Monitoring and evaluating the status of bumble bees in Illinois

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Final Report

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Executive Summary

Bumble bees (Hymenoptera: Apidae: *Bombus* spp.) are distinctive bees known for their large size and ground-nesting behavior. While predominantly social, the cuckoo bumble bees are solitary brood parasites of other bumble bee species. The group is globally threatened, with bumble bees in marked decline across the northern hemisphere in Europe, North America, and Asia, with habitat loss being a primary contributing factor. The conservation status of bumble bees in North America has recently come sharply into focus with the federal listing of the rusty patched bumble bee (*Bombus affinis*) as endangered in 2017. Unfortunately, little is known about the status of bumble bees in Illinois. Currently, four species are listed as Species in Greatest Conservation Need (SGCN) in the Illinois Wildlife Action Plan (IWAP): *Bombus affinis, B. fraternus, B. pensylvanicus,* and *B. vagans.* Additionally, *B. borealis*, *B. ternarius*, *B. terricola*, and *B. variabilis* are on the watch list.

Over the last century, Illinois has lost most of its prairie, woodland, and wetland habitats due to intensive farming and urbanization (Iverson, 1988; Moorhouse, 2016). These natural areas are ideal bumble bee habitats as they provide adequate food and nesting resources (Goulson *et al.*, 2008; Redhead *et al.*, 2016). This drastic removal of Illinois' natural habitat corresponds with bumble bee declines. Between 1900 and 2007, Illinois saw a decrease in bumble bee species richness and substantial range reductions in *B. affinis*, *B. fraternus*, *B. pensylvanicus,* and *B. vagans* (Grixti *et al.*, 2009). However, not all bumble bee species in Illinois may face severe population declines. While *B. pensylvanicus* has seen a sharp drop in distribution and abundance in Illinois, *B. impatiens* populations have remained constant throughout the state. These differences in population change suggest that bumble bee species may have varying responses to landscape change and other threats (Grixti *et al.*, 2009; Lozier *et al.*, 2013). Frequent monitoring efforts are required to better understand the differential response of bumble bee species and assess which species are facing the steepest declines.

Little is known about the current status of bumble bees in Illinois. The last recent statewide bumble bee survey was conducted in 2007 (Grixti *et al.*, 2009). In order to combat Illinois bumble bee declines, current data on Illinois' bumble bee populations is vital to identify species of most concern and develop targeted management strategies. This project aimed to develop a monitoring program throughout the state in order to build a species list, examine distributions, and assess the status of bumble bees in Illinois. The project utilized historical records from the extensive bee collection at the Illinois Natural History Survey (INHS) and new sampling efforts in a wide variety of habitat types to achieve these goals. The project provided baseline data concerning bumble bee diversity, distribution, and status in Illinois, an essential step in conserving our bumble bee fauna.

Throughout the project, a total of 1430 bumble bees from 10 species were captured and either curated or photographed and released. Of these ten species, one was classified as critically endangered (*B. affinis*), one was classified as endangered (*B. fraternus*), and two were classified as vulnerable (*B. fervidus* and *B. pensylvanicus*) based on International Union of Conservation of Nature (IUCN) scores. Sampling efforts from this project resulted in 10 probable new county records, which will be verified and included in a county record publication. An informational brochure was also created for the general public, which will be published through the Illinois extension office and posted on the BeeSpotter website. Using linear mixed-effects models (LMMs), we used local and landscape-level variables to identify the driving forces behind bumble bee abundance and richness. Local assessments consisted of floral quantification and Floristic Quality Index (FQI) scores (explanation and equation for FQI values shown in Expanded Narrative). Landscape-level land use was calculated every year using the CropScape data layer provided by the USDA and a buffer of 1500m, which corresponds to the typical foraging range of most bumble bee species (Osborne *et al.*, 2008). Land use within the buffer was then categorized and added to the LMMs selection process. We determined that FQI values

have a significant positive association with both bumble bee abundance and richness, while both agricultural and natural area land-use percentages surrounding sample sites had a significant negative effect on bumble bee abundance.

Expanded Narrative

Methods

Site Selection

For this study, we chose low- to high-quality sites, including remnant and restored areas. These sites are further described in Table 1, and their locations throughout the state can be seen in **Figure 1**. For each year of the study, a minimum of five sites were selected for comprehensive sampling to systematically quantify potential covariates influencing bumble bee richness and abundance (outlined below). Other sites throughout the state were selected based on habitat quality, county-level coverage across the state, and the logistic sampling ability of the lab based on available personnel.

When possible, sites were visited at least three times throughout the field season. For comprehensively sampled sites, three visits were ensured and spaced apart by approximately 30 days (**Table 1**). Similar sampling efforts were made for abbreviated sampling sites (**Table 1**); however, three visits could not always be achieved due to time and personnel constraints.

