Assessing Bumble Bee Diversity, Distribution, and Status for the Michigan Wildlife Action Plan

Prepared By:

Logan M. Rowe, David L. Cuthrell, and Helen D. Enander
Michigan Natural Features Inventory
Michigan State University Extension
P.O. Box 13036
Lansing, MI 48901

Prepared For:

Michigan Department of Natural Resources
Wildlife Division

12/17/2019

MNFI Report No. 2019-33

Michigan Natural Features Inventory
Discover. Define. Deliver.

MICHIGAN STATE UNIVERSITY | Extension

Suggested Citation:

Rowe, L. M., D. L. Cuthrell., H. D. Enander. 2019. Assessing Bumble Bee Diversity, Distribution, and Status for the Michigan Wildlife Action Plan. Michigan Natural Features Inventory, Report Number 2019-33, Lansing, USA.

Cover: *Bombus terricola* taken by D. L. Cuthrell

Table of Contents

List of Tables

List of Figures

Abstract

Bumble bees (*Bombus* spp.) are an ecologically important group of pollinators that were not adequately addressed in Michigan's original Wildlife Action Plan, and due to a lack of occurrence data within the Natural Heritage database, have not been assigned a state conservation rank (S-rank). In 2016-2019, the Michigan Natural Features Inventory (MNFI) completed a statewide inventory of bumble bee occurrences in Michigan to document historic and current population trends of 20 bumble bee species, and to determine the conservation status of each bumble bee species found in Michigan. For one at-risk bumble bee species, *B. terricola*, we used a habitat suitability model to predict species occurrence in Michigan and to identify the environmental variables associated with it's occurrence in occupied habitats. Based on S-rank calculations, we've identified 6 bumble bee species to receive updated state conservation status: *Bombus affinis* (SH, Endangered), *B. auricomus* (S2, Special Concern), *B. borealis* (S3, Special Concern), *B. penslyvanicus* (S1, Threatened), *B. sandersoni* (S2S3, Special Concern), and *B. terricola* (S2S3, Special Concern). The results of this project will assist agencies in making decisions regarding bumble bee conservation and will enhance the next implementation of the Michigan Wildlife Action Plan.

Introduction

Insect pollinators provide pollination services that are crucial to the functioning and stability of nearly all terrestrial ecosystems (Kevan 1999). Recent assessments of the global biodiversity of insects have documented unprecedented declines in total insect biomass (Hallmann et al. 2017, Thomas et al. 2019), including significant population declines in some pollinator species (NRC 2007, Potts et al. 2010, Murray 2009). In North America, the National Research Council (NRC) began summarizing existing information and research on native bee distributions and statuses. They found a long-term decline in some wild bee species, and attributed declines to a multitude of stressors including habitat loss, pesticides, pathogens, and climate change (NRC 2007).

Bumble bees (*Bombus* spp.) represent a diverse genus of bees that vary considerably in body size, social behavior, dietary requirements, and geographical distribution (Williams 1998). Due to their charismatic nature and the relative ease of identification, bumble bee occurrences have been well documented by scientists and natural historians throughout history (Sladen 1912, Husband et. al 1980, Williams 1982, Kerr et al. 2015). Consequently, researchers have shown changes in the abundance and distribution of many bumble bee species, and some species are known to be in decline throughout their historic ranges (Williams 1982, Richardson et al. 2019, Wood et al. 2019). In Vermont, four species of bumble bees (*B. affinis, B. fervidus, B. pensylvanicus, B. terricola*) are experiencing significant population declines (Richardson et al. 2018). Similar trends of bumble bee populations have been demonstrated in Michigan for five species (*B. affinis, B. auricomus, B. fervidus, B. pensylvanicus, B. terricola*) (Wood et al. 2019). One species, the federally endangered Rusty-patched Bumble Bee (*B. affinis*) has not been found in the state in over 20 years. In 2016, *B. terricola* was listed in the US Fish and Wildlife Service 7-year National Listing Workplan. Furthermore, Michigan's Wildlife Action Plan (WAP) currently lists two species listed as Species of Greatest Conservation Need (SGCN), *B. affinis* and *B. terricola*.

Despite their ecological importance, bumble bees were not adequately addressed in Michigan's original Wildlife Action Plan, and due to a lack of data, have not been assigned a state conservation rank (Badra et al. 2014). In Michigan, most studies of native bees have focused on agroecosystems or field edges (Gardiner et al. 2010, Tuell et al. 2009), and prairie reconstructions (Tuell et al. 2008, Rowe et al. 2019). Few studies have assessed temporal and/or spatial declines in bumble bee species throughout Michigan. One study used data from a variety of sources, including academic research, personal collections, and museum specimen to estimate pollen resource use and the decline of bumble bee species in Michigan at the county level (Wood et al. 2019). However, little is known about the natural habitat associations of Michigan's native bumble bees and the potential extinction risk to species' populations.

In 2016-2019, the Michigan Natural Features Inventory (MNFI) completed a statewide inventory of bumble bee occurrences in Michigan to document historic and current population trends of 20 bumble bee species. This effort included a statewide survey effort as well as compiling specimen records from museum, academic, and personal collections. Our primary objective was to determine the status and conservation needs of bumble bee species in Michigan by determining the current conservation status (S-ranks) of native bumble bee species in Michigan. For one at-risk bumble bee species, *B. terricola*, we used a habitat suitability model to predict species occurrence in Michigan and to identify the environmental variables associated with it's occurrence in occupied habitats. The information collected on the status of bumble bees in Michigan will assist agencies making decisions regarding bumble bee conservation and will enhance the next rendition of the Michigan Wildlife Action Plan.

Methods

Museum Searches

Bumble bee specimens from the Albert J. Cook Arthropod Research Collection (ARC) at Michigan State University were viewed, identifications confirmed/verified, and collection label information was tabulated into a collection data base. Important fields included species identification, locality, date, and any additional collection information including technique or plant species a specimen was collected from. A total of 4,164 bumble bees were inspected from the MSU collection and label information was tabulated with locality information digitized. All of the *Bombus* species (including *B. affinis, B. terricola, B. auricomus,* and *B. pensylvanicus*) are available and published on the IDigBio web site (https://www.idigbio.org/portal/search). In addition, we acquired bumble bee collections from Dr. Thomas Wood in the Department of Entomology at Michigan State University, which include personal collections, verified iNaturalist specimens, and specimens from the University of Michigan Museum of Zoology insect collection. The identity of each specimen has been confirmed by experts, including MNFI Zoologists and Dr. Tom Wood. In total, our non-MNFI data set includes 10,201 bumble bees.

Field Surveys

MNFI conducted a statewide bumble bee survey throughout Michigan in 2016-2019. In general, surveys were prioritized in habitats or locations of historic occurrences of at-risk bumble bee species: *B. affinis*, *B. pennsylvanicus*, and *B. terricola*. Surveys were conducted between June and September, on days that had no rain, temperatures above 15° C (60° F), and when winds were ≤ 25 kph (15 mph). We utilized an aerial-netting technique to collect bees by traversing each site with aerial nets and collecting bumble bees visiting flowers (Figure 1). All collection sites included natural communities, roadsides, old fields, other more anthropogenic habitats. Because of the difficulty in effectively surveying the entire state, surveys within each year were prioritized in different regions of Michigan (Figure 2). In addition, we recorded at-risk specimens collected during surveys as part of the project *Pollinator through enhancement of Michigan's and Wisconsin's grassland, prairie, and savanna habitat* (Hacket et al. 2019, MNFI Report No. 2019-32), at- risk species collected at Fort Custer Training Center in 2019, and at-risk species that were encountered opportunistically. In total, 1,356 individual bumble bees were collected during these combined surveys. Each specimen was processed, identified, and labeled with collection and identification tags. All specimens are stored in the MNFI general collection for future reference.

Figure 1. David Cuthrell using the modified Strange et al. (undated) bumble bee sampling protocol at Allegan State Game Area (left). Bombus auricomus queen collected using aerial collection net (top right). *Bombus terricola* nectaring on spotted knapweed (*Centaurea stoebe* L. ssp. *micranthos*) (bottom right).

