# Pollinator Conservation Through Enhancement of Michigan's and Wisconsin's Grassland, Prairie, and Savanna Habitat


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Cover: Grassland study site taken by L. M. Rowe.

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# Abstract

Declines in pollinator populations have resulted in agencies and organizations placing more emphasis on their conservation. The Michigan Natural Features Inventory (MNFI) worked with the Michigan Department of Natural Resources (MDNR) to assess pollinator and vegetation response to conservation actions implemented to benefit pollinators under a Competitive State Wildlife Grant. Our objective was to monitor focal pollinator and vegetation response to two techniques being used by MDNR to promote habitat for insect pollinators, prescribed fire and disking with forb inter-seeding. Study areas were selected by MDNR on State and nearby private lands in either the southeast or southwest Lower Peninsula of Michigan. Sites were former agricultural land converted to warm-season grassland with forbs interspersed. In 2018 and 2019, focal pollinator and vegetative surveys were conducted at each site during three periods: spring (mid-May – late June), early summer (late June – late July), and late summer (late July – mid September). We observed 1057 bumble bees across all sites. The most common species encountered included common eastern bumble bee (*Bombus impatiens*) and two-spotted bumble bee (*B. bimaculatus*). Nearly 70% of all bumble bees were recorded visiting a total of 5 plant species: Canada goldenrod (*Solidago canadensis*), wild-bergamot (*Monarda fistulosa*), hairy vetch (*Vicia villosa*), grass-leafed goldenrod (*Euthamia graminifolia*), and horse-nettle (*Solanum carolinense*). Both mean abundance and richness of bumble bees was greater in the second-year post treatment, regardless of treatment type (mean abundance: $X^2 = 12.12$, $p < 0.005$; species richness: $X^2 = 4.30$, $p = 0.04$). Given the low number of samples of second year post-treatment sites, gathering data for a greater number of growing seasons would contribute to understanding whether the trends we found in this study were ongoing or noise attributed to site, weather, or other factors. We examined bumble bee and vascular plant communities with non-metric multidimensional scaling, but we found no grouping of sites based on treatment and year post-treatment. The variability among the site communities highlights the need for pre- and post-treatment monitoring. Gathering pre- and post-treatment data at all sites would allow managers to determine if their pre- and post-treatment objectives were achieved and make adjustments to management actions as needed.

# Introduction

Declines in pollinator populations have resulted in agencies and organizations placing more emphasis on their conservation. A variety of Farm Bill Programs and targeted funding have been identified by the United States Department of Agriculture (USDA) to benefit pollinators in the Upper Midwest (USDA 2015a). For the monarch (*Danaus plexippus*) alone, the Monarch Conservation Science Partnership recommended the addition of at least 1 to 1.5 billion milkweed (*Asclepias* spp.) stems and abundant nectar resources to support monarch reproduction and migration (Monarch Joint Venture 2016). However, conservation efforts are hindered by the lack of information about the status of insect pollinators, uncertainty about which conservation practices are most appropriate, and limited resources to assess the success of management. The Pollinator Research Action Plan highlighted the need to gather baseline data on native pollinator status, understand habitat requirements, and identify viable approaches to protect, restore, manage, and enhance pollinator habitat (Pollinator Health Task Force 2015). The North American Monarch Conservation Plan also indicated the need to "evaluate and assess the effects of conservation actions on monarch distribution and abundance" (Commission for Environmental Cooperation 2008). Similarly, the USDA, Forest Service noted the need to evaluate the effects of prescribed burning on monarch habitat availability and suitability (USDA 2015b).

Baseline information about insect pollinator diversity and relative abundance is generally lacking. In Michigan's Wildlife Action Plan (WAP; Derosier et al. 2015), several pollinators were identified as focal species for conservation within prairies and savannas, including rusty-patched bumblebee (*Bombus affinus*), monarch, frosted elfin (*Incisalia irus*), and Karner blue butterfly (*Lycaeides melissa samuelis*). Surveys being conducted for this project to assess pollinator response to management will also provide baseline information about these and other pollinators within prairies, savannas, and managed grasslands in southern Michigan. We are gathering valuable information about the distribution and relative abundance of focal species, as well as more common species (e.g., *Bombus* spp.). Information collected on the status of these insect pollinators is needed to assist agencies in making decisions regarding listing of species as threatened or endangered at the state or federal level.

The Michigan Natural Features Inventory (MNFI) worked with the Michigan Department of Natural Resources (MDNR) to assess pollinator and vegetation response to conservation actions implemented to benefit pollinators under a Competitive State Wildlife Grant. Our objective was to monitor focal pollinator and vegetation response to two techniques being used by MDNR to promote habitat for insect pollinators, prescribed fire and disking with forb inter-seeding. By monitoring the plant and pollinator response to grassland management, we will assist the MDNR in evaluating the effectiveness of their pollinator conservation actions, thus allowing them to adjust management strategies as needed within an adaptive framework.

# Study area

Study areas were selected by MDNR on State and nearby private lands in either the southeast Lower Peninsula or southwest Lower Peninsula of Michigan. Sites were former agricultural land converted to warm-season grassland with forbs interspersed, except for one site in Allegan State Game Area ($42^{nd}$ Street – 18010), which was oak-pine savanna. To minimize the influence of grassland size and shape on our results, we selected sites that were at least 2 ha (5 ac) and no more than 32 ha (80 ac) in area, and no less than 100 m in width. The seed mixes used by MDNR for the disking and inter-seeding technique were not consistent among all sites. Each of the 15 study sites fit at least two circular pollinator plots of approximately one hectare in area. The pollinator plot served as the experimental unit in our analyses.

Table 1. List of study areas. Sites are organized by region in Michigan's Lower Peninsula, ownership, and site name. The numbers correspond to the labels on Figure 1.

| | Region | Ownership | Study Site | Area (ha) | No. of Plots | Treatment |
|---|---|---|---|---|---|---|
| 1 | Southeast | Gagetown State Game Area (SGA) | Williamson Road | 16.3 | 3 | Unmanaged |
| 2 | Southeast | Shiawassee River SGA | Prior Road | 24.5 | 3 | Burn |
| 3 | Southeast | Verona SGA | Pangborn Road | 8.7 | 2 | Unmanaged |
| 4 | Southeast | Verona SGA | Philip Road | 28.4 | 3 | Burn |
| 5 | Southwest | Allegan SGA | 42nd Street (18010) | 9.8 | 2 | Burn |
| 6 | Southwest | Allegan SGA | 119th Avenue (24133) | 4.6 | 2 | Disc / seed |
| 7 | Southwest | Allegan SGA | 117th Avenue (24403) | 6.3 | 2 | Burn |
| 8 | Southwest | Allegan SGA | 58th Street (24408) | 4.2 | 2 | Disc / Seed |
| 9 | Southwest | Allegan SGA | 54th Street (24931) | 14.2 | 2 | Burn |
| 10 | Southwest | Barry SGA | Bowen Mill Road | 4.2 | 2 | Disc / Seed |
| 11 | Southwest | Barry SGA | Storybrook Road | 2.9 | 2 | Disc / Seed |
| 12 | Southwest | Kalamazoo Nature Center | Harris Prairie (2A) | 4.9 | 2 | Burn |
| 13 | Southwest | Pierce Cedar Creek Institute | Center-West | 2.5 | 2 | Unmanaged |
| 14 | Southwest | Pierce Cedar Creek Institute | Southeast | 10.0 | 2 | Burn |
| 15 | Southwest | Pierce Cedar Creek Institute | Southwest | 8.2 | 2 | Disc / Seed |

# Methods

### Sample Design

The focus of this project was to manage native plant species and ecosystems for the benefit of at-risk pollinators, thus we monitored only grasslands dominated by native warm-season grasses. Our goal was to compare pollinator use and vegetation characteristics among three management categories: burned only (henceforth: burn), disked with forb interseeding (henceforth: disc and seed), and unmanaged. We attempted to balance the number of sites and plots between southwestern and southeastern Michigan (Figure 1); however, site availability limited our sampling to 4 sites and 11 plots in the southeast and 11 sites and 22 plots in the southwest Lower Peninsula (Table 1).