Transect Sweep Netting

Sampling plots consisted of a centrally located, 100m transect divided into five segments of 20m each (**Figure 2**). Sampling areas comprised a 5m netting buffer on either side of the 100m transect. Each sampling period consisted of a morning (9am) and afternoon (3pm) netting session. For each netting session, one hour of active netting was conducted (60 minutes divided by the number of people sampling); bumble bee handling time was excluded from the hour sampling time (**Figure 3**). Afternoon sampling followed the same sampling regimen. Captured bumble bees were stored in 50ml centrifuge tubes that were labeled with the date, site, person capturing, and the flower on which the bee was caught. Bee specimens were then cold anesthetized in a cooler filled with ice and photographed. Voucher specimens were taken for one male and one female of each species (when available). The remaining bumble bees were released.

Traps

Blue vane traps were deployed during the first year of the grant (2019); however, due to a surprisingly low bumble bee capture rate and relatively large amount of by-catch, these traps were dropped from the sampling protocol in subsequent years. For the 2019 sampling season, blue vane traps were used during the June and July sampling periods (excluding August to reduce destructive capture of newly emerged queens). During each sampling session, six traps were deployed evenly along the 100m sampling transect (20m between each trap). At approximately 9am, traps were filled with 1-2 inches of soapy water and suspended on shepherd poles (~4ft above the ground). At 3pm, contents were retrieved, strained, and stored in 70% ethanol for later processing, curation, and identification.

Habitat floristic quality assessment

For comprehensive sampling efforts, belt transect sampling was conducted at each 20m increment along the 100m sampling transect (**Figure 2**). Each belt transect consisted of a 4m x 20m rectangle where flower species, number of flowers and/or umbels (when applicable for umbellate flowers), and transect number were recorded. Floral abundance, floral richness, and coefficients of conservatism (CC) for each species were collected and utilized in bumble bee abundance and richness models. Coefficients of conservatism are values assigned geographically that correspond to the tolerance of a given species to disturbances such as environmental degradation, overgrazing, or development. These values range from 0-10, where higher values equate to species with a lower tolerance for disturbance. CC values for this project were assigned from a Critical Trends Assessment Program (CTAP) analysis database provided by Associate Scientist and Plant Ecologist David Zaya PhD, at the Illinois Natural History Survey.

CC scores were used to calculate Floristic Quality Index (FQI) values for each sampling location and time point. FQI is a tool to quantify the ecological integrity of an area based on the plant species composition present. Interestingly, FQIs were developed in Illinois by Gerould Wilhelm and Floyd Swink during the 1970s (Wilhelm, 1977). The index is calculated using the following equation:

$$FQI = \underline{C}\sqrt{n}$$

in which:

$\underline{C}$ = Mean coefficient of conservatism value for all species encountered at the sample site.

$\sqrt{n}$ = The square root transformation of the total number of species encountered at the sample site.

This method generates an index that can attach a numeric value to habitat quality. Plant analysis was conducted within the extent of each sampling transect and not over the entirety of the habitat. While this sampling method likely omitted floral species from each sampling location, the standardized methodology allows for a more comparable analysis of habitat quality per unit area. As a result, FQI values for each site sampled appear artificially lower than an entire site-level analysis. Results of these analyses should therefore be compared between sites for this project rather than generally accepted ranges for habitat quality.

Geospatial land-use analysis

Land use within common bumble bee foraging ranges was quantified to determine the effect of the surrounding landscape (both within and beyond sample sites) on bumble bee richness and abundance. Land-use designations were assigned using the USDA CropScape Cropland data layer for each corresponding year (Boryan *et al.*, 2011). For ease of analysis, land-use designations were categorized into five groups (agriculture, developed, natural, semi-natural, and unused). As the 2022 CropScape data layer has not yet been published, current analyses exclude 2022. These data will be included in the final analysis and publication.

Surrounding land use was truncated using a 1500m radius buffer to better characterize the probable forage land that bumble bees captured at each site would encounter. This value corresponds to a realistic foraging range for most bumble bees (Osborne *et al.*, 2008). An additional analysis examined the potential effect of honey bee competition on bumble bee richness and abundance. Registered honey bee hives with a 2156m radius from the sample sites were quantified (Couvillon *et al.*, 2014), however, due to a relatively low level of overlap between sample sites and honey bee hives, these data were not included in the final analysis.

Statistical Analyses

Bumble bee abundance and richness models were established using linear mixed-effects models (LMMs), with final models being selected using AICc comparisons. AICc model selection was chosen because it helps identify a candidate model that best explains the variance within the data while taking into account potential issues with overfitting from too many explanatory variables. For both bumble bee abundance and richness models, potential fixed effects of plant abundance, plant richness, FQI, percentage of surrounding agricultural usage, surrounding natural area, and surrounding developed area (Figure 5) were considered and narrowed down using AICc comparisons. The sample sites were considered a random effect for the bumble bee abundance model. This allowed us to cluster analyses at the site level and account for the non-independence of repeated sampling efforts at the same locations. For the bumble bee richness model, the random effect structure consisted of year being nested within site. The random effects differed between the models due to the amount of model variance attributed to the random effect structure. This was narrowed down using the rePCA function, which conducts a principal component analysis of the random-effects variance-covariance estimates. Functionally it allowed us to identify random effect components that did not explain any model variation and remove them from our model structure. The normality of residuals for both models was assessed visually and via Shapiro-Wilk normality tests. All model assumptions were met.