S-rank Calculations

We used NatureServe's Element Rank Calculator to calculate the current S-ranks for each bumble bee species in Michigan (Version 2.0, Faber-Langendoen et al. 2009). The conservation rank calculator is a standardized tool that uses ten conservation status factors within three broad categories (rarity, trends, and threats) to develop an overall conservation rank (see Table 1). Experts input information on rarity, trends, and threats, each of which has several components (e.g., range extent, area of occupancy, population size, number of occurrences, short-term trend, long-term trend, and threat impact). The calculator then performs a series of algorithms based on pre-defined or user-defined parameter weights to generate an S-rank. This is a widely used tool and is the tool that has been used to update most of Michigan's SGCN S-ranks (Badra et al. 2014).

Table 1. Subnational Conservation Status Ranks (S-ranks) and definitions.

S-rank	Definition
S1	Critically Imperiled: At very high risk of extirpation in the state due to very restricted range, very few populations or occurrences, very steep declines, severe threats, or other factors.
S2	Imperiled: At high risk of extirpation in the state due to restricted range, few populations or occurrences, steep declines, severe threats, or other factors.
S3	Vulnerable: At moderate risk of extirpation in the state due to a fairly restricted range, relatively few populations or occurrences, recent and widespread declines, threats, or other factors.
S4	Apparently Secure: At a fairly low risk of extirpation in the state due to an extensive range and/or many populations or occurrences, but with possible cause for some concern as a result of local recent declines, threats, or other factors.
S5	Secure: At very low or no risk of extirpation in the state due to a very extensive range, abundant populations or occurrences, with little to no concern from declines or threats.
S#S#	Range Rank: A numeric range rank (e.g., S2S3 or S1S3) is used to indicate any range of uncertainty about the status of the species or ecosystem. Ranges cannot skip more than two ranks (e.g., SU is used rather than S1S4).
S#?	Inexact Numeric Rank—Denotes inexact numeric rank; this should not be used with any of the Variant Subnational Conservation Status Ranks, or SX or SH
SX	Presumed Extirpated: Species or ecosystem is believed to be extirpated from the state. Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered. [Equivalent to “Regionally Extinct” in IUCN Red List terminology].
SH	Possibly Extirpated: Known from only historical re-cords but still some hope of rediscovery. There is evidence that the species or ecosystem may no longer be present in the state, but not enough to state this with certainty. Examples of such evidence include (1) that a species has not been documented in approximately 20-40 years despite some searching and/or some evidence of significant habitat loss or degradation; (2) that a species or ecosystem has been searched for unsuccessfully, but not thoroughly enough to presume that it is no longer present in the state.
SU	Unrankable: Currently unrankable due to lack of information or due to substantially conflicting information about status or trends.
SNR	Unranked: State level conservation status not yet assessed.
SNA	Not Applicable: A Conservation Status Rank is not applicable because the species or ecosystem is not a suit-able target for conservation activities.

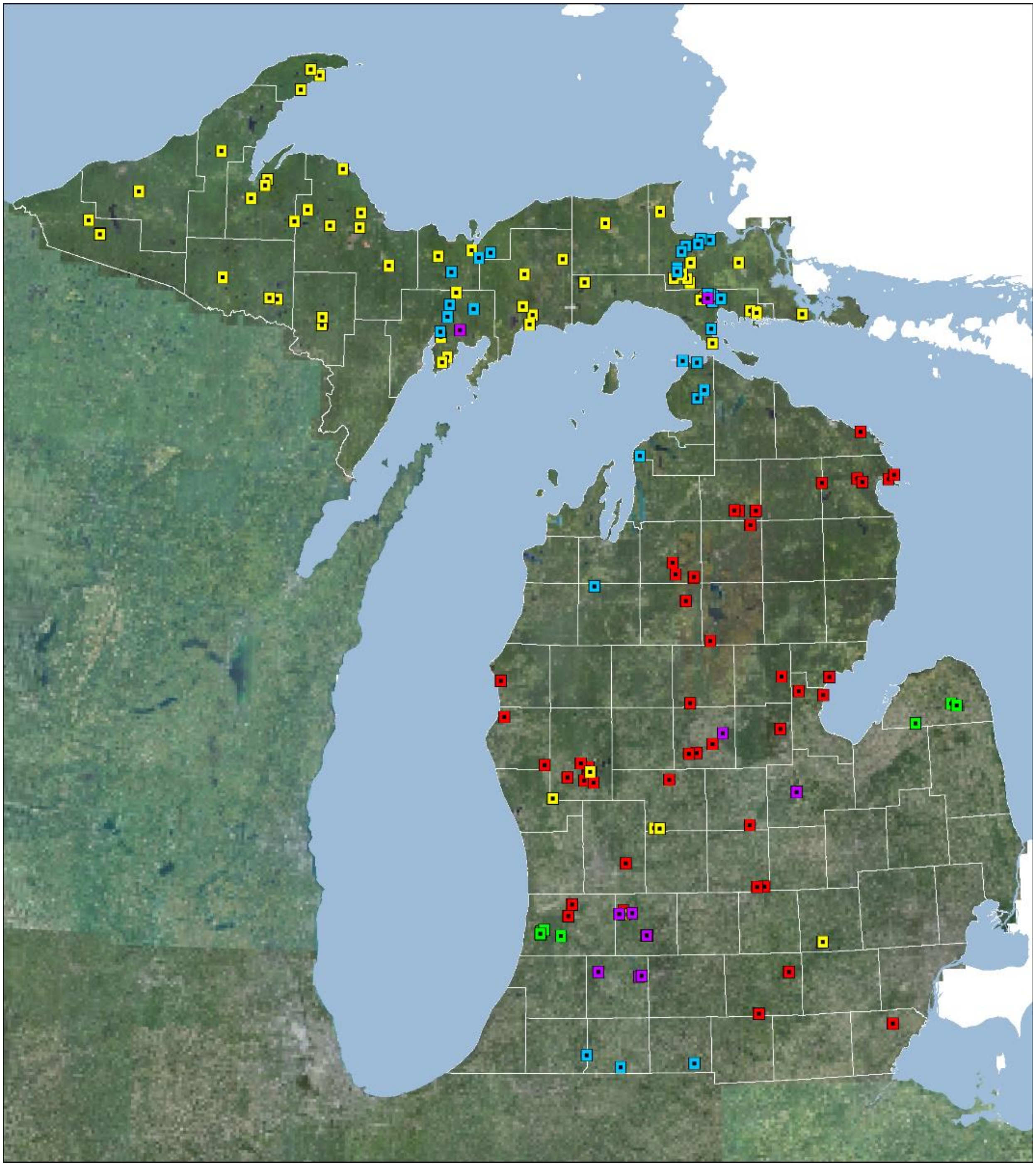

Figure 2. Locations of MNFI bumble bee surveys during 2016 (red), 2017 (yellow), 2018 (blue). Additional sites sampled as part of the cSWG grant: Pollinator Conservation thorough enhancement of Michigan's and Wisconsin's Grassland, Prairie, and Savanna Habitat (green), and incidental surveys (purple) are also shown.

Current and Historic Distribution Maps

All *Bombus* recorded were split into two temporal groups, current (1999-2019) and historic (pre-1999). 8-digit Hydrologic Unit Code (HUC) watershed polygons (USDA 2019) were populated with species presence information in both time periods. The HUC geographic units were selected because they are similar in size (average 1,233 square miles in Michigan), and were deemed to be an appropriate scale given the locational accuracy of the historic presence data. Additionally, unlike geopolitical units that are often used to delineate range boundaries, watersheds have similar abiotic (i.e. climate, topography, solar radiation) conditions and are naturally occurring geographic divisions.

Habitat Suitability Modeling for *B. terricola*

Habitat suitability models were created with the maximum entropy algorithm (Maxent ver. 3.3.3k) (Phillips et al. 2006), a presence-only modeling method. High resolution (GPS) presence locations of *B. terricola* for the years 2000-2019 were selected and spatially thinned, retaining only occurrences that were at least a distance of 1 km apart (n=58) 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. Fourteen environmental predictor variables (30 m cell size) remained after variable reduction (Table 2). 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. In order 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.