Initially we defined "unmanaged" sites as grasslands lacking any management (i.e., burning, mowing, or disking) within the last 10 years; however, we were unable to find grasslands fitting this definition, even when the length of time since last management was reduced. Our minimimum number of seasons without management for unmanaged sites was two complete growing seasons. The warm-season grasslands we investigated were managed on a nearly annual basis, often with multiple techniques (e.g., burning, mowing, herbicide) used in concert or rotating annually. We were only able to find three suitable unmanaged sites, so we focused our monitoring and analyses on comparing sites managed by burning and disking with interseeding. Treatments among the sites did not occur during the same calendar year, so we described each site as year or growing season post-treatment.

cSWG Pollinator Project Sites

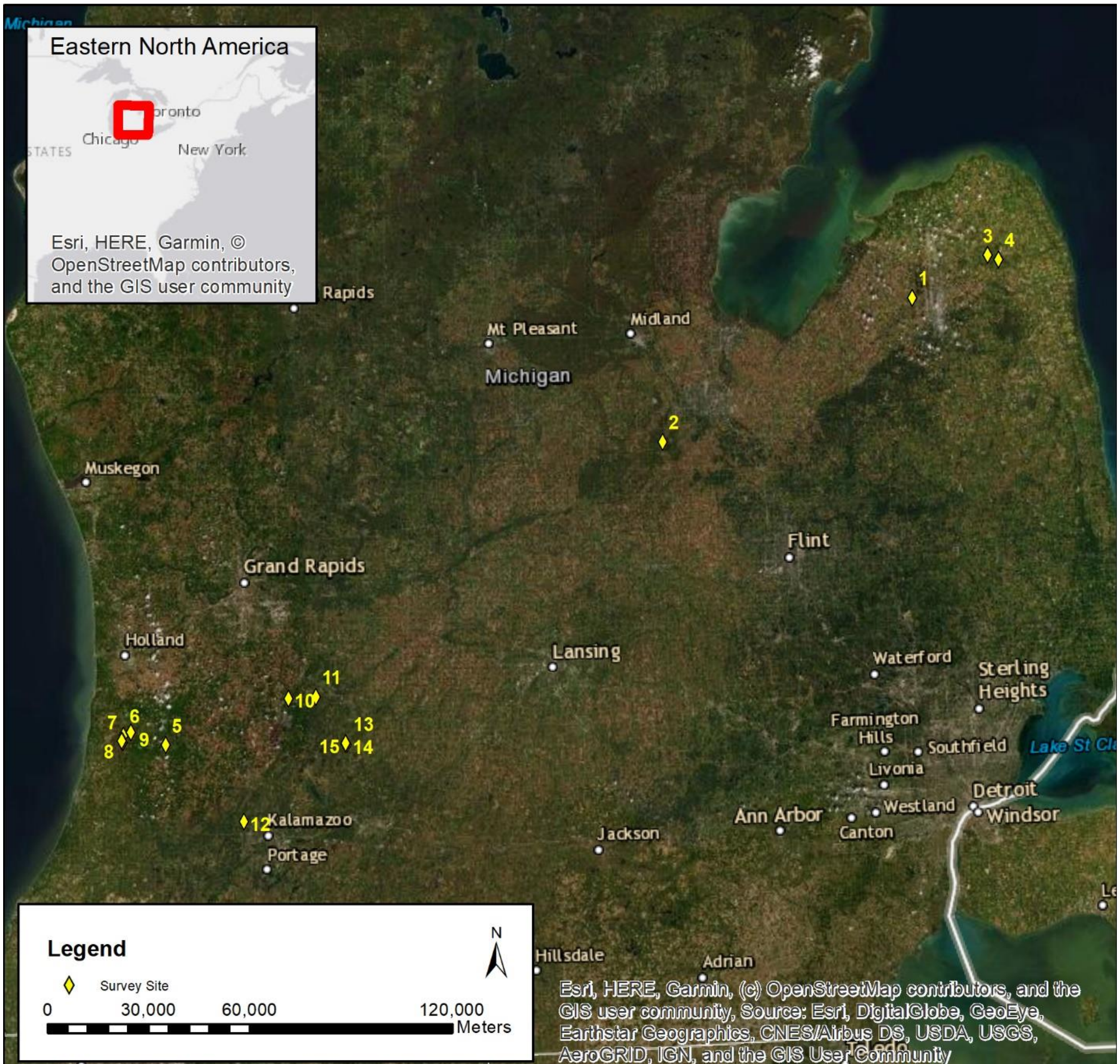



Figure 1. Locations of study sites managed for pollinators where vegetation and pollinator surveys occurred in 2018 and 2019. Numbers refer to sites listed in Table 1.

**Pollinator Surveys**

In 2018 and 2019, focal pollinator surveys were conducted at each site during three periods: spring (mid-May – late June), early summer (late June – late July), and late summer (late July – mid September). During the first visit to each site, we recorded the plot centers used for bumble bee surveys using GPS and placed a physical marker in the field, so the same plots could be visited during subsequent surveys. At least two 112.8-m diameter (1 hectare) plots were placed at each site. Plots were placed randomly within the grassland at least 50 m from the site boundary and a minimum of 100 m from adjacent plots. Narrow dimensions of a few sites caused us to skew the shape of the plot to meet the minimum area requirement.

We conducted pollinator surveys on days that had no rain, temperatures above 15° C (60° F), and when winds were ≤ 25 kph (15 mph). At the start and end of each survey, we recorded the air temperature (°F), relative humidity (%), wind speed (kph), and cloud cover (%) associated with the plot. At Verona State Game Area – Phillip Road site on June 14, 2019, we had one instance where we conducted a pollinator survey with a starting temperature of 13.9° C (57.0° F) and cloud cover of 0%, when there was adequate observed bumble bee activity. The ending temperature after 1 hour of survey was 16.1° C (61.0° F). At Pierce Cedar Creek Institute on September 28, we had wind speed exceptions at three pollinator plots. Given the weather predictions for the week and the observed bumble bee activity at the time, we conducted the pollinator surveys at wind speeds of 27, 32, and 32 kph (17, 20 mph).

Plots were surveyed using a modified version of the sampling protocol described by Strange et al. (undated) for bumble bees, which is a standardized method used for both national- and local-level surveys. Bumble bee surveys were conducted for a total of one collector hour per plot by walking equally spaced transects at a consist pace throughout the entire plot (Figure 2). To ensure all areas of the plot were surveyed equally, we divided each plot into 4 subplots and surveyed each subplot for a total of 15 person-minutes. Observed bumble bees were collected using a handheld aerial insect net and placed in 20 mL vials for processing (Figure 3). If possible, bumble bees were sexed and identified to species in the field directly following each survey. For species we were unable to identify in the field, preserved specimen vouchers were brought back to the lab and identified using published keys (Williams et al. 2014). Each preserved specimen was labeled with the date, site name, survey period, plot number, and the plant species from which the bumble bee was collected.

All focal and non-focal butterfly species detected during surveys were documented, and monarch butterflies seen within plot boundaries were counted and recorded. All field data was collected and stored using Survey 123 for ArcGIS.

Figure 2. David Cuthrell using the modified Strange et al. (undated) bumble bee sampling protocol at Allegan State Game Area, 117th Avenue (24133).

Figure 3. Black and gold bumble bee (*Bombus auricomus*) in a sample vial observed at Barry State Game Area – Bowens Mill Road.

**Vegetation Surveys**

Vegetation sampling was completed during each of the same three periods used for pollinator surveys using the same marked plots as centers. We documented plant species blooming in the pollinator plot and their relative abundance using the DAFOR scale (i.e., dominant, abundant, frequent, occasional, rare). We also noted presence of other nectar sources immediately adjacent to the grassland being sampled (e.g., flowering shrubs or spring ephemerals in adjacent forest), which could influence focal pollinator use of the study site.

We sampled at least 10 randomly placed 1-$m^2$ quadrats at each site (i.e., 5 quadrats per plot) during each of the three survey periods (Figure 4). One quadrat was placed randomly between the plot center and the outer plot boundary in each of the four cardinal directions (i.e., north, south, east, west), and a fifth quadrat was placed using a randomly selected bearing and distance. We measured the following metrics in each quadrat: maximum vegetation height, average vegetation height, categorical litter depth, percent cover of plant structural categories (e.g., grasses, forbs, and shrubs), percent cover of all vascular plant species by taxa, and stem density of milkweeds (Figure 5). Because of the typically low density of milkweeds, we also counted the number of stems within one quadrant of the 1-hectare pollinator plot.

Figure 4. Photograph of a 1 $m^2$ quadrat at a field site.