All statistics and graphs were done using R 4.2.2 (R Core Team, 2022) and the following R packages: *bbmle* (*v1.0.23*.1; Ben Bolker, 2020), *ggplot2* (*v3.2.1*; Hadley Wickham, 2016), *ggthemes* (*v4.2.0;* Jeffrey B. Arnold, Gergely Daroczi, Bo Werth, Brian Witzner, Joshua Kunst, Baptise Auguie, Bob Rudis, Hadley Wickham, 2019), *lme4* (*v1.1*-21; Douglas Bates, Martin Maechler, Ben Bolker, Steve Walker, 2015), *performance* (*v0.5*.0; Daniel Lüdecke, Dominique Makowski, Philip Waggoner, Indrajeet Patil, 2020), and *plyr* (*v1.8.6;* Hadley Wickham, 2020).

Results and Discussion

Bumble Bee Diversity

Throughout the four-year duration of the project, 1430 bumble bees from 10 species were captured and either curated or photographed and released. Of these ten species, one was classified as critically endangered (*B. affinis*), one was classified as endangered (*B. fraternus*), two were classified as vulnerable (*B. fervidus* and *B. pensylvanicus*), and six were classified as least concern (*B. auricomus, B. bimaculatus, B. citrinus, B. griseocollis, B. impatiens,* and *B. vagans*), based on International Union of Conservation of Nature (IUCN). A list containing species, number of individuals captured, IUCN conservation status, and Species in Greatest Conservation Need (SGCN) in the Illinois Wildlife Action Plan (IWAP) designations can be found in **Table 3.**

Bumble bee distribution

Bumble bees were collected from 34 unique sites (**Table 1)** from 17 counties (**Table 2**) across Illinois (**Figure 1**). Because of personnel constraints, unforeseen COVID restrictions, and sampling overlap (particularly in the northern portion of the state), most sampling sites were located in central and southern Illinois. Sampling efforts from this project resulted in 10 probable new county records. Despite being in a well-sampled state with management and registration laws for managed pollinators such as honey bees, our findings show that further monitoring efforts are needed. We are working with Illinois extension and BeeSpotter to publish an informational brochure (see volume 1 attached). This document is meant to increase awareness of bumble bee distributions, floral associations, and conservation status, hoping to bolster citizen science participation. As bumble bees provide essential economic and environmental services and numerous species have been identified as declining or endangered, it is crucial that monitoring efforts and habitat management practices continue.

Local and landscape-level effects on Bumble bee diversity

Throughout the project, bumble bees were collected from 50 unique flower species. Floral species were identified and recorded for all collected individuals except those captured mid-flight or via blue vane traps. A list of floral associations with bumble bee species from this project can be seen in **Table 4.** This list of associations only reflects bumble bee captures on flowers that occurred during this project and should not be considered a comprehensive list of floral associations for each bumble bee species.

Bumble bee abundance and richness patterns were assessed using linear mixed-effect models. These models were used to determine the directionality and significance of predictor variables such as: surrounding land use within a bumble bee foraging range, local floral abundance and richness, and FQI scores. Full models are outlined in **Table 1** and visually depicted in **Figure 6**. Bumble bee abundance was found to be significantly affected by FQI (Coefficient = 1.92, F = 5.724, P =.064), percent surrounding agriculture (Coefficient = -1.04, F = -3.330, P =<.001), and percent surrounding natural area (Coefficient = -1.66, F = 4.945, P =.001). Signs of the coefficient values (positive or negative) indicate the directionality of the relationship between the predictor variable and bumble bee abundance. For example, the percent of surrounding agriculture had a coefficient of -1.04, meaning that for every increase in the percent of surrounding agriculture, there was a corresponding decrease of 1.04 bumble bees per site. The relationship between bumble bee abundance and surrounding natural areas was rather peculiar. We expected a positive relationship between surrounding natural areas and bumble bee abundance, however the relationship was significantly negative (-1.66). It is possible that this finding could be an artifact of the grouping criteria used to categorize land use as natural areas. Forests frequently appeared in these groupings. While certain bumble bee species are associated with forests (i.e. *Bombus vagans*), most species live underground and prefer open areas with abundant flowering plants. We plan to look into this trend further by including our 2022 specimens in our analysis.

Bumble bee richness was found to have a significant positive association with FQI (Coefficient = .126, F = 2.18, P = .041). Surrounding land-use factors and floral abundance did not significantly affect bumble bee richness. These findings are subject to change when we include 2022 specimens in our analysis and further disentangle land-use variables (see natural areas explanation above). Our findings showing the positive relationship between bumble bee abundance and richness with FQI scores and correspondingly high mean coefficients of conservatism relative to floral richness, align with previous studies (Hines & Hendrix, 2005; Rosenberger & Conforti, 2020). The consistencies between this project and previous literature further stress the need for increased management of natural areas. In order to improve coefficients of conservatism and FQI, we recommend regimented use of restorative burns and targeted additions of diverse seed mixes, as these practices have been shown to positively influence mean CC and FQI respectively (Hansen & Gibson, 2014).