Table 2. Environmental variables selected to inform habitat suitability model for *B. terricola*. Variables were selected reducing a set of 150 environmental variables to a set expected to influence bumble bee occupancy within a given habitat.

Variable Type	Variable	Description
Climate[1]	Max Temperature of Warmest Month (BIO5)*	Maximum temperature of warmest month
Climate	Precipitation Seasonality (BIO15)	Normalized dispersion (CV) of precipitation
Hydrography[2]	Distance to inland waters	Distance to any NHD stream/river, river area, or waterbody
Landcover[3]	Forest cover 10-cell mean	Mean upland and wetland forest cover within 10-cell radius
Landcover	Grassland 10-cell mean	Mean grassland cover within 10-cell radius

Landcover	Open upland cover 10-cell mean	Mean grassland and shrub within 10 cell radius
Landcover	Crop cover 10-cell mean	Mean agricultural cropland within 10-cell radius
Landcover	Mean percent impervious cover 10-cell mean	Mean percent impervious surface cover in 10-cell radius
Landcover	Forest cover 100-cell mean	Mean upland and wetland forest cover within 100-cell radius
Landcover	Grassland 100-cell mean	Mean grassland cover within 100-cell radius
Landcover	Grassland and pasture 10-cell mean	Mean grassland and/or pasture cover within a 10 cell radius
Landcover	Grassland and pasture 100-cell mean	Mean grassland and/or pasture cover within a 100 cell radius
Climate	Temperature Seasonality (BIO4)	Standard deviation * 100
Climate	Mean Temperature of Driest Quarter (BIO9)	Mean Temperature of Driest Quarter

[1] Bioclimatic variables (1980-2014) calculated based on means from PRISM (precipitation) and TopoWX (temperature only).
[2] USGS National Hydrography Dataset (NHD) 1:24,000
[3] NOAA's Coastal Change Analysis Program (C-CAP) 2016 Regional Land Cover Data

Results

We surveyed a total of 189 sites throughout Michigan from 2016-2019 as part of this project including 152 sites for targeted bumble bee surveys, 27 sites as part of Hackett et al. 2019, and 10 locations where we recorded incidental observations for at-risk species. Bumble bee species varied considerably in the number of sites occupied during 2016-2019. In general, MNFI collection data aligns with collection data from non-MNFI sources during this time period (Table 3). However, MNFI surveys produced valuable occurrence data for species not fully accounted for in other surveys, including the only occurrence data for *B. pensylvanicus* (American bumble bee) since 1993.

Table 3. Each species of bumble bee historically found in Michigan and the number of occupied sites encountered during MNFI surveys from 2016-2019 and non-MNFI surveys since 1999.

Species	**Common Name**	**No. occupied sites***		
		MNFI collections	non-MNFI collections	**Total**
Bombus affinis	Rusty-patched bumble bee	0	1	**1**
Bombus auricomus	Black-and-gold Bumble Bee	4	17	**21**
Bombus bimaculatus	Two-spotted Bumble Bee	27	181	**208**
Bombus ashtoni	Gypsy Cuckoo Bumble Bee	0	0	**0**
Bombus borealis	Northern Amber Bumble Bee	40	38	**78**
Bombus citrinus	Lemon Cuckoo Bumble Bee	17	10	**27**
Bombus fervidus	Yellow bumble bee	73	11	**84**
Bombus fernaldae	Fernald's Cuckoo Bumble Bee	0	0	**0**
Bombus fraternus	Southern Plains Bumble Bee	0	0	**0**
Bombus frigidus	Frigid Bumble Bee	0	0	**0**

Bombus griseocollis	Brown-belted Bumble Bee	79	186	**265**
Bombus impatiens	Common Eastern Bumble Bee	93	270	**363**
Bombus insularis	Indiscriminate Cuckoo Bumble Bee	0	0	**0**
Bombus pensylvanicus	American bumble bee	2	0	**2**
Bombus perplexus	Confusing Bumble Bee	22	100	**122**
Bombus rufocinctus	Red-belted Bumble Bee	4	0	**4**
Bombus sandersoni	Sanderson's Bumble Bee	13	1	**14**
Bombus ternarius	Tri-colored Bumble Bee	70	73	**143**
Bombus terricola	Yellow banded bumble bee	33	20	**53**
Bombus vagans	Half-black Bumble Bee	93	150	**243**

S-rank Calculations

Conservation Status Ranks for each species of bumble bee historically found in Michigan are shown in Table 3. Five species of bumble bees are ranked as either *Secure* or *Apparently Secure*, and five are ranked as *Vulnerable*. Since the last recorded occurrence of *B. affinis* was in 1999, we assigned this species an SH (*Possibly Extirpated*). We identified one species as S1 (*Critically Imperiled*: *B. pensylvanicus*), one species as S2 (*Imperiled*: *B. auricomus*), and two species as S2S3 (*Imperiled - Vulnerable*: *B. sandersoni* and *B. terricola*). We were unable to locate any current records for five species that historically occupied habitats in Michigan and classified them as SH (*Possibly Extirpated*: *B. ashtoni*, *B. fernaldae*, *B. fraternus*, *B. frigidus*, and *B. insularis*).

Table 4. Each species of bumble bee historically found in Michigan and their associated global rank, state rank for Michigan, Wisconsin, New York, and Indiana, and state status in Michigan.

Species	Common Name	Global Rank	State Rank				State Status - MI
			Michigan	Wisconsin	New York	Indiana	
Bombus affinis	Rusty-patched bumble bee	G2	**SH**	S1	SH	S1	proposed Endangered
Bombus auricomus	Black-and-gold Bumble Bee	G4G5	**S2**	S3	S1	S3	Special Concern (SC)
Bombus bimaculatus	Two-spotted Bumble Bee	G5	**S4**	S4	S5	S5	
Bombus ashtoni	Gypsy Cuckoo Bumble Bee	G3G5	**SH**	S1?	SH	S1	
Bombus borealis	Northern Amber Bumble Bee	G4G5	**S3**	S3	S1	SH	proposed SC
Bombus citrinus	Lemon Cuckoo Bumble Bee	G4	**S3**	S3	S5	S4	
Bombus fervidus	Yellow bumble bee	G3G4	**S3**	S2	S1	S3	
Bombus fernaldae	Fernald's Cuckoo Bumble Bee	G5?	**SH**	SNR	SH	SNR	
Bombus fraternus	Southern Plains Bumble Bee	G2G4	**SH?**	--	--	S3	
Bombus frigidus	Frigid Bumble Bee	G5	**SH?**	S1	--	--	
Bombus griseocollis	Brown-belted Bumble Bee	G5	**S5**	S4	S5	S5	
Bombus impatiens	Common Eastern Bumble Bee	G5	**S5**	S5	S5	S5	
Bombus insularis	Indiscriminate Cuckoo Bumble Bee	G3	**SH**	S1S2	SH	SX	
Bombus pensylvanicus	American bumble bee	G3G4	**S1**	S1	S1	S3	proposed Threatened
Bombus perplexus	Confusing Bumble Bee	G5	**S3S4**	S1	S4	S3	
Bombus rufocinctus	Red-belted Bumble Bee	G4G5	**S3S4**	S4	S3S4	SNR	
Bombus sandersoni	Sanderson's Bumble Bee	G4G5	**S2S3**	S1S3	S3S4	--	proposed SC
Bombus ternarius	Tri-colored Bumble Bee	G5	**S4**	S4	S3S4	SH	
Bombus terricola	Yellow banded bumble bee	G3G4	**S2S3**	S1	S1	SH	SC
Bombus vagans	Half-black Bumble Bee	G4	**S4**	S4	S4	S3	

Current and Historic Distributions of Michigan Bumble Bees

The current and historic distributions of each bumble bee species in Michigan are described on pages 10-15. Distributions for 7 species (*B. ashtoni, B. fernaldae, B. fraternus, B. frigidus, B. insularis, B. sandersoni, B. rufocinctus*) are not shown due to a lack of current or historic data.

