Examining effects of site level and landscape scale factors on butterfly communities in greenspaces across a rural-urban gradient

Submitted by
Nicholas S. Barba

Bachelor of Science in Environmental Sciences (Sustainability & Natural Resource Management)

In partial fulfillment of the
requirement to graduate from
The Honors College

Mentor: Dr. Mary Jamieson, Professor of Biology
Department of Biological Sciences
Oakland University

3 December 2020

Abstract

Examining effects of site level and landscape scale factors on butterfly communities in greenspaces across a rural-urban gradient

Nicholas S. Barba

Adviser: Mary Jamieson, Ph.D.

Insect communities around the world are facing threats from increasing human land-use, including urbanization and agricultural intensification. Habitat degradation has greatly impacted invertebrate pollinators, and butterfly species are no exception. Butterflies are especially sensitive to environmental change, most notably in the larval stage, and often serve as indicator species of ecosystems as a result. In order to help conserve butterfly communities in urban environments, this study aimed to examine how anthropogenic land-use affects butterfly abundance and diversity as well as their interactions with floral resources. To accomplish this, I surveyed butterflies and floral resources at twelve sites (six parks and six farms) in the metro-Detroit area. Then, I examined how several environmental attributes at the local and landscape scale influenced butterfly assemblages at these sites. Park sites supported higher butterfly diversity than farm sites. In addition, butterfly richness increased with greater urbanization, which may be explained by a higher concentration of floral resources within a generally more inhospitable urban matrix. Larger sites supported more larval specialists, whereas a greater amount of edge habitat was associated with more larval generalists. Finally, high native plant species richness positively influenced butterfly diversity. These findings indicate that butterfly conservation efforts in urban areas should focus on enlarging green spaces and supporting high-quality habitat edge with diverse native plant resources as well as increasing the abundance of plant resources that support larval specialist species.

Introduction

Butterflies are just one of the many insect groups that have undergone major declines globally in the last few decades (Ricketts et al. 2008, Van Dyck et al. 2009, Hallmann et al. 2017, Lister & Garcia 2018). Human activities, such as habitat destruction and anthropogenic climate change, have been identified as likely drivers of worldwide insect declines (Van Dyck et al. 2009, Lister & Garcia 2018, Winfree et al. 2011, Haddad et al. 2015, Sánchez-Bayo & Wyckhuys 2019), and losses in insect biodiversity have troubling implications for the many ecosystem services that they provide, including nutrient cycling, pest control, and, most relevant to this study, pollination (Kremen et al. 2002, Hartley & Jones 2008, Keitt 2009, Gallai et al. 2009, Haddad et al. 2015, Raj 2017). As a result, insect conservation efforts have come to the forefront of scientific research in recent years, as well as in media coverage.

Invertebrate pollinator species have not been excluded from this so-called "ecological armageddon" of insects (Potts et al. 2010, van Swaay et al. 2006, VanEngelsdorp et al. 2008, National Research Council 2007); one report even argued that approximately 40 percent of invertebrate pollinators face extinction across the globe (IPBES 2016). This has caused concern, considering the beneficial role pollinators play within ecosystems. Since animals pollinate 87% of the world's wild plants, disruptions in pollinator communities could cause major plant species and biomass loss (Winfree et al. 2011, Potts et al. 2010, Traveset et al. 2017). In addition, pollinators greatly contribute to food production. An estimated 35 percent of global food production volume is dependent on the pollination of crops, valuing at $577 billion per year (Klein et al. 2007, IBPES 2016). That 35 percent includes some of our most nutritious foods, like fruits and vegetables, which contain essential nutrients and vitamins for the human diet (Eilers et al. 2011). While pollinator-dependent crops made up approximately 9.5% of total agricultural

output in 2005, they accounted for 70% of crops used directly for human consumption (Gallai et al. 2009, Klein et al. 2007). Human food production could undergo major changes as pollinator populations decrease more and more, causing nutritional deficiencies and food shortages. In order to compensate for the loss of animal-pollinated crops, agricultural industries may have to increase cultivated land at a rate several times higher than what is lost to pollinator declines, disproportionately harming developing countries (Aizen et al. 2009).