Objectives and Status

Objective 1: ***Investigate the distribution of bumble bees throughout the state, with particular focus on federally listed species (rusty patched bumble bee, B. affinis), state SGCN listed species (B. fraternus, B. pensylvanicus, and B. vagans), and bumble bees currently on the state watch list (B. borealis, B. ternarius, B. terricola, and B. variabilis).***	**Status of Objective 1:** In 2019 we encountered *B. affinis* at a new site in Woodford County and reported this to IDNR as mentioned in previous annual reports. It was decided after 2019 that we would search outside of areas where *B. affinis* is known to be present, so these results are not surprising. Our samples from the 2019, 2020, 2021, and 2022 field seasons have been fully curated and identified (when possible) from their photos and/or pinned specimens. We have added several new sites (and counties) for SGCN listed species (*B. fraternus*, *B. pensylvanicus*, and *B. vagans*) from our 2019, 2020, 2021, and 2023 field seasons (Table 2). Numerous new records have been added to our database. We are currently working with BeeSpotter and utilizing the Global Biodiversity Information Facility (GBIF) database to create a county record publication that includes the findings in Table 2.
Objective 2: Develop a comprehensive list of bumble bee species in Illinois by county and compare that to past distribution information to fully assess their current distributions and examine their conservation status.	**Status of Objective 2:** We are currently comparing our SWG collection data with the recently published statewide county record publication by former University of Illinois graduate Brenna Decker (Decker *et al.*, 2020). As previously mentioned, we intend to expand upon Brenna's previous publication by publishing new county records (Table 2) from this SWG project and more recent records present in the GBIF and BeeSpotter.
Objective 3: To establish a monitoring program for bumble bees throughout the state.	**Status of Objective 3:** During the 2021 sampling season, we developed an abbreviated sampling regimen, which required half the amount of time needed in our previous sampling protocol. While data received from this sampling technique must be qualified during data analysis and do not provide as complete a picture regarding floral abundance, the development of a new, standardized sampling technique offers a more tangible monitoring platform for future monitoring efforts. We have developed brochures (attached) and other outreach materials (posters distributed at the Illinois State Fair) that contain bumble bee and plant identification guides in addition to the standardized sampling protocol (attached document) so that this method of monitoring can be more broadly applied.

Objective 4: Provide management recommendations identifying preferred floral resources and regions of concern; this will include brochures featuring bumble bee friendly practices for natural areas, parks and yards.	**Status of Objective 4:** We compiled information on the floral resources used by each bumble bee during capture. Thus far, we have noted 50 different plant species on which bumble bees were caught (**Table 4**). In addition, we have also been quantifying the floral resources available during our timed netting periods at several sites. This allowed us to provide species lists of flowers that bumble bees use, emphasizing those used by more rare species. Management recommendations based on local and landscape level factors can be found under the "Local and landscape-level effects on Bumble bee diversity" section of the Results and Discussion. Version 1 of an informational brochure can be found attached.
Objective 5: Deliver annual reports. Deliver final report at the end of the 3-year project life. At the end of the project also deliver: lists of species from the surveys, maps of distributions including GIS coordinates for surveyed locations and/or individual records, assessment of distribution change, current conservation status using NatureServe Conservation Rank Calculator and/or SGCN criteria, and management recommendations (including the brochures from objective 4). Much of the deliverables information will be contained within the final report, but separate files will be also be provided for GIS coordinate data, occurrence records, and any floristic data for IDNR to input into the Natural Heritage Database Program or wherever else this data may be useful.	**Status of Objective 5:** ● Annual reports were delivered for every year throughout the project. ● A specimen containing all current bumble bee records from the project is attached. This document includes elements stated in the objective such as GIS coordinates, individual locations, etc. ○ Some of these records are subject to change prior to the final publication of the project, however all species records will be deposited and databased into the Illinois Natural History Survey insect collection. ● A floral inventory of the species observed and abundance of flowers for all comprehensive sampling efforts is attached. ● A species list with IUCN conservation status, SGCN in the IWAP, and the number of individuals collected for each species during this project can be seen in Table 3. ● A map of all locations can be seen in Figure 1. ● The attached brochure represents the first volume and does not include all of the information that will be included for the first publication. We will be adding in: an introductory page describing how the brochure is designed to be used, a bee morphology page to provide a visual guide for bee morphological terminology, a list of easily grown plants that are attractive to many bumble bee species (so that the general public knows which plants they can grow that will easily establish), detailed species identification descriptions (shown on each species page), a glossary, an index, and a reference page. ● A floristic data and bumble be interaction matrix is shown in Table 4.

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Tables and Figures

Table 1. A site list of sampling locations chosen in Illinois for this study. Habitat type, County, sampling method used, and Floristic Quality Index (FQI) are provided for each site. Please see "Habitat floristic quality assessment" under the Methods section for FQI calculation and analysis qualification.