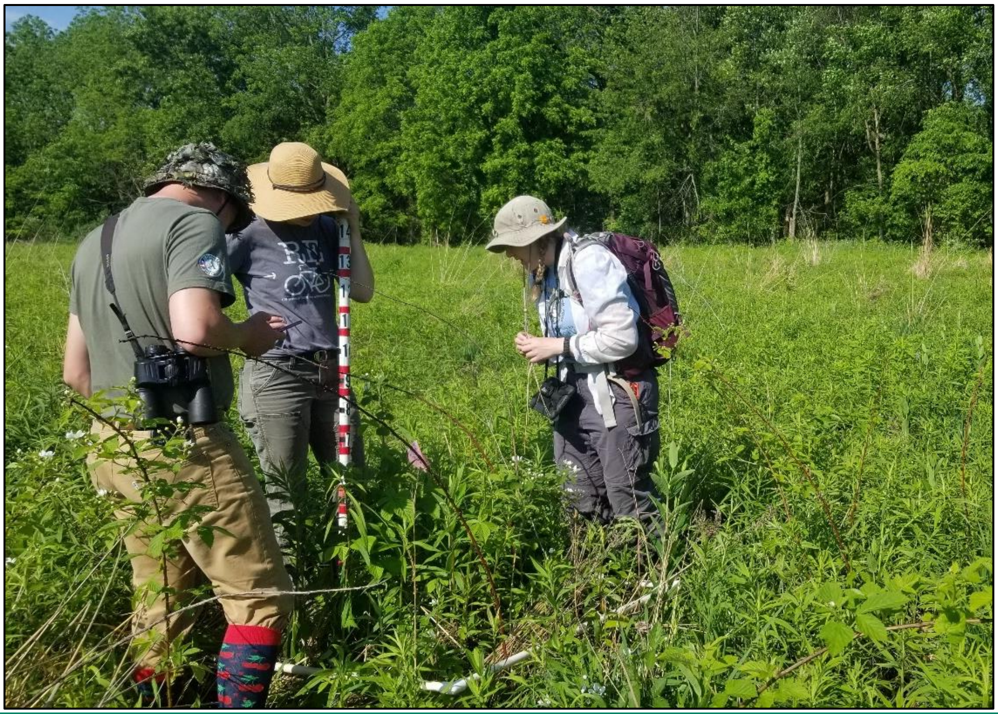


Figure 5. Rachel Hackett training Huron Pines AmeriCorps members Frank Schroyer and Courtney Ross in vegetation sampling.

**Analysis**

Given our objective of treatment comparisons, we grouped our data by site, survey period, and year post-treatment. For each group, we calculated the following and used side-by-side box plots to visualize: 1) mean abundance of bumble bees per pollinator plot; 2) bumble bee species richness per pollinator plot; 3) mean blooming vascular plant species richness per plot; 4) vascular plant species richness per site; and 5) native vascular plant species richness per site. We also calculated mean abundance of monarch butterflies per pollinator plot and mean number of milkweed stems per pollinator plot. We ran chi-squared analyses to determine differences among these factors by the three treatment types and year post-treatment.

We used mixed effects models to determine the effect of treatment type, year post treatment, and the interaction between treatment type and year post treatment on the response variables of mean abundances of bumble bees, monarch butterflies, and bumble bee species richness (Pinheiro et al. 2019). Five candidate models were built with combinations of treatment, year post-treatment, and/or and interaction variable of treatment and year post-treatment as fixed effects and survey period, plot number, and/or site as random effects. We compared candidate sets of models using AICc rank comparisons for each response variable. The model with the lowest AICc value for each response variable was used in final analyses. We used site identity and survey period as random effects to account for the variability among sites and survey periods.

We assessed the relationship between bumble bee abundance and the species richness of currently blooming plants using general linear regression. This relationship has consistently been shown to influence bee abundance (Ebeling et al. 2008). We also explored a general linear relationship between mean number of monarchs per site and mean number of monarch stems.

We used non-metric multidimensional scaling (NMDS) to examine bumble bee and vascular plant communities in relation to treatments and year post-treatment (Oksanen et al. 2019). For bee community NMDS, species incidence was used with a Bray-Curtis dissimilarity matrix. Due to low numbers of bees recorded at each site during independent survey periods, we grouped data across survey periods within a year at each site for the bee species analysis. For plant community NMDS, percent sample cover was used with a Bray-Curtis dissimilarity matrix. All analyses were conducted were conducted in R 3.4.0 or R 3.6.1 (R Studio Team 2016; R Core Team 2019).

# Results

**Abundance and species richness**

We observed 1057 bumble bees across all sites: 541 and 516 in 2018 and 2019, respectively. The most frequently encountered bumble bee species were common eastern bumble bee (*B. impatiens*; n = 690 individuals), two-spotted bumble bee (*B. bimaculatus*; n = 166), and brown-belted bumble bee (*B. griseocollis*; n = 140).

We observed 2 uncommon bumble bee species at much lower frequencies: Black-and-gold bumble bee (*B. auricomus*,) at n = 4, state special concern, recorded on hairy vetch (*Vicia villosa*); Golden northern bumble bee (*B. fervidus*) at n = 8, recorded on wild-bergamot (*Monarda fistulosa*), horse-mint (*M. punctata*), red clover (*Trifolium pratense*), and hairy vetch. Two *B. auricomus* were observed at Barry State Game area; Storybrook Road site in 2018, unmanaged; and Bowens Mill Road site in 2019 post-disc and seed treatment. The third *B. auricomus* was recorded at Pierce Cedar Creek Institute – Center-west unmanaged site in 2019. Of the seven *B. fervidus* recorded during this study, three were recorded at burn sites, two were recorded at disc and seed sites, and three were recorded at unmanaged sites. In 2018, B. fervidus was observed in both southwest and southeast regions, but in 2019 it was found only in the southwest region. In both years it was observed at Kalamazoo Nature Center – Harris Prairie (2A) and Allegan State Game Area – 117$^{th}$ Avenue (24133).

In our mixed model analyses, all three response variables had the same top model with fixed effects of treatment and an interaction of treatment and year post-treatment and random effects of survey period and site. We did not find any relationship between treatment or the interaction between treatment and year post treatment on bumble bee abundance or species richness. However, the number of bumble bee observations approximately doubled from the first to second year post-treatment in three of the five sites having second year post-treatment data (Table 2). This change was seen more dramatically at the disc and seed sites (Figure 6). Both mean abundance and richness of bumble bees was greater in the second-year post treatment, regardless of treatment type (mean abundance: $X^2 = 12.12$, $p < 0.005$; species richness: $X^2 = 4.30$, $p = 0.04$; Figure 6). Similar differences were seen between first and second year-post treatment for overall plant species richness and native species richness (Figure 7).

Nearly 70% of all bumble bees were recorded visiting a total of five plant species (Table 3), while the remaining plant species were visited at much lower frequencies. We found a significant, positive relationship but high variability, between mean bumble bee abundance and species richness of blooming, non-graminoid plants ($r^2 = 0.11$, $p = 0.002$; Figure 8). The mean abundance of monarch butterflies did not vary by treatments or year post-treatment. However, the mean abundance of monarchs recorded at a site was positive and linearly related to the total number of milkweed stems counted regardless of treatment type ($r^2 = 0.41$, $p < 0.005$).

There were no trends in vegetative height when averaged across site, treatment, and year post-treatment for the late July to mid-September survey period (Table 4). Percent cover of graminoids was greatest in the unmanaged sites and least in the two year post-disc treatment sites. Percent forb cover differed less than 15% among treatments and years. Percent shrub/tree cover was greater in the two year post-treatment sites than in year one.