Bee pollinators like the European Honeybee (*Apis mellifera*) have gained widespread media attention in recent years as their populations have reached alarming rates of decline, but other pollinator species are not as prevalent in the public eye. *Lepidoptera* species, however, make up an interesting order of invertebrate pollinators also facing threats to their abundance. Moths and butterflies are a diverse group of insects with aesthetic and ecological value. While bees have been called more "important" pollinators, as they more effectively pick up and deposit pollen using thicker proboscises, butterflies and moths have been shown to visit flowers more frequently (Fenster et al. 2004, Ne'eman et al. 2010, Barrios-O'Neill et al. 2016, Rader et al. 2016). Some flower species have adapted to be more efficiently pollinated by *Lepidoptera* (Moré et al. 2007, Funamoto 2019), elevating their status as beneficial pollinators. *Mandevilla tenuifolia*, a tropical flowering vine, has even been shown to be solely pollinated by butterflies (de Araújo et al. 2014). In addition, non-bee pollinators like butterflies and moths have been shown to offer unique benefits to crop production, including increased fruit set and nocturnal pollination (Cutler et al. 2012, Brittain et al. 2013, Rader et al. 2016).

Lepidoptera species have also shown to have beneficial effects on ecosystem services other than pollination. *Lepidoptera* act as a major food source for many animals, like birds, small mammals, and other insects (Finkbeiner et al. 2012, Mebs et al. 2017, Rojas et al. 2017,

Hermann et al. 2019), and have also been shown to actively participate in nutrient cycling (Frost & Hunter 2004, Kaukonen et al. 2013, McTavish et al. 2019). Declines in *Lepidoptera* populations, therefore, could cause detrimental trophic cascades and disrupt nutrient availability, affecting predator species and decreasing ecosystem stability (vanBergen et al. 2006, Haddad et al. 2009, Narango et al. 2017, Seibold et al. 2019). Evidence also supports that butterflies act as umbrella species of their habitats, due to their short lifespan and rapid response to environmental change (Thomas et al. 2004, van Swaay & Warren 2006, Spitzer et al. 2009, Krauss et al. 2010). Without butterflies, significant threats to ecosystem health may go unnoticed. On a larger scale, butterfly species have been used to study the significance of global environmental change that has provided implications for approaching mass extinction events (Thomas et al. 2004, Settele et al. 2008, Breed et al. 2013).

Increasing urbanization poses a threat to *Lepidoptera* communities and the ecosystem services they provide. From 1900 to 2000, urban area in the United States increased from approximately 10,800 km^2 to 157,000 km^2 and is expected to triple by 2050 (Klein Goldewijk et al. 2010, Center for Sustainable Systems 2019). Land-use change, including urbanization and agricultural intensification, as well as subsequent habitat fragmentation, has had a negative impact on the species diversity and abundance of pollinators worldwide (Warren et al. 2001, Winfree et al. 2011, Ricketts et al. 2008, Van Dyck et al. 2009, Seibold et al. 2019). Urbanization degrades pollinator habitat quality by decreasing plant biomass and habitat patch size, as well as increasing the space between patches (Chacoff & Aizen 2006, Ricketts et al. 2008, Potts et al. 2010, Santos et al. 2018, Kurylo et al. 2020). As urban areas are likely to have more severe habitat fragmentation than natural areas (more and farther habitat patches), butterfly metapopulations are more at risk of extinction and lack of recolonization (Hanski 2011, Haddad

et al. 2015). Butterfly habitats are more likely to support diverse and abundant butterfly communities if habitat patches are larger, closer together, and more connected (Hill et al. 1996, Tewksbury et al. 2002, Öckinger & Smith 2007, Brückmann et al. 2011, Haddad et al. 2015), in which patches of low butterfly abundance can be "recharged" by immigration from more stable patches.

The impacts of land-use intensification on butterfly communities can be countered by improvements in patch quality, namely through the increase in abundance and richness of native floral resources (Cusser & Goodell 2013, Burghardt et al. 2009, Narango et al. 2017, Ries et al. 2001, Solis-Gabriel et al. 2017, Habel et al. 2019). Butterfly habitat patches must consist of diverse plant resources to support stable populations. While adult butterflies are mostly generalist feeders, meaning they nectar on many species of flowers, those in larval stages are often specialist, feeding upon a small specific set of plant species (Swengel 2003). The Monarch caterpillar (*Danaus plexippus*) is a famous example of this, having adapted to feed solely on Milkweed (*Asclepias*) plants, which are toxic to most other herbivores (Pleasants & Oberhauser 2013, Mebs et al. 2017). If a caterpillar's restricted food resources are depleted, they will likely die off (Pleasants & Oberhauser 2013, Haber et al. 2016), and so a diverse set of plant resources should support a diverse community of specialist caterpillars. This is well represented in the case of the Karner Blue butterfly (*Lycaeides melissa samuelis*), a federally endangered species that became dangerously low in population size nationwide with the degradation of oak savanna ecosystems and subsequently its sole host plant *Lupinus perennis*, or Wild Lupine (Michigan Department of Natural Resources 2010).