Site	Habitat Type	County	Sampling Method	FQI
Beadles Barrens Nature Preserve	Planted Restored Prairie	Edwards	Comprehensive Sampling	15.83
Eldon Hazlet State Recreational Area	Planted Restored Prairie	Clinton	Comprehensive Sampling	8.19
Foley Sand Prairie	Sand Prairie Recovering from Grazing	Lee	Abbreviated Sampling	-
Fox Ridge State Park	Planted Restored Prairie	Coles	Abbreviated Sampling	-
Fults Hill Prairie State Natural Area	Remnant Hill Prairie	Monroe	Comprehensive Sampling	15.27
Greenlee Cemetery Prairie Nature Preserve	Cemetery Prairie	Henry	Abbreviated Sampling	-
Henry Allan Gleason	Sand Prairie	Mason	Abbreviated Sampling	-
Herschel Workman Pheasant Habitat Area	Planted Restored Prairie	Vermilion	Abbreviated Sampling	-
Horn's Prairie Grove	Remnant Prairie	Fayette	Comprehensive Sampling	-
Iroquois County State Wildlife Area	Old field	Iroquois	Abbreviated Sampling	-
Kennekuk Cove County Park	Cemetery Prairie	Vermilion	Abbreviated Sampling	-
Loda Cemetery Prairie	Cemetery Prairie	Iroquois	Abbreviated Sampling	-
Long Branch Sand Prairie	Restoration Sand Prairie	Mason	Abbreviated Sampling	-
Lyndon Prairie Nature Preserve	Wet Mesic Prairie	Whiteside	Abbreviated Sampling	-
Meredosia Hill Prairie Nature Preserve	Remnant Sand Prairie	Morgan	Comprehensive Sampling	13.22
Merwin Savanna Preserve	Remnant Oak Savanna and Hill Prairie	McLean	Comprehensive Sampling	8.57
Munson Township Cemetery Prairie	Cemetery Prairie	Henry	Abbreviated Sampling	-
Nachusa Grasslands	Planted Restored Prairie	Lee	Abbreviated Sampling	-
John M. Olin Hill Prairie	Remnant Hill Prairie	Madison	Comprehensive Sampling	10.29
John M. Olin Prairie	Planted Restored Prairie	Madison	Comprehensive Sampling	9.19

Pellsville Cemetery Prairie	Cemetery Prairie	Rankin	Abbreviated Sampling	-
Perdueville Pheasant Habitat Area	Planted Restored Prairie (Grassland)	Ford	Abbreviated Sampling	-
Prospect Cemetery Prairie	Cemetery Prairie	Ford	Abbreviated Sampling	-
Revis Hill Prairie Nature Preserve	Loess Hill Prairie	Mason	Abbreviated Sampling	-
Ridgetop Hill Prairie	Remnant Hill Prairie	Woodford	Abbreviated Sampling	-
Russell M Duffin Nature Preserve	Planted Restored Prairie	Vermilion	Comprehensive Sampling	3.72
Sam Parr State Park	Planted Restored Prairie	Jasper	Comprehensive Sampling	10.19
Sand Prairie Scrub Oak	Sand Prairie	Mason	Abbreviated Sampling	-
South of Ludlow	Roadside Prairie	Champaign	Comprehensive Sampling	5.73
South of Paxton	Roadside Prairie	Ford	Abbreviated Sampling	-
Twelve Mile Prairie	Remnant Prairie	Effingham	Abbreviated Sampling	-
Vermillion River Observatory	Old field	Vermilion	Abbreviated Sampling	-
Weston Cemetery	Cemetery Prairie	McLean	Abbreviated Sampling	-
Wildcat Hollow State Habitat Area	Old field	Effingham	Abbreviated Sampling	-

Table 2. A bumble bee species occurrence by County matrix. The highlighted cells represent potential new county records (pending secondary identification). Country record comparisons are made from the recent publication, Decker *et al.* 2020. Marks correspond to year of capture (x = 2019, y = 2020, z = 2021, w = 2022).

County	*auricomus*	*bimaculatus*	*citrinus*	*fervidus*	*fraternus*	*griseocollis*	*impatiens*	*pensylvanicus*	*vagans*
Champaign	z	x		z		xz	x	xz	y
Clinton	x	x			x	x	x	y	x
Coles						z			
Edwards	xz	xz	z		x	xz	xz	x	x
Effingham	x	yz			x	xy	xy	x	
Fayette				w		w		w	x
Ford	x			x		x	x	x	
Henry						w	w		
Iroquois	x	x				x			
Jasper	z	zw	z			zw	zw	z	
Lee				x	w	x	w		
Madison	zw	z				zw	zw	zw	
Mason	x	x			xzw	xz	xzw	xw	

McLean	x	x				x	x	x	
Monroe	xw	xyzw			xyz	xzw	xzw	xw	x
Morgan		w			zw	zw	z	z	
Vermillion			z	z	z	xw	z	z	z
Woodford						xw	xw		
Whiteside	w					w	w		

Table 3. Bumble bee abundance by species. International Union for Conservation of Nature (IUCN) status is given for each species.

