Journal of Photogrammetry and Remote Sensing 146: 108–123