Table 2. Summary of descriptive statistics of bumble bees (*Bombus* spp.), monarch (*Danaus plexippus*), milkweed (*Asclepias* spp.), and vascular plant survey results. Sites were grouped by treatment and year or year since treatment. We did not parse for survey period to simplify the table. Flowering plant species are vascular, non-graminoid plants that were blooming at the time of survey.

| | Sites | Treatment | Year post-treatment | No. of surveys / plots | Mean no. of *Bombus*[1] | *Bombus* species richness[1] | Mean no. of monarchs[1] | Mean no. milkweed stems[1] | Flowering plant species richness[1] | Plant species richness[2] | Native plant species richness[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Gagetown SGA - Williamson Road | Unmanaged | 0 (2018) | 9 | 14 | 2 | 0 | 46 | 9 | 34 | 19 |
| | | Unmanaged | 0 (2019) | 9 | 5 | 1 | 1 | 11 | 6 | 38 | 18 |
| 2 | Shiawassee River SGA - Prior Road | Unmanaged | 0 | 9 | 0 | 0 | 2 | 2 | 7 | 35 | 23 |
| | | Burn | 1 | 3 | 0 | 0 | 0 | 2 | 6 | 20 | 10 |
| | | Burn and Disc | 1 | 3 | 1 | 1 | 1 | 1 | 7 | 29 | 18 |
| | | Disc and seed | 1 | 3 | 0 | 0 | 1 | 5 | 6 | 18 | 9 |
| 3 | Verona SGA - Pangborn Road | Unmanaged | 0 (2018) | 6 | 2 | 1 | 5 | 500[3] | 12 | 39 | 20 |
| | | Unmanaged | 0 (2019) | 6 | 2 | 1 | 3 | 500[3] | 10 | 47 | 25 |
| 4 | Verona SGA - Philip Road | Unmanaged | 0 | 9 | 8 | 2 | 1 | 17 | 10 | 55 | 34 |
| | | Burn | 1 | 9 | 3 | 2 | 2 | 46 | 8 | 52 | 34 |
| 5 | Allegan SGA - 42nd Street (18010) | Unmanaged | 0 (2018) | 6 | 4 | 1 | 0 | 4 | 3 | 19 | 19 |
| | | Unmanaged | 0 (2019) | 4 | 1 | 1 | 1 | 19 | 4 | 16 | 16 |
| 6 | Allegan SGA - 119th Ave (24403) | Burn | 1 | 6 | 2 | 1 | 3 | 97 | 9 | 35 | 20 |
| | | Burn | 2 | 6 | 2 | 1 | 1 | 40 | 9 | 35 | 19 |
| 7 | Allegan SGA - 117th Ave (24133) | Unmanaged | 0 | 6 | 5 | 2 | 9 | 500[3] | 9 | 28 | 11 |
| | | Disc and seed | 1 | 6 | 4 | 2 | 3 | 500[3] | 11 | 33 | 11 |
| 8 | Allegan SGA - 58th Street (24408) | Unmanaged | 0 | 6 | 4 | 1 | 2 | 62 | 8 | 25 | 13 |
| | | Disc and seed | 1 | 6 | 2 | 1 | 0 | 6 | 8 | 29 | 16 |
| 9 | Allegan SGA - 54th Street (24931) | Unmanaged | 0 | 6 | 6 | 2 | 10 | 500[3] | 12 | 46 | 22 |
| | | Burn | 1 | 6 | 4 | 1 | 5 | 500[3] | 10 | 43 | 20 |
| 10 | Barry SGA - Bowen Mill Road | Unmanaged | 0 | 2 | 9 | 3 | 1 | 130 | 8 | 17 | 6 |
| | | Disc and seed | 1 | 4 | 3 | 1 | 1 | 58 | 10 | 19 | 12 |
| | | Disc and seed | 2 | 6 | 13 | 2 | 1 | 112 | 14 | 50 | 25 |
| 11 | Barry SGA - Storybrook Road | Unmanaged | 0 | 2 | 3 | 2 | 1 | 214 | 10 | 18 | 4 |
| | | Disc and seed | 1 | 4 | 10 | 2 | 0 | 5 | 11 | 20 | 11 |
| | | Disc and seed | 2 | 6 | 9 | 2 | 1 | 12 | 12 | 49 | 25 |

[1] Per pollinator plot
[2] Per site
[3] Quarter of pollinator plot had greater than 500 stems and were not precisely counted

| | Sites | Treatment | Year post-treatment | No. of surveys / plots | Mean no. of *Bombus*[1] | *Bombus* species richness[1] | Mean no. of monarchs[1] | Mean no. milkweed stems[1] | Flowering plant species richness[1] | Plant species richness[2] | Native plant species richness[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | Kalamazoo Nature Center - Harris Prairie (2A) | Burn | 1 | 6 | 4 | 1 | 1 | 25 | 10 | 39 | 32 |
| | | Burn | 2 | 6 | 13 | 2 | 0 | 30 | 9 | 49 | 37 |
| 13 | Pierce Cedar Creek Institute - Center West | Unmanaged | 0 | 6 | 5 | 1 | 1 | 7 | 18 | 42 | 26 |
| | | Unmanaged | 1 | 6 | 8 | 2 | 2 | 21 | 11 | 56 | 35 |
| 14 | Pierce Cedar Creek Institute - Southeast | Burn | 1 | 6 | 7 | 1 | 2 | 19 | 20 | 55 | 34 |
| | | Burn | 2 | 6 | 14 | 2 | 2 | 5 | 13 | 72 | 55 |
| 15 | Pierce Cedar Creek Institute - Southwest | Unmanaged | 0 | 6 | 5 | 1 | 2 | 3 | 14 | 41 | 26 |
| | | Disc and seed | 1 | 6 | 3 | 1 | 1 | 22 | 12 | 57 | 35 |