Species	IUCN Conservation Status	SGCN Designation	Number captured
affinis	Critically Endangered	Rare and declining populations	1
auricomus	Least Concern	-	165
bimaculatus	Least Concern	-	91
citrinus	Least Concern	-	18
fervidus	Vulnerable	-	7
fraternus	Endangered	Declining populations	33
griseocollis	Least Concern	-	673
impatiens	Least Concern	-	330
pensylvanicus	Vulnerable	Declining populations	67
vagans	Least Concern	Declining populations	10

Table 4. Plant and bumble bee interaction matrix. Cells shaded gray and containing an "x" indicated that during this project, the indicated specie of bumble bee was captured off the corresponding flower. This interaction matrix is not exhaustive and further interactions are likely. Coefficients of conservatism (CC) are provided for each floral species.

	CC	*auricomus*	*bimaculatus*	*citrinus*	*fraternus*	*griseocollis*	*impatiens*	*pensylvanicus*	*vagans*
Agrimonia parviflora	5					x			

Amorpha canescens						x	x		
Asclepias syriaca	0		x			x	x	x	
Asclepias viridiflora	9				x				
Baptisia alba	6	x	x	x		x	x	x	
Chamaecrista fasciculata	1	x				x	x	x	
Dalea candida	9								
Dalea purpurea	8		x		x	x	x		
Daucus carota	0						x		
Desmodium canadense	5					x			
Dipsacus laciniatus	0						x	x	
Echinacea purpurea	6	x	x			x			
Erigeron strigosus	2					x			
Eryngium yuccifolium	7					x	x		
Eupatorium altissimum	2				x	x	x	x	x
Geranium carolinianum	*2*						x		
Helianthus mollis	*7*		x		x	x	x		
Heliopsis helianthoides	*4*					x			
Lepidium campestre	*0*				x		x	x	
Lespedeza virginica	*5*						x		
Liatris cylindracea	*8*							x	
Liatris pycnostachya	*6*					x			
Medicago sativa	*0*					x			
Melilotus albus	*0*		x			x	x		
Melilotus officinalis	*0*					x	x		
Monarda fistulosa	*4*	x	x			x	x	x	

Nepeta cataria	*0*					x			
Oligoneuron lutescens	*10*						x		
Opuntia humifusa	*5*				x	x	x	x	
Pediomelum tenuiflorum	*8*					x			
Penstemon digitalis	*4*	x	x					x	
Platanthera bifolia	*9*							x	
Psoralidium tenuiflorum	*8*				x				
Pycnanthemum tenuifolium	*4*		x	x	x	x	x		x
Pycnanthemum virginianum	*5*			x		x		x	
Rhus glabra	*1*	x	x						
Rudbeckia hirta	*2*						x		
Ruellia humilis	*3*	x							
Securigera varia	*0*					x			
Silene regia	*9*				x		x		x
Silphium integrifolium	*5*		x			x	x		
Silphium laciniatum	*5*					x	x		
Solanum carolinense	*0*						x		
Solidago canadensis	*1*						x		
Teucrium canadense	*3*	x	x			x			
Tradescantia bracteata	*7*						x		
Tradescantia ohiensis	*3*						x		
Verbesina helianthoides	*6*					x			
Vernonia fasciculata	*5*	x						x	
Vernonia missurica	*5*					x			

Table 5. Summary of the response and predictor variables for both bumble bee abundance and richness models. Model coefficients, test statistics, and *p*-values are reported for each predictor variable.

Response variable	Predictor variables	Coefficients	*F-value*	*P – value*
Bumble Bee Abundance	Intercept	108.42	14.859	<.001
	FQI	1.92	2.392	0.026
	Percent surrounding agriculture	-1.04	-3.40	0.003
	Percent surrounding natural area	-1.67	-3.76	<.001
Bumble bee Richness	Intercept	1.66	2.37	.027
	FQI	0.126	2.18	.041

Figure 1. A map of the locations where bumble bees were collected during the study. Site names can be found in Table 1.