Many studies have suggested that diverse plant communities be made up of native plants in order to promote biodiversity (Burghardt et al. 2009, Narango et al. 2017, Ries et al. 2001,

Solis-Gabriel et al. 2017). Exotic plant species are more likely to disrupt ecosystems through relatively easy invasion and rapid spread (Gioria & Osborne 2014). Established butterfly species, especially larval specialists, are not equipped to utilize new plant resources, and, though more successful than specialists (Warren et al. 2001, Cusser & Goodell 2013), even generalist larvae have been shown to have difficulty consuming exotic plant mass (Tallamy et al. 2010). While adult butterflies can easily nectar on exotic flowers (Richardson et al. 2000, Staab et al. 2020), thereby increasing non-native plant populations through pollination, most butterfly larvae cannot easily use exotic plant bodies as hosts. As a result, the populations of butterfly larvae can decrease, as well as the populations of their predators, like birds; the introduction of exotic plants can produce bottom-up effects that disrupt whole ecosystem stability (Flanders et al. 2006, Burghardt et al. 2009, Narango et al. 2017, Sirami et al. 2019). In addition, invasive exotic plant species take growing space and resources from native plants, decreasing native plant populations (Barnett et al. 2016, Gioria & Osborne 2014). Exotic species becoming dominant will decrease species evenness, or relative abundance, of a plant community (Flanders et al. 2006). Since diversity in vegetation resources is beneficial for butterfly population stability, invasive exotic species are especially detrimental to butterfly communities (Potts et al. 2003, Ebeling et al. 2008), though a few studies have shown ecosystem benefits to exotic plant diversity, especially when kept at low limits (Frankie et al. 2019, Staab et al. 2020, Salisbury et al. 2015).

Sufficient vegetation availability is important for non-larval butterfly growth stages as well (Haddad et al. 2001, Aguirre-Gutiérrez et al. 2017, Konvicka & Kadlec 2011). Especially in colder climates, hibernation space in trees and shrubs are vital for overwintering, or non-migratory, butterfly species (USDA Natural Resources Conservation Service 2000, Kurylo et al. 2020). Dispersal distances of butterflies have been shown to decrease significantly in

inhospitable matrices, especially in species with already low dispersal ability (Baguette et al. 2003, Nowicki et al. 2014). Therefore, a diverse vegetation structure may become increasingly necessary to support stable butterfly populations in urban habitat patches, especially those with overwintering species of low dispersal ability (Hanspach et al. 2015, Habel et al. 2016).

The biological and ecological traits of butterflies, like diet breadth and dispersal ability, vary widely among different species (Bukovinszky et al. 2005, Thomas 2005, Brito et al. 2014), and these varying traits produce different responses to changes in land-use (Warren et al. 2001, Gámez-Virués et al. 2015, Swengel et al. 2011, Eskildsen et al. 2015). Larval specialists, for example, have exhibited less ability to survive in the face of environmental change (Beismeijer et al. 2006, Krauss et al. 2010, Filz et al. 2013, Brückmann et al. 2011, Swengel et al. 2011, Winfree et al. 2011, Brito et al. 2014); their floral hosts are limited, and they are unable to quickly adapt to feed on a new plant species if their current one is heavily reduced in biomass or removed entirely from the local ecosystem (Schweiger et al. 2008). As a result, specialist species often follow a resource concentration model, in which greater abundances of specialist species will be found in larger patch sizes because they offer more a stable food source (Steffan-Dewenter & Tscharntke 2000, Hämback et al. 2007, Brückmann et al. 2010). In general, habitat degradation could cause significant decreases in the populations of unique specialist butterfly species (or even cause their extinction), decreasing butterfly diversity in natural and urban ecosystems (Brito et al. 2014, Brückmann et al. 2010, Habel et al. 2019).

The distribution of other functional traits in butterfly communities have also been shown to change in the face of urbanization and agricultural intensification. Resulting landscape simplification decreases functional trait diversity in butterfly communities, threatening population stability (Eskildsen et al. 2015, Perovic et al. 2015). Traits often related to generalist

species, like greater wing length, greater voltinism (multiple generations per year), and longer flight period, are usually selected for as land-use is intensified, as they have a greater ability to recolonize frequently disturbed habitats (Beismeijer et al. 2006, Börschig et al. 2013, Brito et al. 2014, Gámez-Virués et al. 2015). Interestingly, greater density of resources at habitat edges has had varying effects on functional trait diversity of butterfly communities (Kuussaari et al. 2007, Perovic et al. 2015, Filgueiras et al. 2016, Ries & Debinsky 2001), though habitat specialists may benefit if edges have a high abundance of their preferred plant resources (Perovic et al. 2015, Filgueiras et al. 2016).