Family **Apidae**
Subfamily **Apinae**
Genus ***Bombus*** Latrielle
Subgenus ***Bombias*** Robertson

auricomus (Robertson 1903). (Figure 3). Historically uncommon throughout the southern half of the lower peninsula. Currently uncommon throughout the southern half of the lower peninsula.

Subgenus ***Bombus*** Latrielle s. s.

affinis Cresson 1863. (Figure 4). Historically common in the lower peninsula. Current records from one county in 1999.
terricola Kirby 1837 (Figure 5). Historically common throughout Michigan. Current records are primarily from the upper peninsula and extending into northern lower peninsula.

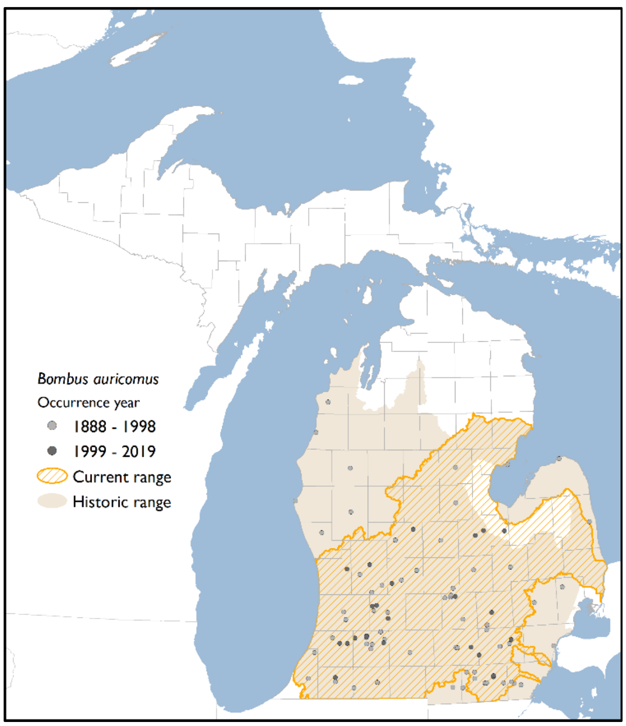

Figure 3. Historic and current distribution of *B. auricomus* in Michigan.

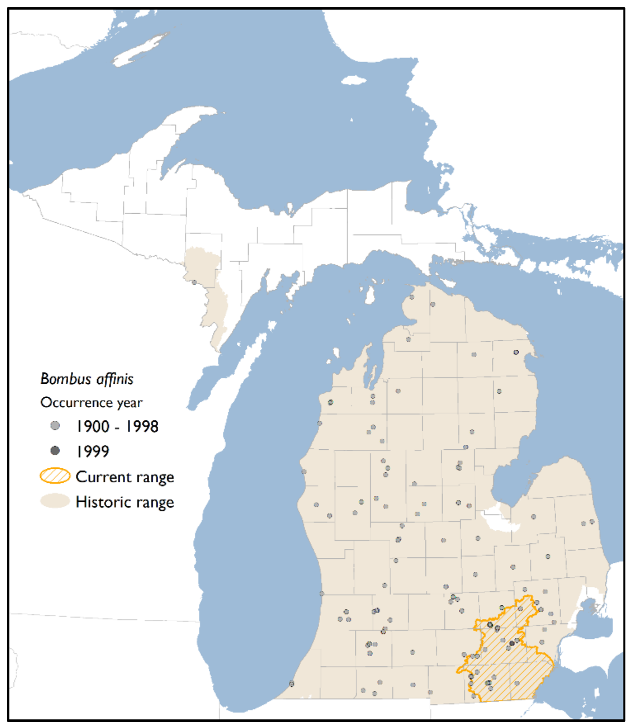

Figure 4. Historic and current distribution of *B. affinis* in Michigan.

Subgenus ***Cullumanobombus*** Vogt

fraternus (Smith 1854). Historically uncommon throughout Michigan. No current records.
griseocollis (DeGeer 1773). (Figure 6). Historically common throughout the lower peninsula and uncommon in the upper peninsula. Current records common throughout the lower and upper peninsulas.
rufocinctus Cresson 1863. Historically uncommon throughout Michigan. Current records uncommon in the lower peninsula.

Subgenus ***Psithyrus*** Lepeletier

ashtoni (Cresson 1864). Historically uncommon throughout the upper peninsula and northern lower peninsula. No current records.
citrinus (Smith 1854). (Figure 7). Historically uncommon throughout the lower peninsula and rare in the upper peninsula. Current records uncommon in the lower peninsula and rare in the upper peninsula.
fernaldae (Franklin 1911). Historically rare in the upper peninsula. No current records.
insularis (F. Smith 1861). Historically rare in the upper peninsula and northern lower peninsula. No current records.

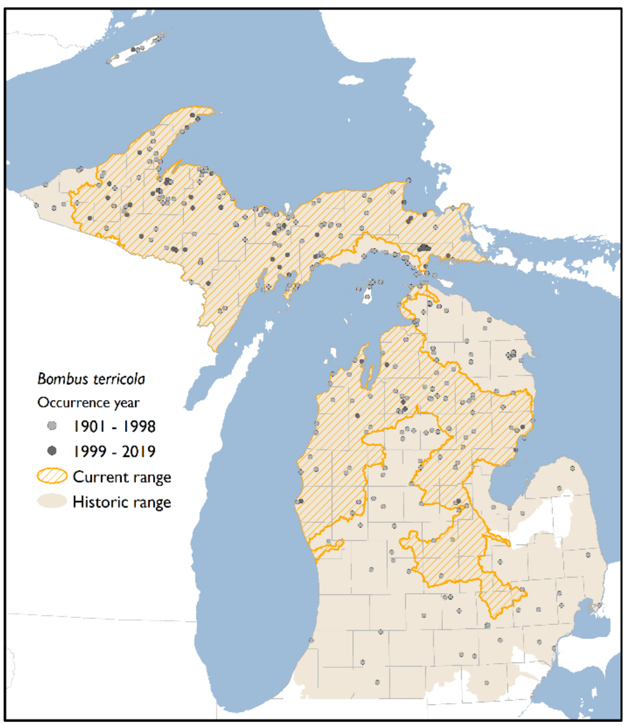

Figure 5. Historic and current distribution of *B. terricola* in Michigan.

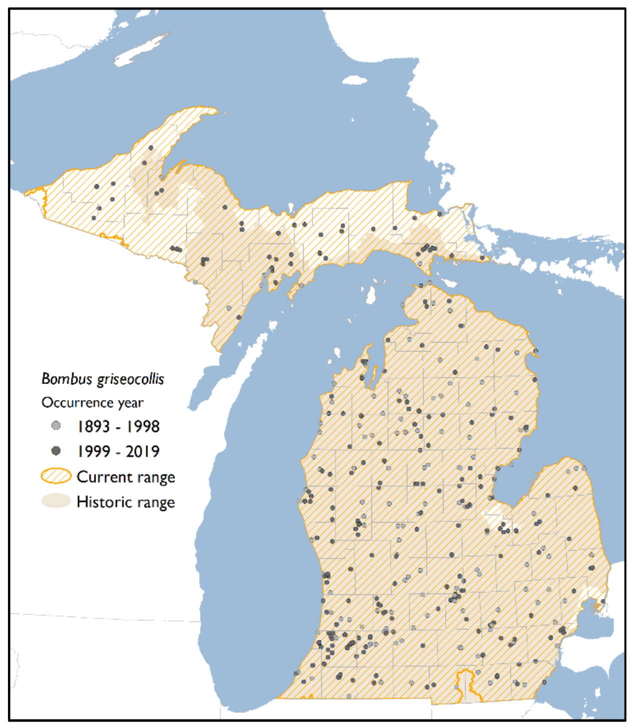

Figure 6. Historic and current distribution of *B. griseocollis* in Michigan.