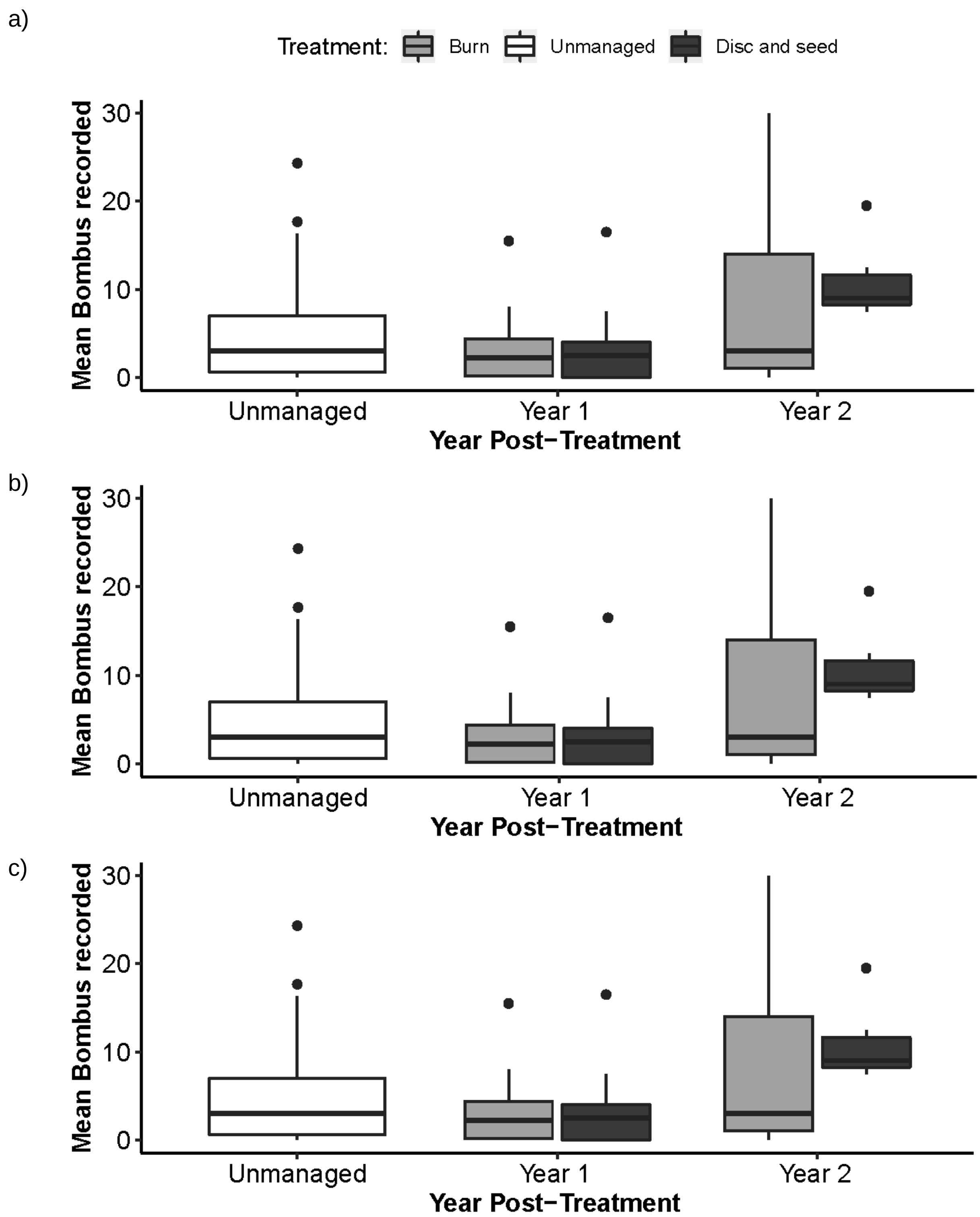
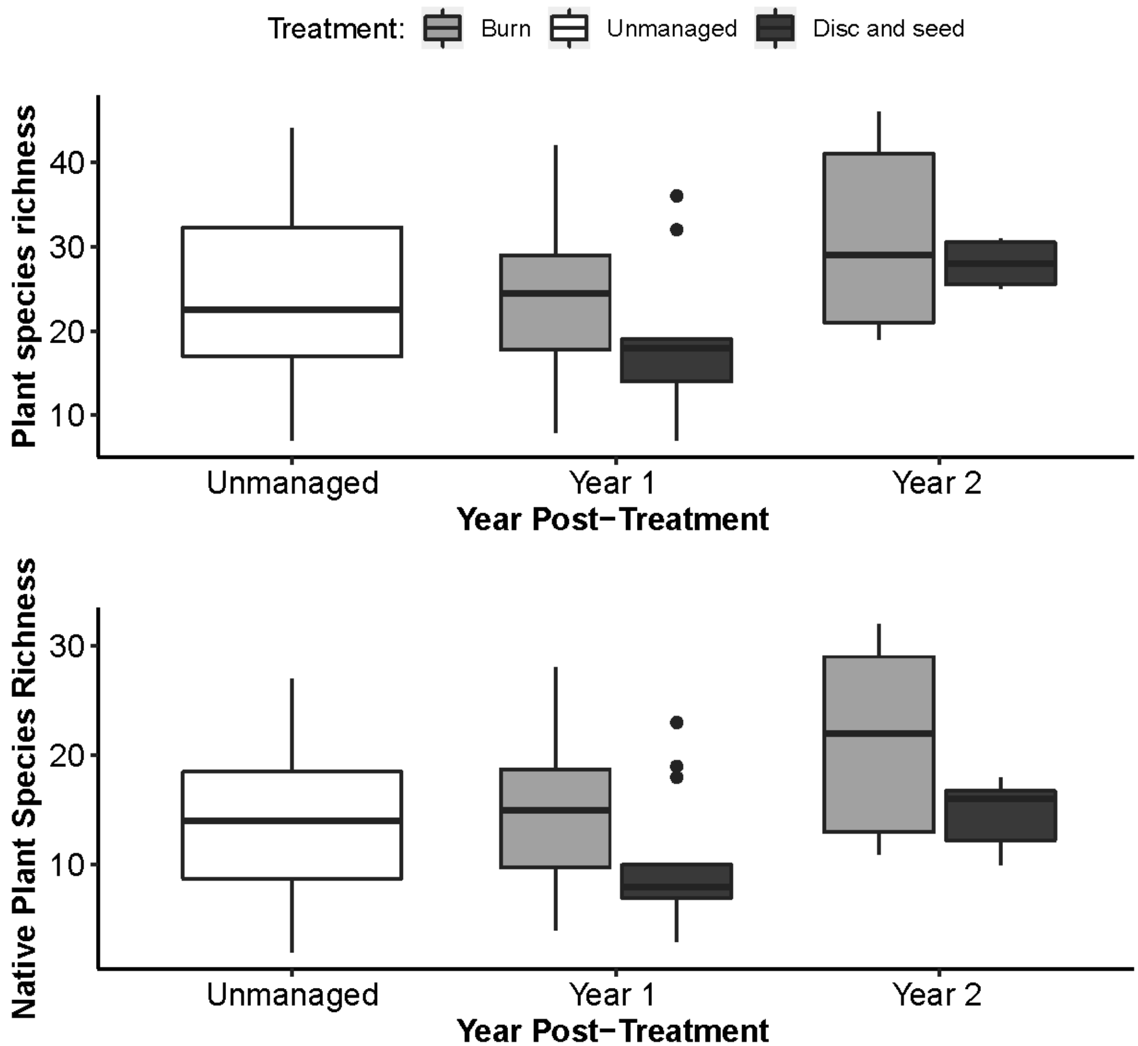



Figure 6. Boxplots comparing median, quantiles, and outliers among treatments and year post-treatment for a) mean number of bumble bees (*Bombus* spp.) observed per plot per site, b) mean *Bombus* spp. species richness per plot per site, and c) mean species richness of flowering non-graminoid plants per plot per site.

a)




b)

Figure 7. Boxplot comparing median, quantiles, and outliers among treatments and year post-treatment for a) plant species richness across each site and b) native plant species richness across each site.

Table 3. The total number of each bumble bee species (*Bombus* spp.) recorded using the top 5 plant species visited by the overall bumble bee community in 2018 and 2019.

| Bumble bee species | Total Recorded | | Number of bumble bees visiting top 5 most frequently visited plant species | | | | |
|---|---|---|---|---|---|---|---|
| | 2018 | 2019 | *Solidago canadensis* | *Monarda fistulosa* | *Vicia villosa* | *Euthamia graminifolia* | *Solanum carolinense* |
| *B. auricomus* | 1 | 2 | 0 | 0 | 2 | 0 | 0 |
| *B. bimaculatus* | 43 | 123 | 6 | 95 | 36 | 0 | 3 |
| *B. citrinus* | 3 | 2 | 1 | 0 | 0 | 0 | 0 |
| *B. fervidus* | 4 | 4 | 0 | 2 | 1 | 0 | 0 |
| *B. griseocollis* | 90 | 50 | 5 | 28 | 42 | 0 | 0 |
| *B. impatiens* | 377 | 313 | 241 | 114 | 22 | 54 | 49 |
| *B. perplexus* | 1 | 4 | 0 | 1 | 1 | 0 | 0 |
| *B. rufocinctus* | 4 | 0 | 0 | 1 | 0 | 0 | 0 |
| *B. sandersoni* | 1 | 4 | 0 | 0 | 0 | 0 | 0 |
| *B. vagans* | 17 | 14 | 3 | 9 | 3 | 0 | 0 |
| **Totals** | **541** | **516** | **256** | **250** | **107** | **54** | **52** |

Table 4. Summary of vegetative characteristics grouped by treatment and year post treatment. Only values from the late July to mid-September survey period were used to derive these calculations.

| | 1 Year post-burn | 2 Year post-burn | 1 Year post-disc/seed | 2 Year post-disc/seed | Unmanaged |
|---|---|---|---|---|---|
| **Mean maximum vegetation height (cm)** | 178 | 153 | 111 | 153 | 152 |
| **Mean average vegetation height (cm)** | 92 | 89 | 57 | 69 | 87 |
| **Percent Cover Bare ground (%)** | 12 | 3 | 5 | 10 | 1 |
| **Percent Cover Litter (%)** | 26 | 34 | 57 | 46 | 39 |
| **Percent Cover Graminoid (%)** | 50 | 44 | 34 | 22 | 60 |
| **Percent Cover Forb (%)** | 44 | 43 | 31 | 34 | 38 |
| **Percent Cover Shrub/Tree (%)** | 8 | 11 | 6 | 14 | 8 |
| **Percent Cover Moss (%)** | 2 | 0 | 0 | 0 | 0 |

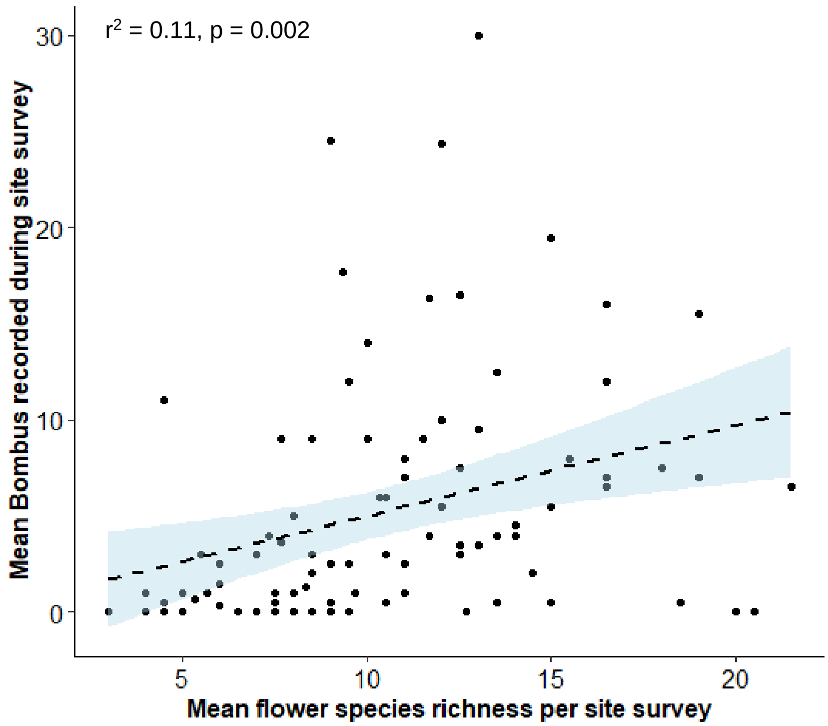



Figure 8. General linear regression between the mean number of bumble bees per site per survey period and the mean species richness of flowering non-graminoid plants per pollinator plot per site per survey period. Each black dot represents a survey period at a site. The light blue area represents the 95% confidence interval.