Due to the growing concerns over butterfly community stability in rapidly expanding urban areas, I conducted a study to examine how environmental attributes influence butterfly community metrics across twelve greenspaces in the metro-Detroit area of southeastern Michigan. The aim of this study was to inform butterfly conservation. Specifically, I evaluated effects of landscape scale attributes including urbanization and habitat fragmentation (edge density and patch connectivity) in addition to local site level factors such as habitat type, floral resource availability, and habitat size. This project addressed three key objectives:

(1) to characterize key differences between habitat types (parks and farms) and to determine how these habitat types differ in floral resource availability and butterfly community metrics, such as butterfly abundance, richness, or diversity, and foraging activity, and to compare these findings with known trends in butterfly diversity of the tri-county region sourced from the citizen science database “iNaturalist”

(2) to examine how urbanization and habitat fragmentation affect butterfly communities,

(3) and to assess the influence of native plant abundance and richness on butterfly communities.

I hypothesized that park sites would have less urbanization and habitat fragmentation than farm sites, contributing to a greater butterfly abundance, species richness, diversity, and foraging activity. Further, I hypothesized that butterfly richness and diversity would decrease as urbanization and patch connectivity increases. Finally, I predicted that sites with greater native plant bloom cover and species richness would support more abundant and diverse butterfly communities in addition to larval specialists.

Methodology

Survey Site Characteristics

Study sites consisted of 12 greenspaces in southeast Michigan located in Wayne, Macomb, and Oakland counties (Figure 1). Greenspaces were characterized by habitat type, as either farms or parks. Each farm and park site were spatially paired; a paired farm and park site were no more than 20 miles from each other. Farms consisted of community gardens with a variety of crop and wildflower plantings, as well as weedy flowers and plants; parks, on the other hand, were made up of inner-city parks and larger Metroparks that contained a variety of wildflowers and weedy plants. Each site category had a variety of native and nonnative plant species. Total site sizes were sourced from a related study (Tawril 2020). While a minimum of 125 m^2 (0.031 ac) of each site was surveyed, farms ranged in size from three to 27 acres (mean= 8.13, SD=9.32), and parks ranged from 26.8 to 4461 acres (mean=1125.97, SD=1706.72). Site attributes and descriptions can be found in Appendix Table A.1.