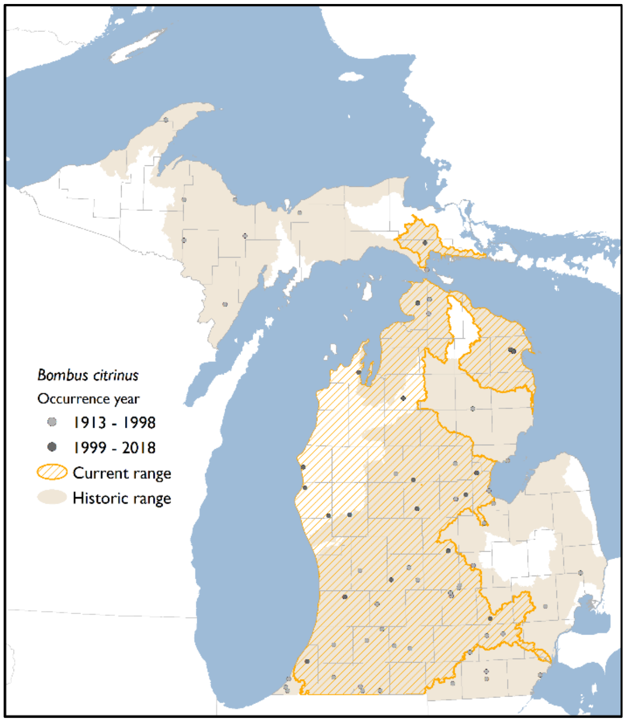

Figure 7. Historic and current distribution of *B. citrinus* in Michigan.

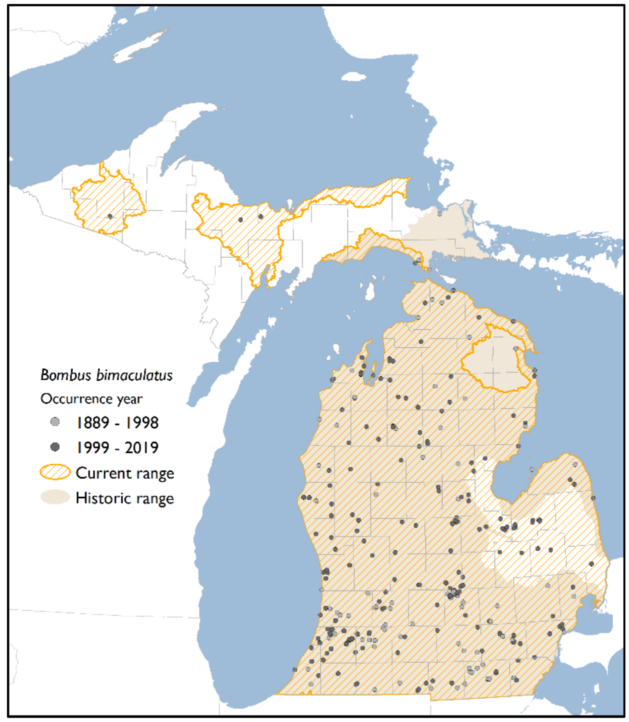

Figure 8. Historic and current distribution of *B. bimaculatus* in Michigan.

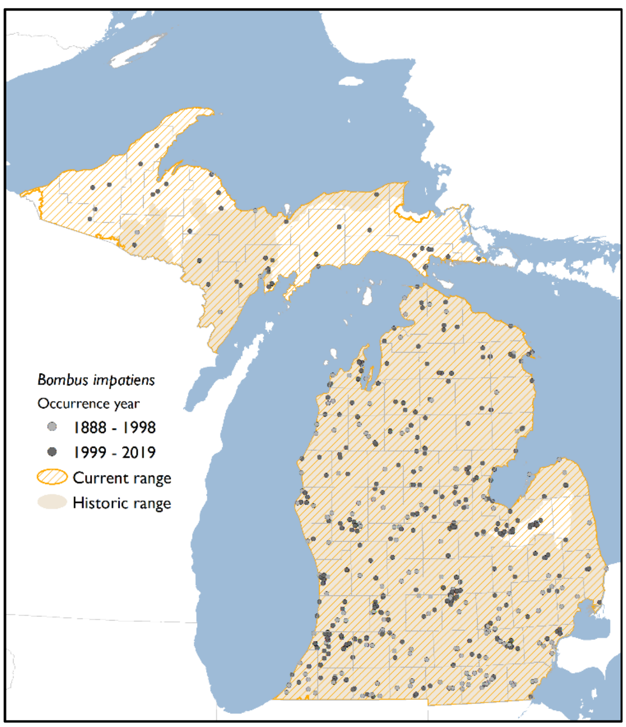

Figure 9. Historic and current distribution of *B. impatiens* in Michigan.

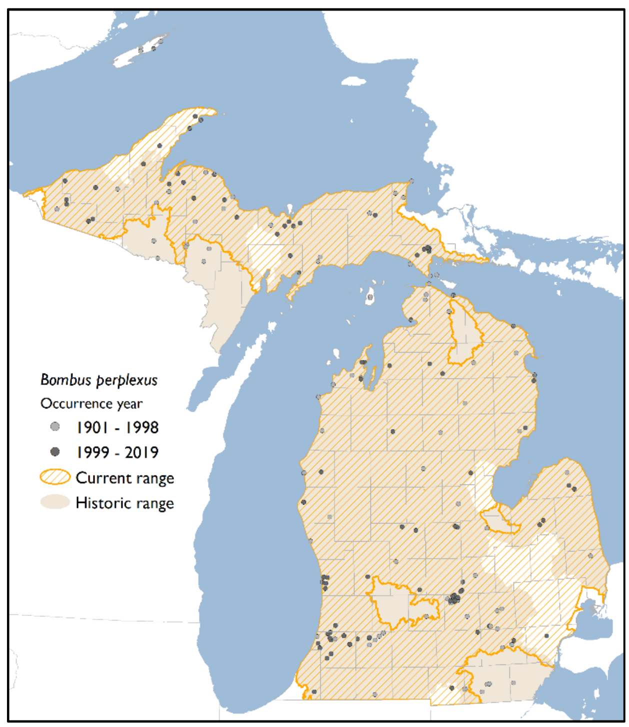

Figure 10. Historic and current distribution of *B. perplexus* in Michigan.

Subgenus ***Pyrobombus*** Dalla Torre

bimaculatus Cresson 1863. (Figure 8). Historically common throughout the lower peninsula. Current records common throughout the lower peninsula and uncommon in the upper peninsula.
frigidus Smith 1984. Historically rare in the western upper peninsula. No current records.
impatiens Cresson 1863. (Figure 9). Historically common throughout the lower peninsula and uncommon in the upper peninsula. Current records common throughout the lower and upper peninsulas.
perplexus Cresson 1863. (Figure 10). Historically uncommon throughout the lower and upper peninsulas. Current records uncommon throughout the lower and upper peninsulas.
sandersoni Franklin 1913. Historically uncommon throughout the upper and lower peninsula. Current records uncommon throughout the lower and upper peninsulas.
ternarius Say 1837. (Figure 11). Historically common throughout the upper peninsula and northern lower peninsula. Current records common throughout the upper peninsula and northern lower peninsula.
vagans F. Smith 1854. (Figure 12). Historically common throughout the lower and upper peninsulas. Current records common throughout the lower and upper peninsulas.