**Community structure**
We conducted an NMDS analysis of the bumble bee community with 2 dimensions resulting in a stress value of 0.088. The bumble bee community showed no clustering based on treatment type or year post-treatment (Figure 9). NMDS 1 was weighted in the positive direction by the brown-belted bumble bee (*B. griseocollis*) and in the negative direction by common eastern bumble bee (*B. impatiens*), half-black bumble bee (*B. vagans*), and golden northern bumble bee (*B. fervidus*). NMDS 2 was weighted in the positive direction by the brown-belted bumble bee and in the negative direction by black-and-gold bumble bee (*B. auricomus*).

We examined vascular plant communities with NMDS at 2 dimensions with a stress value of 0.180 (Figure 10). When examining vascular plant percent cover, the Allegan State Game Area site on 42nd Street (18010) was segregated from the other sites and treatments along the first dimension. The vascular plant NMDS was reanalyzed without the plant communities from the Allegan 42nd Street site (stress = 0.195 at 2 dimensions; Figure 10). Native vascular plant communities were also examined, but the ordination showed little difference with that including both native and non-native species.

The vascular plant communities showed no clustering based on treatment type or year post-treatment (Figure 11). Of the 244 plant species in the analysis, 54 had significance in the NMDS ($p < 0.05$). NMDS 1 was weighted in the positive direction by Canada goldenrod (*Solidago canadensis*), grass-leaved goldenrod (*Euthamia graminifolia*) and in the negative direction by the non-native horse-nettle (*Solanum carolinense*). NMDS 2 was weighted in the positive direction by hairy vetch, purple prairie-clover (*Dalea purpurea*), and switchgrass (*Panicum virgatum*) and in the negative direction by big bluestem (*Andropogon gerardii*). Unmanaged sites tended to have lower percent cover of some species, such as purple prairie-clover, butterfly-weed (*Asclepias tuberosa*), spotted knapweed (*Centaurea stoebe*), and hairy vetch, but overall, treated sites could not be separated from unmanaged sites.

We examined blooming, non-graminoid plant communities with NMDS at 2 dimensions with a stress value of 0.146 (Figure 12). The blooming plant communities showed no clustering based on treatment type or year post-treatment. Of the 181 plant species in the analysis, 53 had significance in the NMDS ($p < 0.05$). NMDS 1 was weighted in the positive direction by wild-bergamot and grass-leafed goldenrod and in the negative direction by autumn olive (*Elaeagnus umbellata*) and common blackberry (*Rubus allegheniensis*). NMDS 2 was weighted in the positive direction by hairy vetch and horse-nettle and in the negative direction by red clover. Native blooming plant communities were also examined, but the ordination showed little difference with that including both native and non-native species.

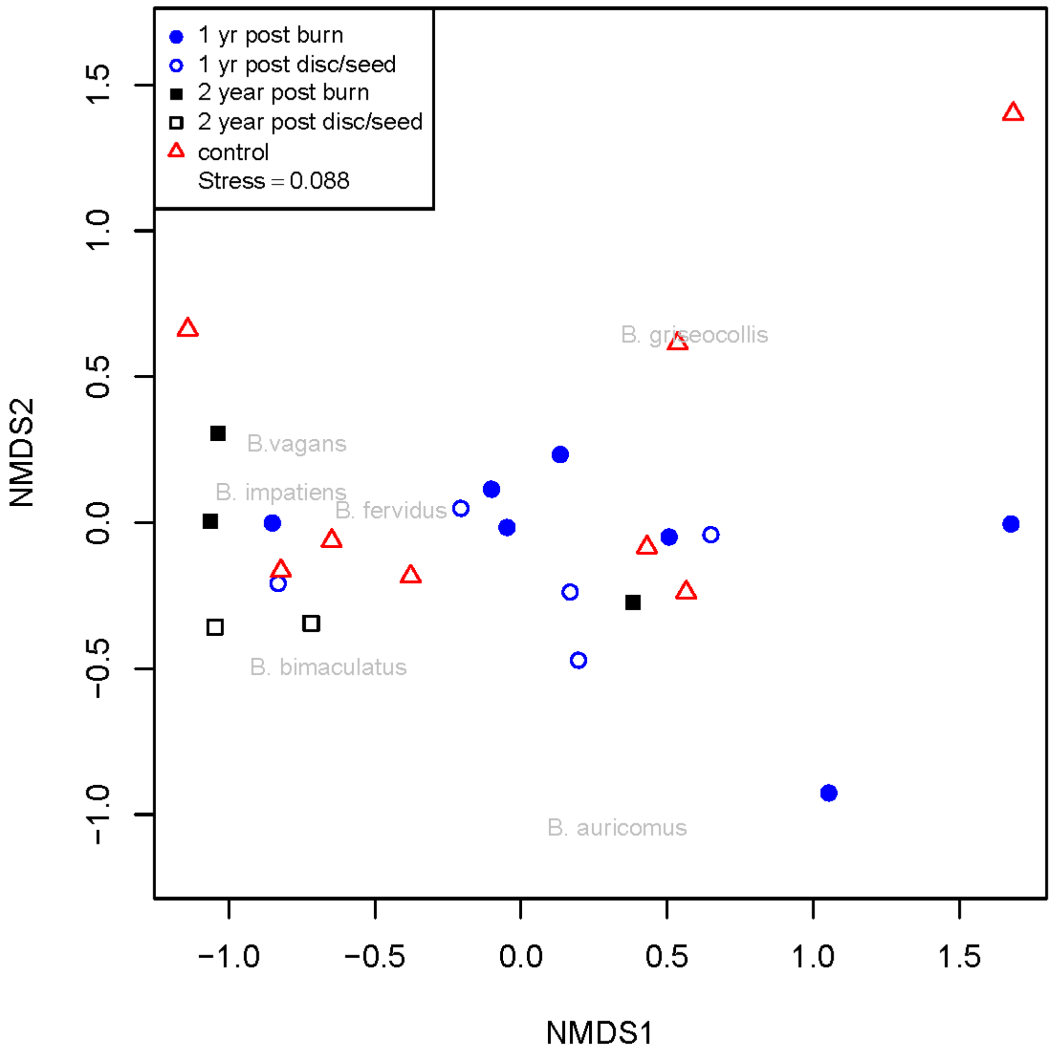



Figure 9. Biplot of non-metric multidimensional scaling (k = 2) of bumble bee community as grouped by site, year, and year post-treatment. Symbol color and shape indicates treatment blue circles = burned; black squares = disc and seeded; and red triangles = unmanaged. Symbol fill represents times since last treatment: solid = 1 year; open = 2 years. The gray scientific names are those of the bumble bee species used in the analysis.