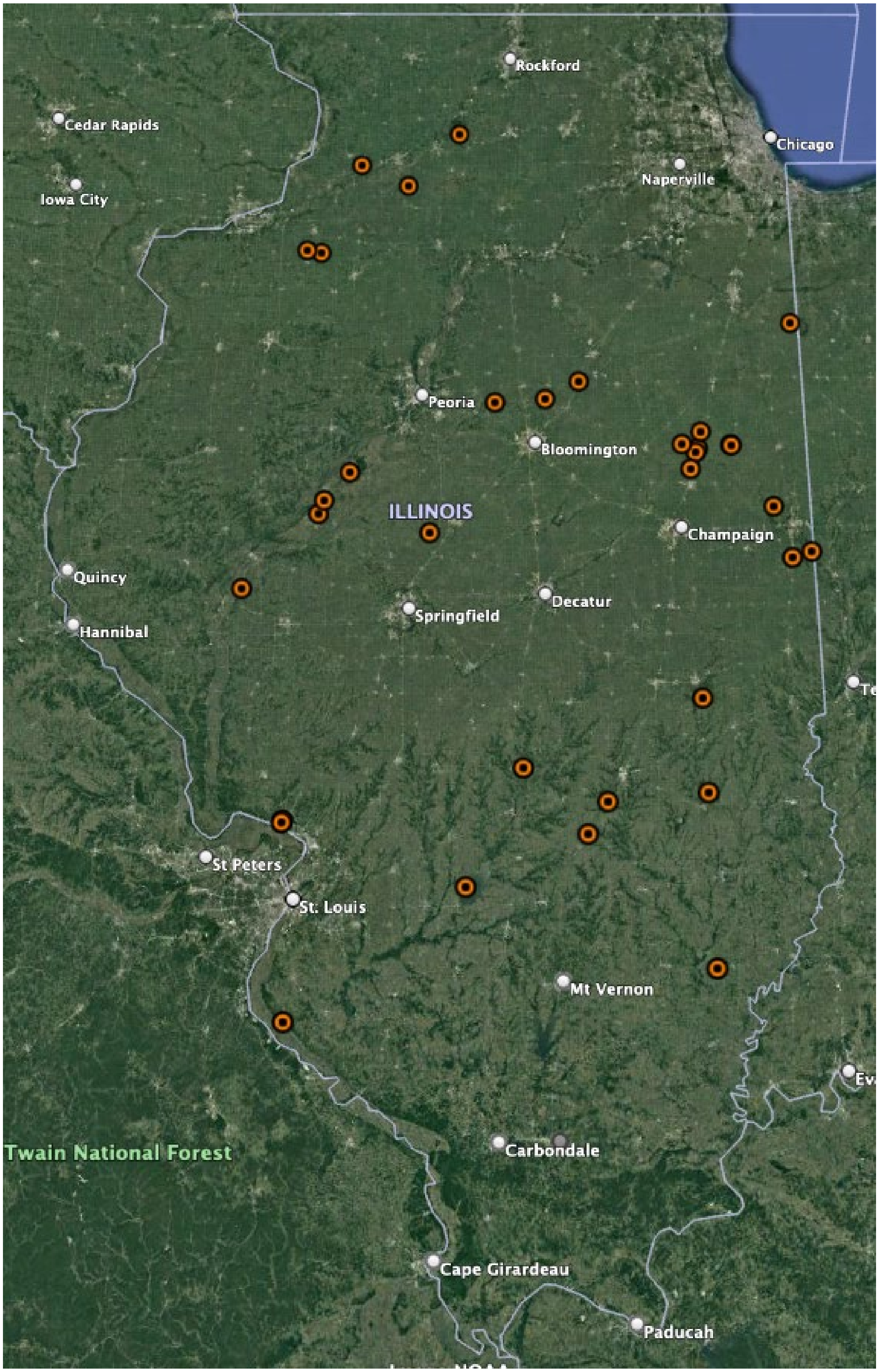


Figure 2. A satellite image of the clifftop prairie sampled at John M. Olin Nature Preserve. Points along the sampling transect are shown in blue (Olin1 – Olin6). These points represent the locations where belt transect floral quantification was conducted.

Figure 3. A depiction of a sampling site. The extent of the habitat is depicted as a blue polygon, the central red line shows the sampling transect, the bee netting area is depicted as the orange cloud flanking the central transect, and floral quantification transects are shown as green rectangles perpendicular to the central transect.