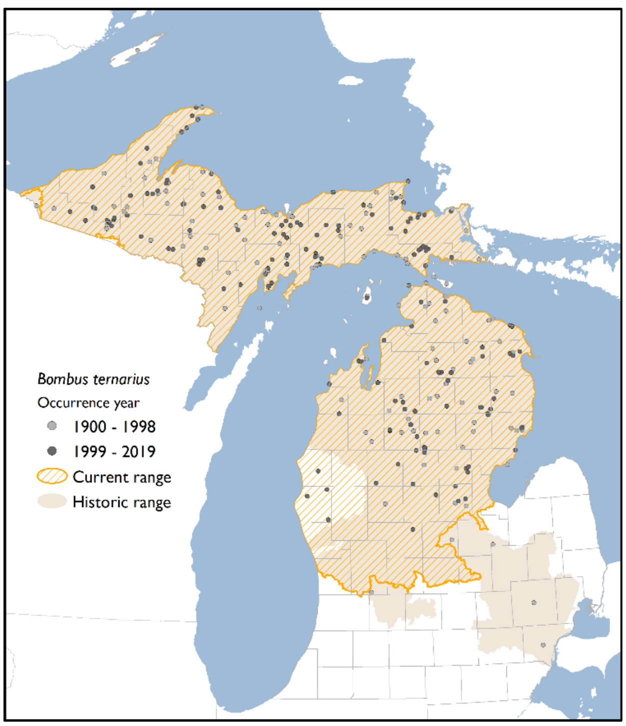

Figure 11. Historic and current distribution of B. ternarius in Michigan.

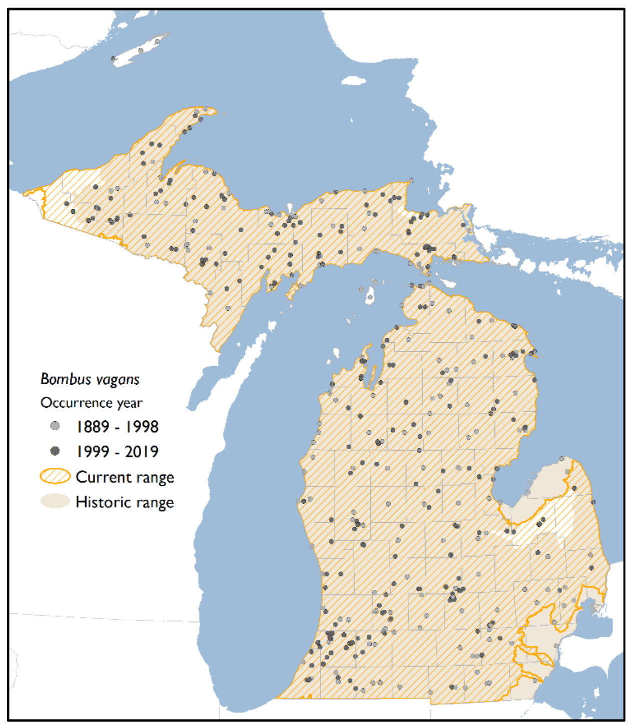

Figure 12. Historic and current distribution of *B. vagans* in Michigan.

Subgenus ***Subterraneobombus*** Vogt

borealis Kirby 1837. (Figure 13). Historically uncommon throughout the lower and upper peninsulas. Current records uncommon throughout the lower and upper peninsula. Most lower peninsula records concentrated in the northern lower peninsula.

Subgenus ***Thoracobombus*** Dalla Torre

fervidus (Fabricius 1798). (Figure 14). Historically common throughout the lower peninsula uncommon in the upper peninsula. Current records throughout the lower peninsula with a higher concentration in southern lower peninsula.

pensylvanicus (DeGeer 1773). (Figure 15).Historically common throughout the southern half of the lower peninsula. Current record from a single high-quality dry sand prairie in mid-Michigan.

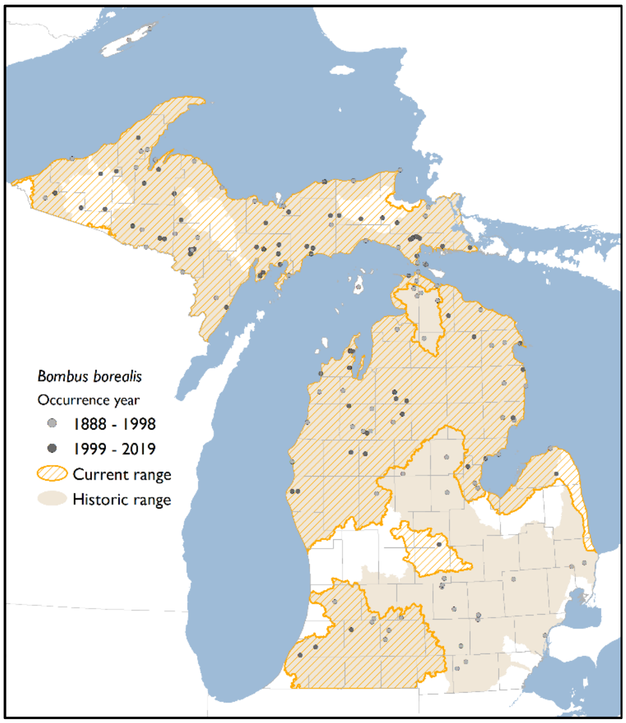

Figure 13. Historic and current distribution of *B. borealis* in Michigan.

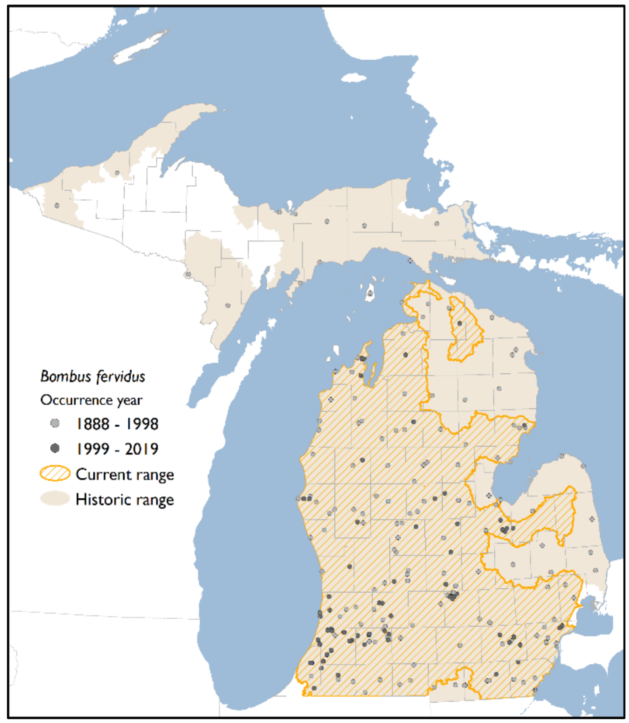

Figure 14. Historic and current distribution of *B. fervidus* in Michigan.

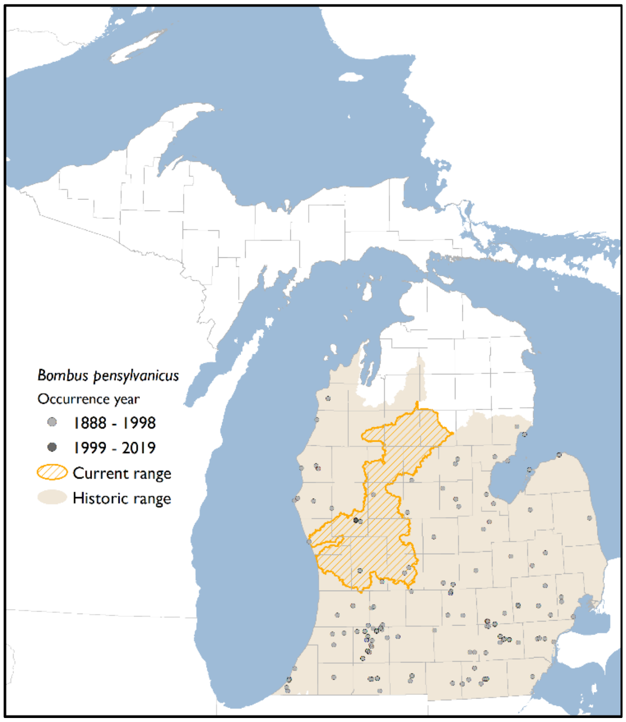

Figure 15. Historic and current distribution of *B. pensylvanicus* in Michigan.