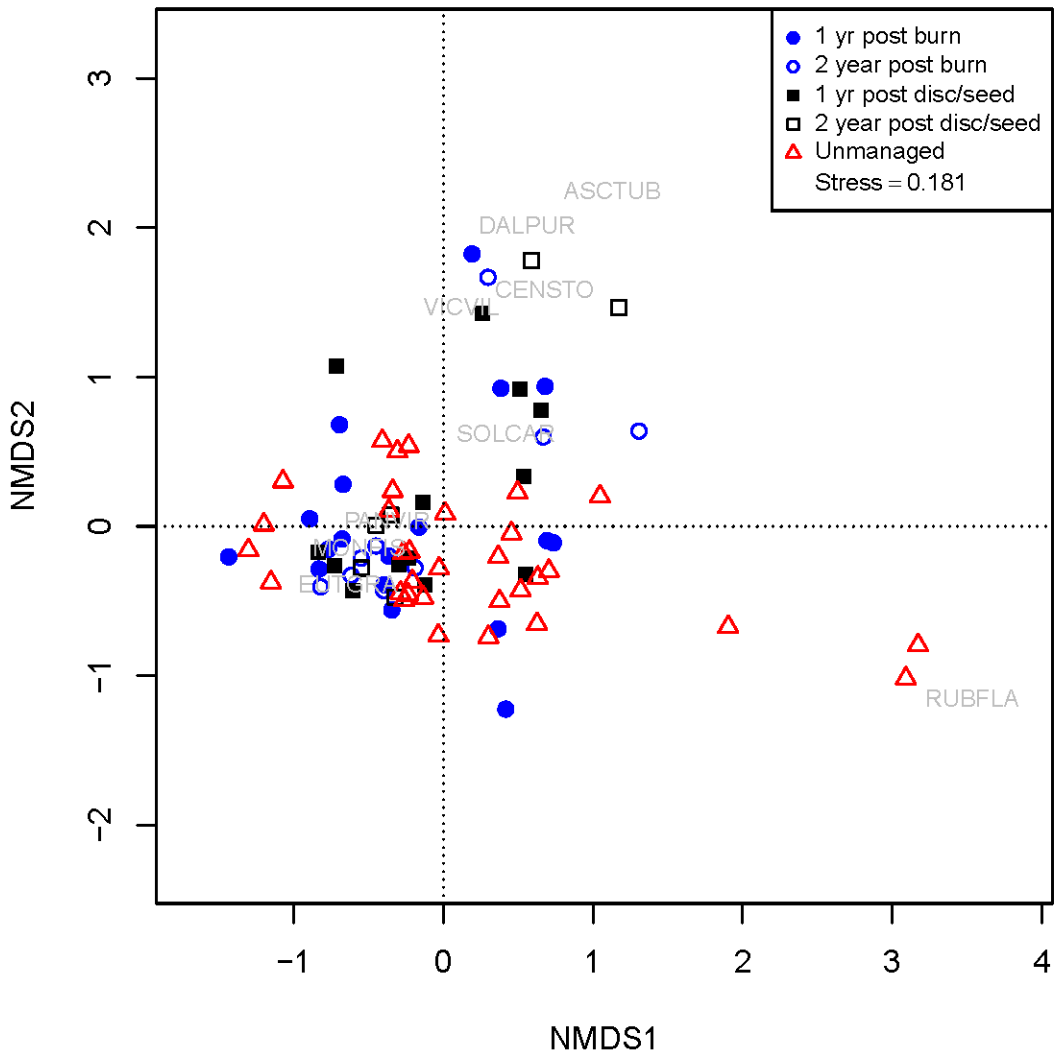



Figure 10. Biplot of non-metric multidimensional scaling (k = 2) of vascular plant communities as grouped by site, survey period, and year post-treatment. Each point represents a site during a survey period and year post-treatment. Symbol color and shape indicates treatment blue circles = burned; black squares = disc and seeded; and red triangles = unmanaged. Symbol fill represents times since last treatment: solid = 1 year; open = 2 years. The displayed plant abbreviations were selected from species significant in the analysis and that were highly abundant or observed nectaring species of bumble bees (Table 5).

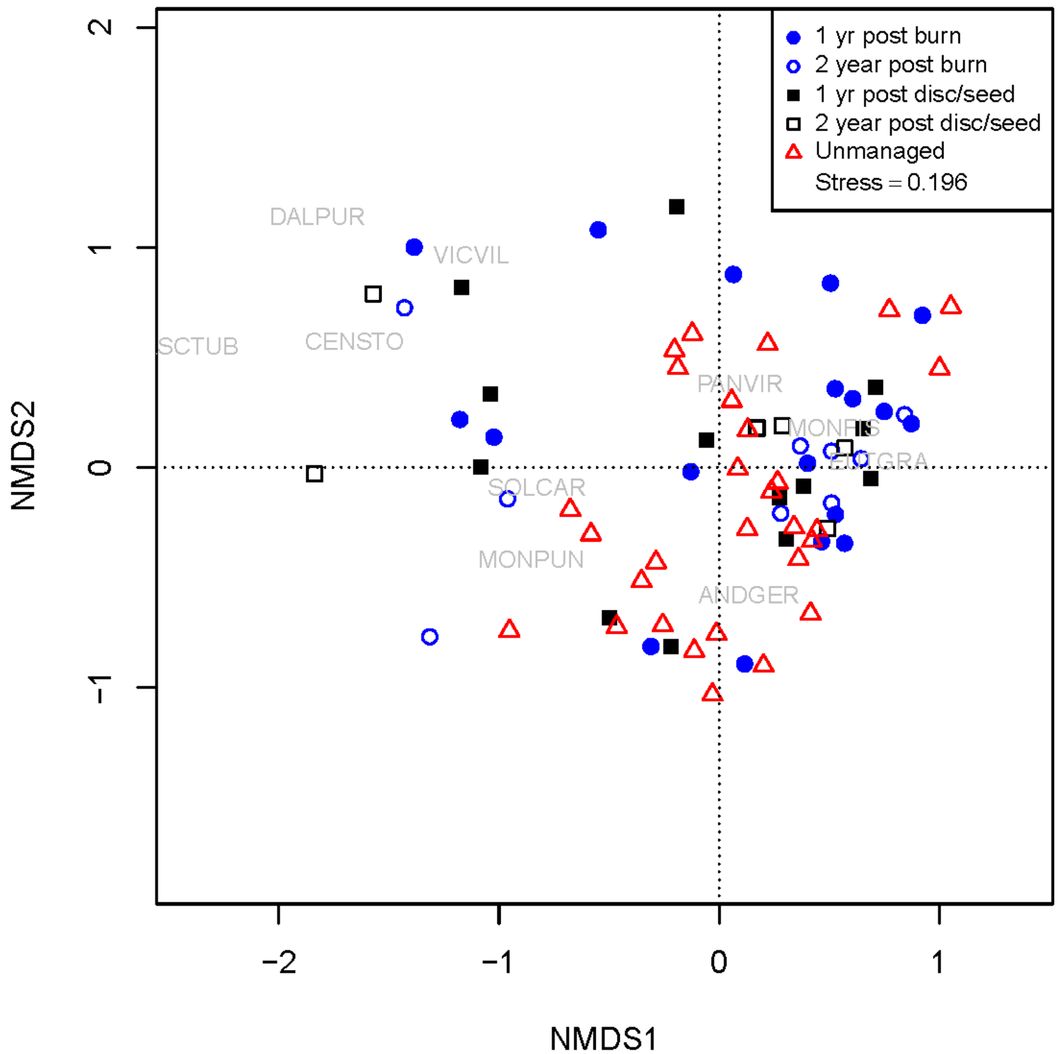



Figure 11. Biplot of non-metric multidimensional scaling (k = 2) of vascular plant communities as grouped by site, survey period, and year post-treatment without savanna site: Allegan State Game Area – 42nd St (18010). Each point represents a site during a survey period and year post-treatment. Symbol indicates treatment: blue circles = burned; black squares = disc and seeded; and red triangles = unmanaged. Symbol fill represents times since last treatment: solid = 1 year; open = 2 years; and triangle = over 2 years. The displayed plant abbreviations were selected from species significant in the analysis and that were highly abundant or observed nectaring species of bumble bees (Table 5).