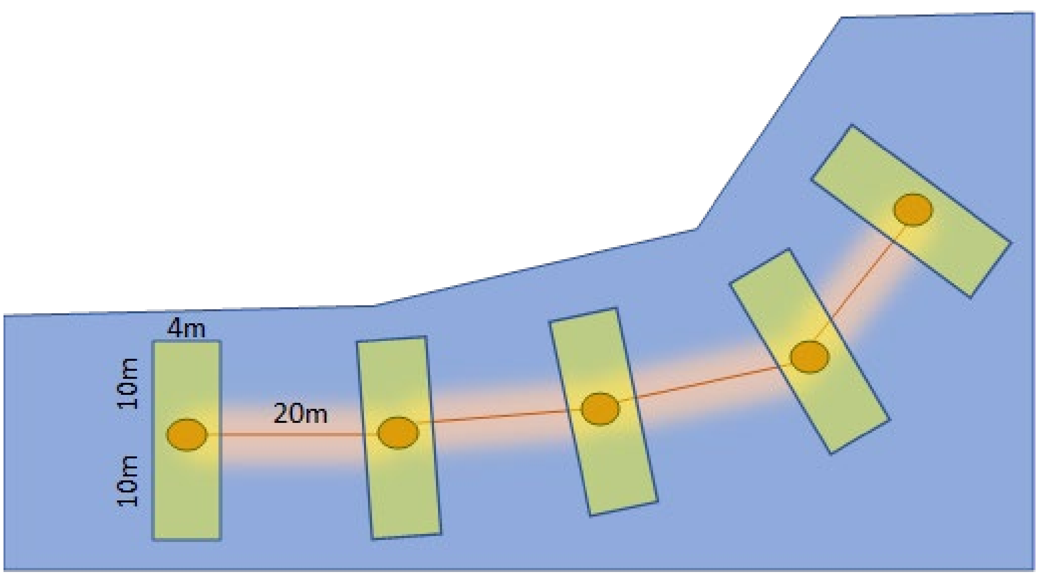
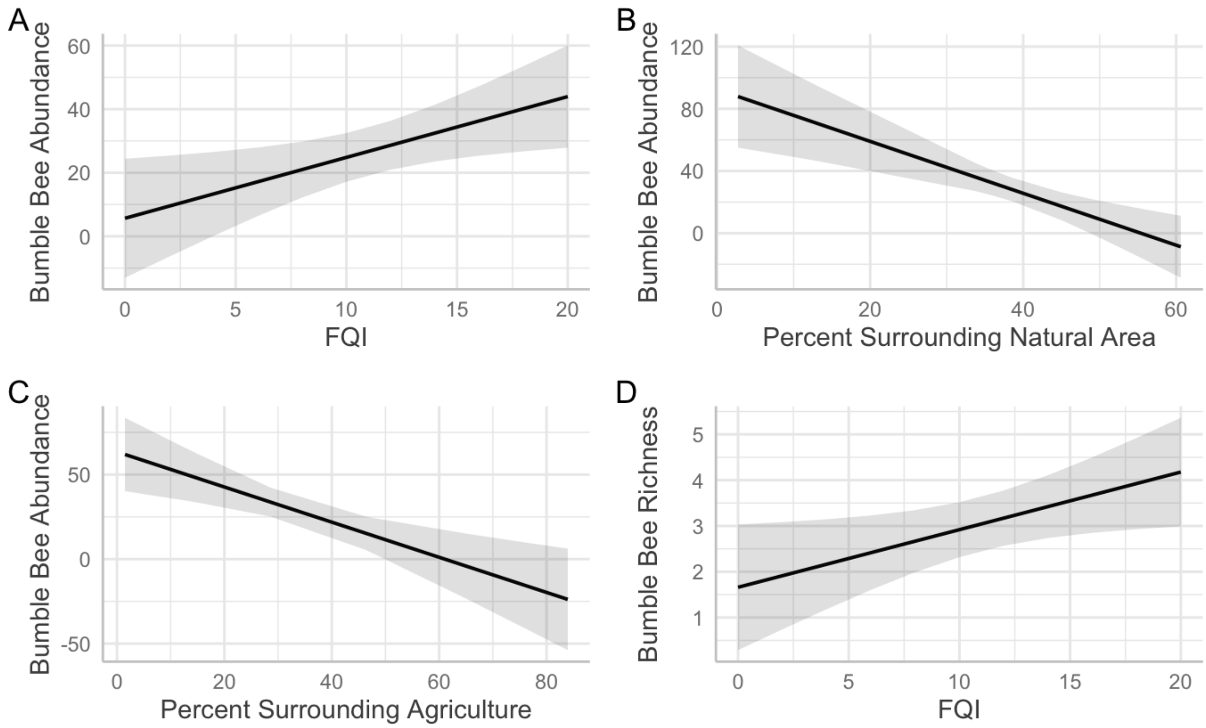


Figure 4. A photo of bumble bee netting and plant quantification at Fults Hill Prairie (Monroe County), in June of 2022.

Figure 5. A screenshot of land-use geospatial analysis for Sam Parr State Park generated using ArcGIS. A 1500m radius buffer representing common bumble bee foraging range is depicted as an opaque circle surrounding the central sampling point.

Figure 6. Visual depictions of the marginal fixed effects in bumble bee abundance and richness models. Plots A-C correspond to the marginal fixed effects in the bumble bee abundance model (FQI, percent surrounding natural area, and percent surrounding agriculture, respectively). Plot D corresponds to the only marginal fixed effect in the bumble bee richness model, FQI. 95% confidence intervals are shown in gray surrounding each regression line.



Project Timeline:

	2018				**2019**							
Obj.	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1. Investigate bumble bee distribution												
2. Develop bumble bee species list (compare to historical data)												
3. Establish monitoring program												
4. Provide management recommendations for site manager												
5. Annual Report												

	2019 (cont)				**2020**							
Obj.	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug

1. Investigate bumble bee distribution												
2. Develop bumble bee species list (compare to historical data)												
3. Establish monitoring program												
4. Provide management recommendations for site managers												
5. Annual Report												

	2020 (cont)				**2021**							
Obj.	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1. Investigate bumble bee distribution												
2. Develop bumble bee species list (compare to historical data)												
3. Establish monitoring program												
4. Provide management recommendations for site manager												
5. Annual Report												
6. Final Report and turn in deliverables (moved to 2022)												

	2021 (cont)				2022								
Obj.	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1. Investigate bumble bee distribution													
2. Develop bumble bee species list (compare to historical data)													
3. Establish monitoring program – w/increased focus on establishing long-term protocol for identified areas of concern													
4. Provide management recommendations for site managers													
5. Annual Report (and other reports)													
6. Final Report and turn in deliverables													

	2022 (cont)				2023								
Obj.	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1. Investigate bumble bee distribution													
2. Develop bumble bee species list (compare to historical data)													
3. Establish monitoring program – w/increased focus on establishing long-term protocol for identified areas of concern													
4. Provide management recommendations for site managers													
5. Annual Report (and other reports)													
6. Final Report and turn in deliverables													