Habitat Suitability Modeling for *B. terricola*

The best model had a test AUC of 0.873, significantly better than a random model. After setting a binary threshold that equally weighed sensitivity (correctly predicted presence) and specificity (correctly predicted absence), the model correctly classified 80% of *B. terricola* occurrences in Michigan and predicted 23% of Michigan to be suitable habitat (8,869, 585 acres), primarily dispersed throughout the upper peninsula of the state (Figure 16). The variables determined to be most important for habitat suitability included maximum temperature of the warmest month (77.3% contribution, negative relationship), mean forest cover within a 100-cell radius (13.8% contribution, positive relationship), and mean impervious surface within a 10-cell radius (8.9% contribution, negative relationship) (Figure 17).

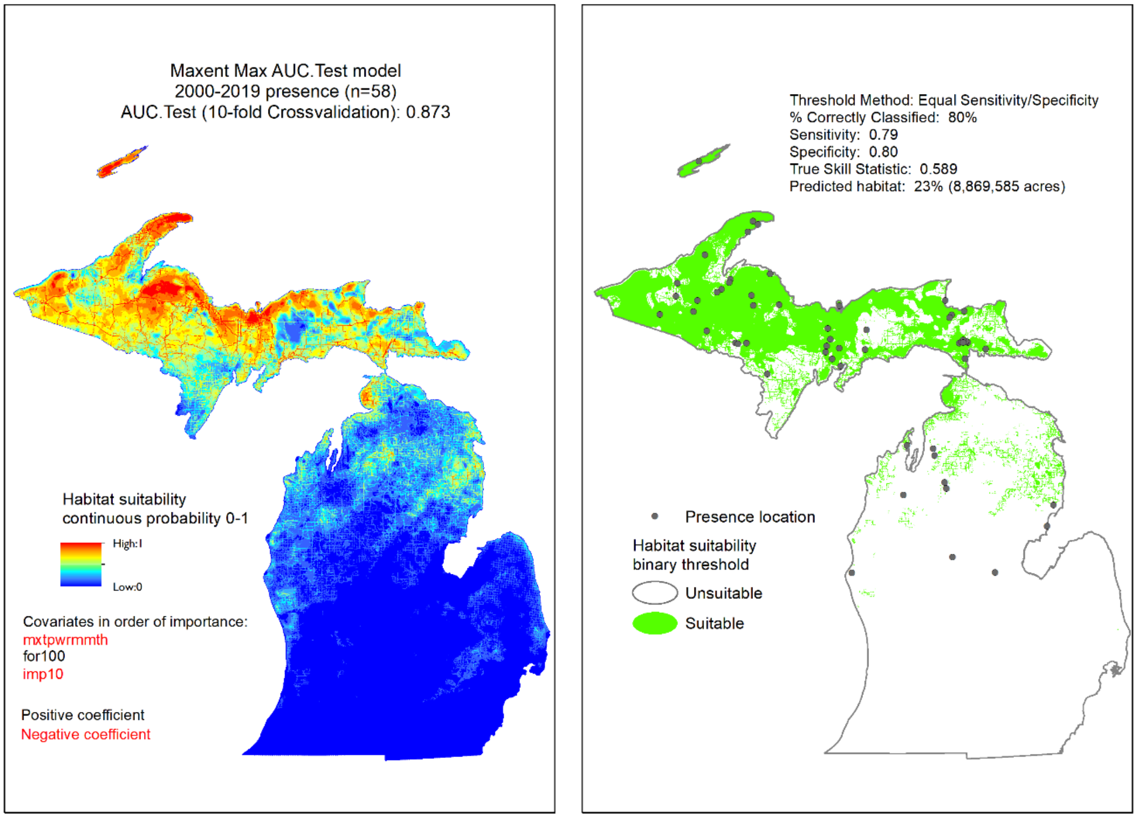

Figure 16. Continuous predicted distribution of *B. terricola* in Michigan based on the highest AUC Maxent model (right), and a binary thresholded layer defining suitable/unsuitable habitat (left). Environmental variables associated with *B. terricola* occurrence are shown for the model. Red covariates represent a negative relationship while black covariates represent a positive relationship.

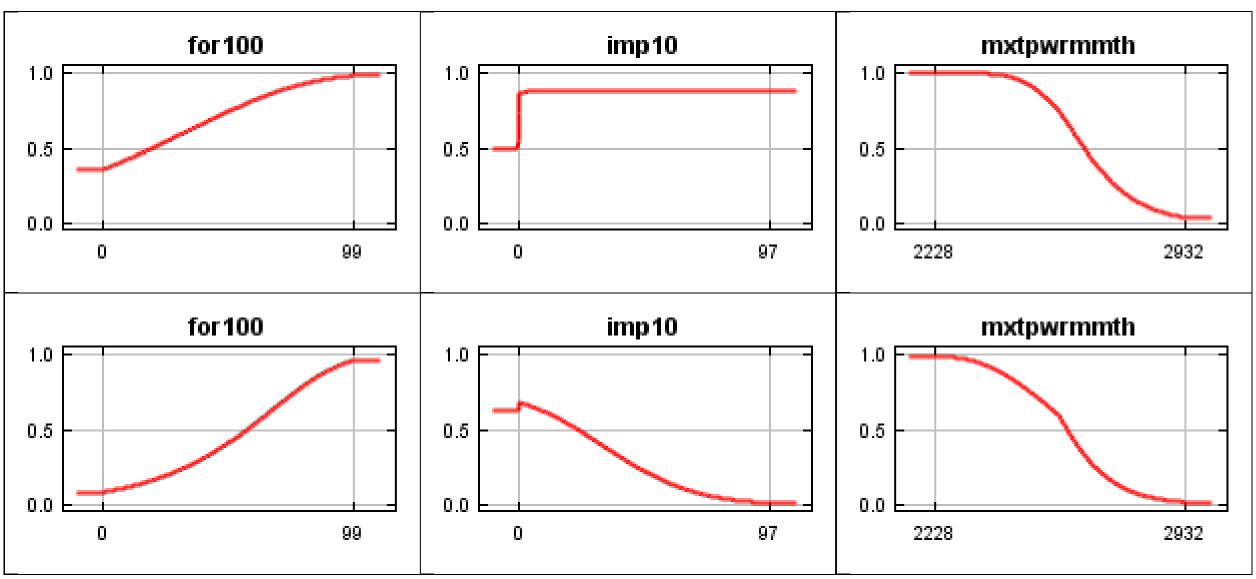

Figure 17. Variable response curves for environmental variables found to associated with suitablr habitat for *B. terricola* in Michigan when a) variable is assessed while all other variables held at means, and b) variable is assessed independent of additional variables.

Discussion

Declines in bumble bee species populations across Michigan have raised concerns among scientists and prompted conservation actions aimed at supporting at-risk species. In this report, we were unable to collect any current occurrence data for five bumble bee species (*B. ashtoni, B. fernaldae, B. fraternus, B. frigidus, B. insularis*). Each of these species is likely extirpated from the state. For species we were able to collect data on, we show that at least eight species have experienced decline in occupied ranges when compared to historic statewide distributions (*B. affinis*, *B. auricomus*, *B. borealis*, *B. citrinus*, *B. fervidus*, *B. pensylvanicus*, *B. sandersoni*, and *B. terricola*). In contrast, a few species have experienced range expansions, most notably *B. impatiens*, *B. bimaculatus*, and *B. griseocolis*. Species experiencing declines are under a multitude of environmental pressures, including habitat loss, pesticides, pathogens, and climate change (NRC 2007). Furthermore, bumble bee species in Michigan may vary in their sensitivity to environmental pressures due to unique life histories and the pressures associated with occupied ranges.