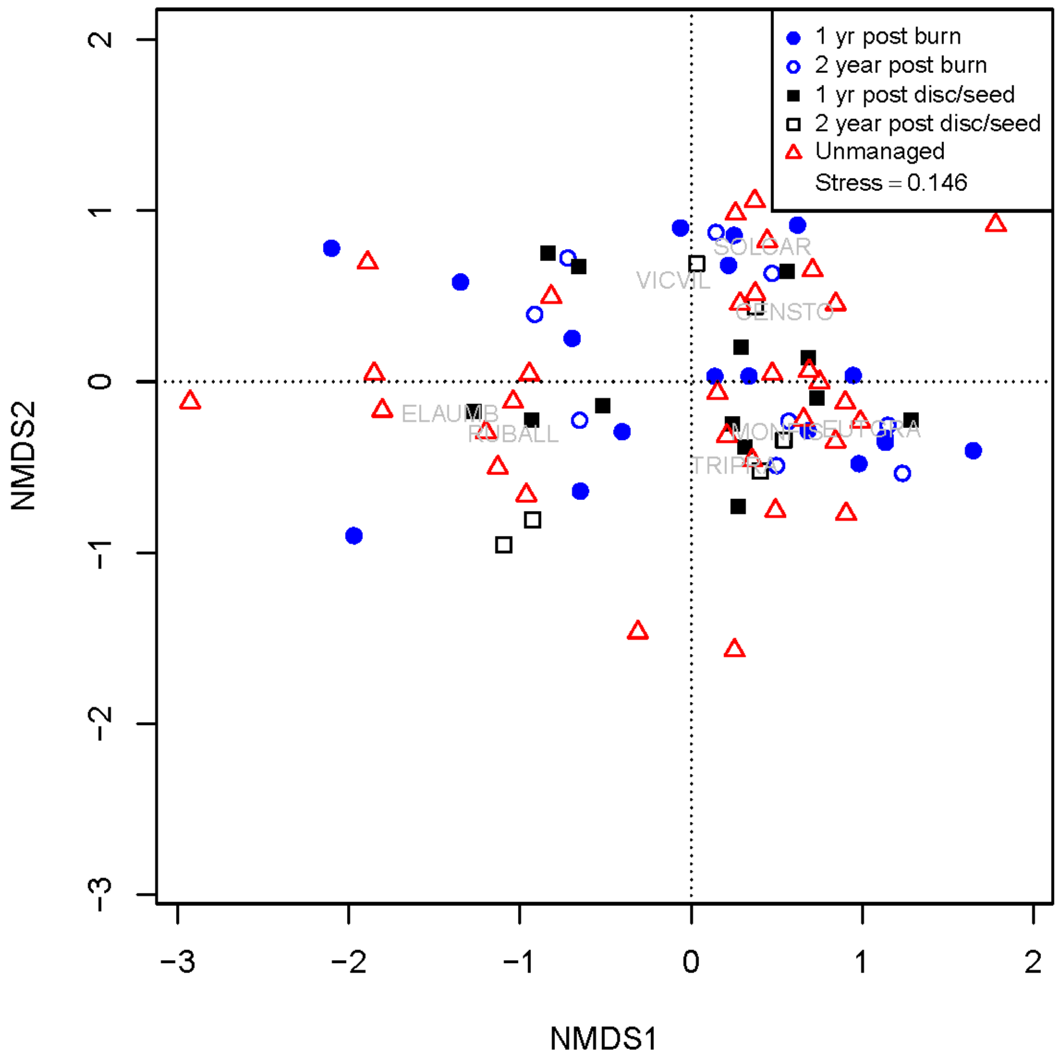



Figure 12. Biplot of non-metric multidimensional scaling (k = 2) of blooming, non-graminoid plant communities as grouped by site, survey period, and year post-treatment Symbol indicates treatment: blue circles = burned; black squares = disc and seeded; and red triangles = unmanaged. Symbol fill represents times since last treatment: solid = 1 year; open = 2 years; and triangle = over 2 years. The displayed plant abbreviations were selected from species significant in the analysis and that were highly abundant or observed nectaring species of bumble bees (Table 5).

Table 5. Abbreviations of plant species names included in Figure 10, Figure 11, and Figure 12.

| Abbreviation | Scientific name | Common name |
|---|---|---|
| ANDGER | *Andropogon gerardii* | Big bluestem |
| ASCTUB | *Asclepias tuberosa* | Butterfly-weed |
| CENSTO | *Centaurea stoebe* | Spotted knapweed |
| DALPUR | *Dalea purpurea* | Purple prairie-clover |
| ELAUMB | *Elaeagnus umbellata* | Autumn-olive |
| EUTGRA | *Euthamia graminifolia* | Grass-leaved goldenrod |
| MONFIS | *Monarda fistulosa* | Wild-bergamot |
| MONPUN | *Monarda punctata* | Horse mint |
| PANVIR | *Panicum virgatum* | Switchgrass |
| RUBALL | *Rubus allegheniensis* | Common blackberry |
| RUBFLA | *Rubus flagellaris* | Northern dewberry |
| SOLCAR | *Solanum carolinense* | Horse-nettle |
| TRIPRA | *Trifolium pratense* | Red clover |
| VICVIL | *Vicia villosa* | Hairy vetch |

# Discussion

The restoration and conservation of natural landscapes is crucial to the long-term stability of plant and pollinator communities. We developed and implemented a monitoring program to assess the effectiveness of two grassland management strategies (burn, disc with forb interseeding) on target populations of native plants and pollinators through comparisons with unmanaged reference sites. By using an adaptive management approach, we anticipate our results to could inform future conservation measures in managed grasslands. However, our assessment was limited by the small number of available unmanaged reference sites. Implementing long-term monitoring at managed grasslands could help ameliorate the lack of unmanaged sites by tracking the response of pollinators and vegetation to rotating management cycles over longer periods.

We observed two bumble bee species that are in decline: black and gold bumble bee (*B. auricomus*) and yellow bumble bee (*B. fervidus*). Each of these species have experienced an approximate 65% decline in their native ranges when compared to historic population levels (Wood et al. 2019). Their use of managed sites is particularly important as it adds value to the conservation effort. Despite lack of patterns in treatment where they were observed, management actions that best support season-long availability of foraging resources are likely the best methods to support declining populations of at-risk bumble bee species. Continued or more focused monitoring at these sites for those species would be beneficial to documenting trends in their range.

Of the five plant species most frequently nectared by bumble bees (Table 3), only wild-bergamot was used widely in the seed mixes. These mixes were assembled with a wide range of pollinators in mind but seem to be lacking in the species most favored by bumble bees or those species are not sprouting as much as others. Greater percentage of seed of bumble bee favored nectaring sources could increase bumble bee visitation to restored areas.

Our results did not indicate any differences among the three treatments in the number of bumble bees collected per survey, bumble bee species richness per survey, flowering non-graminoid plant species richness per plot, nor plant species richness per site. The lack of differences could be attributed to inherent variation among sites, timing of treatments, and/or differences in seed mixes confounding relationships. There is also the potential for unknown legacy effects on the vegetation and bumble bee communities resulting from management occurring on managed/unmanaged sites prior to our study. Monarch abundance also did not vary among the three treatments, but it was positively related to the number of milkweed stems. Management approaches to maintain the high milkweed abundance at high abundance sites and increase milkweed abundance at other sites could be employed to increase monarch use of managed grasslands.

We found a significant effect of year post-management on mean abundance of bumble bees, species richness of bumble bees, and species richness of plant community, with all variables increasing from one to two years post-treatment. Other restoration studies examining a variety of pollinators and/or plants also found some differences in abundance or species richness within three years post-treatment (Redpath-downing et al. 2013; Blackmore and Goulson 2014; Griffin et al. 2017; Lettow et al. 2018; Garrido et al. 2019). One of those studies was a 26-year study in Illinois restored tallgrass prairie that found pollinator response did not resemble those of remnant habitat until five to seven years post-treatment (Griffin et al. 2017). In our assessment of grasslands established on former agricultural lands, it is unknown if this is an increasing trend, or a response to the treatment that will equalize in a few years. Given the low number of samples of second-year post-treatment and unmanaged sites, we recommend caution when interpreting our findings. Gathering data at more sites and for a greater number of growing seasons would contribute to understanding whether the patterns we found in this study were ongoing or variation attributed to site, weather, or other unknown factors. In developing this project, we expected focal pollinator abundance to temporarily decline immediately after implementing conservation actions. It is possible that in the first year post-management important pollen and nectar species are still establishing. Similar year post-treatment trends have been shown in other studies (Meissen et al. 2019).

Our multivariate analyses suggested the overall bumble bee and plant communities were similar across the managed grasslands we investigated, regardless of treatment type or time since last management action. We did not find any differences between bumble bee communities associated with treatment and year post-treatment, likely due to the small number of species observed, and the relatively high abundances of common species at each site. In plant communities, no patterns were associated with treatment type or year post-treatment. Species composition appeared to differ both among sites and treatments. For example, the savanna site at Allegan State Game Area had such a distinct plant community that it skewed the plant community NMDS and had to be removed to better examine patterns among the treatments. Many factors are known to influence plant communities, including site area, surrounding landscape, historic conditions, and past management/disturbance (Zirbel et al. 2017; Porensky et al. 2019; Zirbel et al. 2019). These and other factors could be important drivers of diversity at our managed grassland sites, thus making discernment of patterns among management types more difficult.

The variability among the site communities highlights the need for pre- and post-treatment monitoring. We made the decision to pool pre-treatment and unmanaged sites due to the low number of unmanaged sites and pre-treatment data for some sites, but this was not optimal to analyze the data to answer questions on a regional- or site-level. Gathering pre- and post-treatment data at all sites would allow managers to determine if their pre- and post-treatment objectives were achieved.

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