Based on our S-rank calculations, we identified six bumble bee species to receive updated state conservation status: *Bombus affinis* (SH, Endangered), *B. auricomus* (S2, Special Concern), *B. borealis* (S3, Special Concern), *B. penslyvanicus* (S1, Threatened), *B. sandersoni* (S2S3, Special Concern), and *B. terricola* (S2S3, Special Concern). Of species that currently occupy habitat in Michigan, *B. pensylvanicus* has the most restricted range, which includes a total of two locations in Newaygo county (EOID#22477). Although *B. affinis* was not discovered during MNFI surveys, potential habitat remains throughout the southern lower peninsula. This region should be surveyed to determine if *B. affinis* is still present in Michigan. Continued efforts to monitor populations of at-risk species are needed to document trends in species' distributions and to develop management plans that protect species from the environmental stressors contributing to range loss. The results of S-rank calculations can help inform any subsequent Wildlife Action Plan revision, especially in determining which species should be included on the updated list of Species of Greatest Conservation Need (SGCN) and providing documented rationale for those decisions. Additionally, the information gathered on rarity, trends, and threats, can be used by the Insect Technical Advisory Committee in Michigan Department of Natural Resources' review of Michigan's Threatened and Endangered species list. This will be a valuable source of information in determining if these species should be recommended for state endangered, state threatened, or be considered species of special concern. The newly assigned S-ranks will be available to conservation partners and the public through the rare species explorer on MNFI's website.

Our Maxent model used to determine the distribution of suitable habitat for *B. terricola* provide two main advantages over occupancy-only distribution mapping methods. First, by mapping suitable habitat across Michigan based on predictive environmental variables, we are able to use the information to identify un-surveyed habitats that have a higher probability of *B. terricola* occurrence. This is particularly important when locating and conducting on-the-ground surveys for a species when time and funding is limited. Second, we were able to determine the environmental and landscape variables that are associated with *B. terricola* occurrence. Here, we found that *B. terricola* presence is negatively related to the maximum temperature of the warmest month and the mean impervious surface within a 10-cell radius. Furthermore, we found a positive relationship between occurrence and the mean forest cover within a 100-cell radius. In general, habitat suitably increased in areas that have higher proportion of forested cover, lower proportion of impervious surfaces, and cooler summers. For *B. terricola*, a primarily northern species, we suggest that future conservation efforts take into consideration these variables and prioritize areas that maximize habitat suitability. We stress the need for similar habitat suitability modeling efforts to be performed on other at-risk species. These efforts may help to identify the environmental and landscape variables associated with species specific declines in occupied ranges, since different species likely face distinct environmental pressures. A habitat suitability modeling approach would provide insight to these pressures, which could prove to be useful in developing regional and species-specific conservation actions.

The results of this project provide an important step in identifying bumble bee species at risk of extinction in Michigan, and build on conservation efforts to support imperiled bumble bee species. However, we emphasize the continued need to monitor populations in decline and the active development of on-the-ground habitat enhancement projects aimed at supporting at-risk species. Future work should focus on the habitat use of at-risk species, including species specific foraging preferences, nest site selection, and queen overwintering ecology. The development of a long-term monitoring plan for declining species in Michigan would provide additional occurrence information that would be highly informative for habitat suitability models for at-risk species and to identify the environmental variables associated with species occurrences. Importantly, this project will enhance the implementation of Michigan's Wildlife Action Plan, as well as inform the next revision of the plan.

Literature Cited

Badra, P.J., D. L. Cuthrell, M.J. Monfils, J.J. Paskus, Y. Lee and B.J. Klatt. (2014). Conservation Status Assessments of Michigan's Species of Greatest Conservation Need. Report for MI Dept. of Natural Resources, Wildlife Div. Michigan Natural Features Inventory report number 2014-12. 31pp.

Faber-Langendoen D, Master L, Nichols J, Snow K, Tomaino A, Bittman R, Hammerson G, Heidel B, Ramsay L, Young B (2009) NatureServe conservation status assessments: methodology for assigning ranks. NatureServe, Arlington, Virginia.

Fielding, A.H., and Bell, J.E. (1997). A review of methods for the assessment of prediction errors in conservation presence–absence models. Environ. Conserv. 24:38-49.

Gardiner, MM, J. Tuell, R. Isaacs, J. Gibbs, J. Ascher, and D.A. Landis. (2010). Implications of three model biofuel crops for beneficial arthropods in agricultural landscapes. *BioEnergy Res*. 3:6–19

Hackett, R. A., L. M. Rowe, M. J. Monfils, and D. L. Cuthrell. (2019). Pollinator conservation through enhancement of Michigan's and Wisconsin's grassland, prairie, and savanna habitat. Michigan Natural Features Inventory, Report Number 2019-32, Lansing, USA.

Hallmann, C. A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., ... & Goulson, D. (2017). More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PloS one*, *12*(10), e0185809.

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.

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.

Kerr, J. T., Pindar, A., Galpern, P., Packer, L., Potts, S. G., Roberts, S. M., ... & Wagner, D. L. (2015). Climate change impacts on bumblebees converge across continents. *Science*, *349*(6244), 177-180.

Murray, T.E., M. Kuhlmann, S.G. Potts. Conservation ecology of bees: populations, species and communities. (2009). *Apidologie*, 40 (3)

National Resource Council. (2007). Status of Pollinators in North America. Washington, D.C.: The National Academies Press.

Phillips, S. J., Anderson, R. P., & Schapire, R. E. (2006). Maximum entropy modeling of species geographic distributions. *Ecological modelling*, *190*(3-4), 231-259.

Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: trends, impacts and drivers. *Trends in ecology & evolution*, *25*(6), 345-353.

Richardson, L. L., McFarland, K. P., Zahendra, S., & Hardy, S. (2019). Bumble bee (Bombus) distribution and diversity in Vermont, USA: a century of change. *Journal of Insect Conservation*, *23*(1), 45-62.

Rowe, L., Gibson, D., Landis, D., Gibbs, J., & Isaacs, R. (2018). A Comparison of Drought-Tolerant Prairie Plants to Support Managed and Wild Bees in Conservation Programs. *Environmental entomology*, *47*(5), 1128-1142.

Sladen, F. W. L. (1912). The humble-bee. MacMillan and Co., London, UK.

Thomas, C. D., Jones, T. H., & Hartley, S. E. (2019). "Insectageddon": a call for more robust data and rigorous analyses. *Global change biology*.

Tuell J.K., A.K. Fiedler, D. Landis, and R. Isaacs. (2008). Visitation by Wild and Managed Bees (Hymenoptera: Apoidea) to Eastern U.S. Native Plants for Use in Conservation Programs. *Environ. Entomol.* 37(3): 707-718.

Tuell, J.K and R. Isaacs. (2009). Elevated pan traps to monitor bees in flowering crop canopies. *Entomologia Experimentalis et Applicata.* 131: 93–98.

Williams, P. H. (1982). The distribution and decline of British bumble bees (*Bombus* Latr.). *Journal of apicultural Research*, *21*(4), 236-245.

Williams, P. H. (1998). An annotated checklist of bumble bees with an analysis of patterns of description (Hymenoptera: Apidae, Bombini). *Bulletin-Natural History Museum Entomology Series*, *67*, 79-152.

Williams, N. M., Mola, J. M., Stuligross, C., Harrison, T., Page, M. L., Brennan, R. M., ... & Rundlöf, M. (2019). Fantastic bees and where to find them: locating the cryptic overwintering queens of a western bumble bee. *Ecosphere*, *10*(11).

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.

Acknowledgements

Funding for this project was provided through the Cooperative State Wildlife Grants program grant number F15AP00999 in cooperation with the U.S. Fish and Wildlife Service, Wildlife and Sport Fish Restoration Program. Several individuals from DNR Wildlife Division assisted with the project: Amy Derosier, Daniel Kennedy and Christine Hanaburgh. The following MNFI field technicians/AmeriCorps members conducted surveys: Dave Cuthrell, Logan Rowe, Rachell Hackett, Clint Pogue, Blake Cahill, Lillian Hendrick, John Paskus, Bradford Slaughter, Mike Sanders, Courtney Ross, Frank Schroyer, and Zack Pitman. Administrative support was provided by Brian Klatt, Nancy Toben, and Ashley Adkins (MNFI). Access to Michigan State University insect collections was granted by Anthony Cognato and Gary Parsons. Additional bumble bee occurrence data to support this project was provided by Dr. Thomas Wood from the Department of Entomology at Michigan State University.