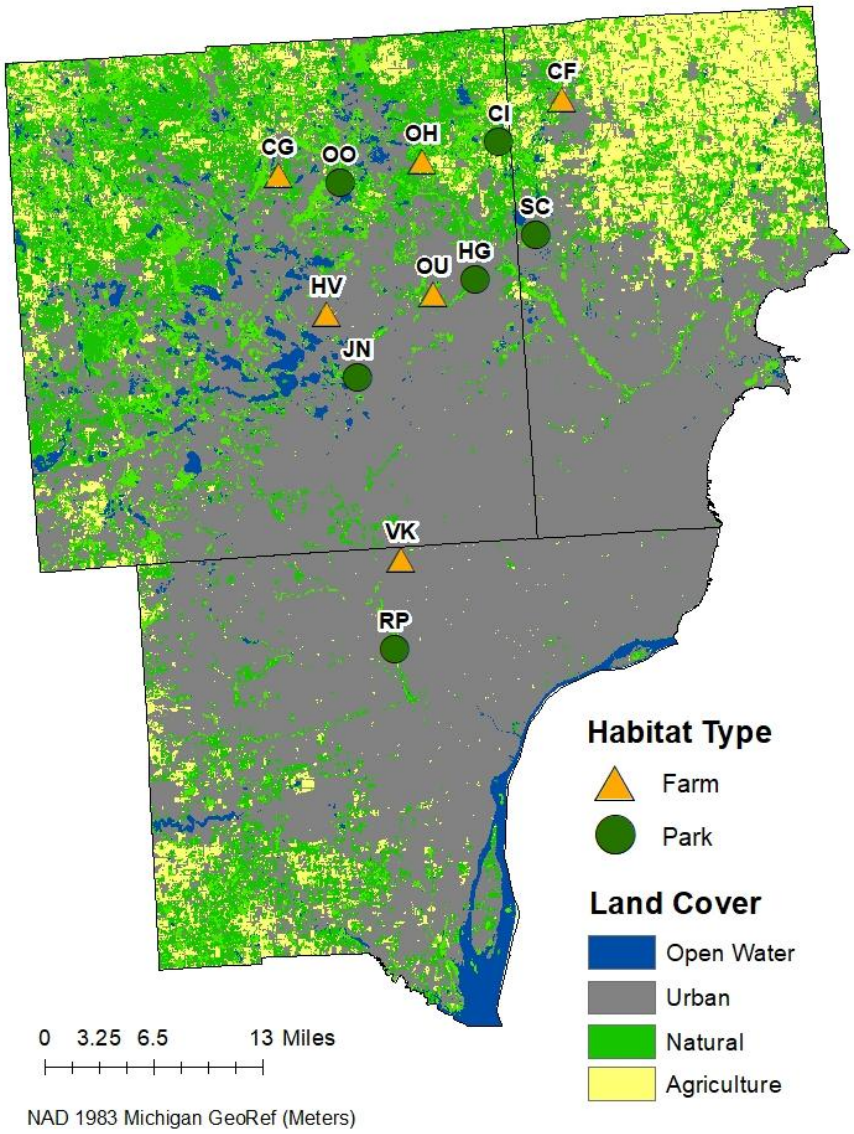


Figure 1: A map portraying the locations of each survey site (names for codes found in the Appendices, Table A.1), showing habitat types as well as land cover of Oakland, Wayne, and Macomb counties. Created in ArcGIS 10.7.1.

Site Level and Landscape Scale Environmental Characterization

I completed environmental attribute characterizations using ArcGIS 10.7.1. All data sources and site locations were projected into the NAD_1983_Michigan_GeoRef_Meters coordinate system in ArcMap. Urbanization was estimated as the proportion impervious surface calculated inside a 1500m buffer using the National Land Cover Database (NLCD) 2016 data: Percent Developed Imperviousness [CONUS] (Dewitz 2019; Figure 2).

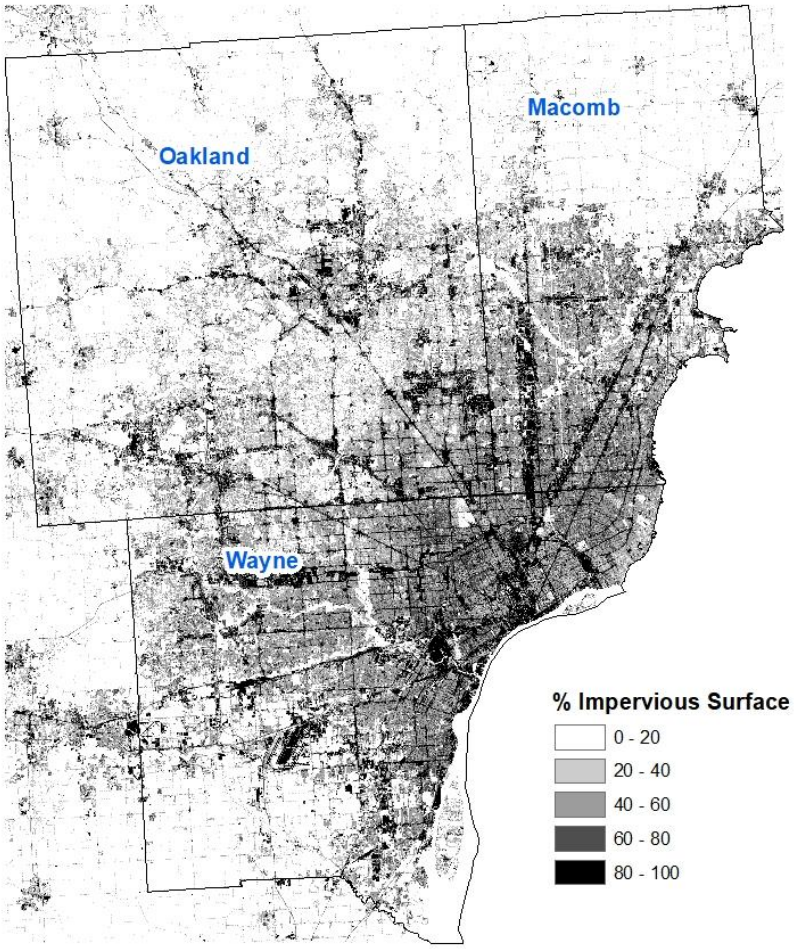


Figure 2: A map portraying the percent impervious surface of Wayne, Macomb, and Oakland counties. Created in ArcGIS 10.7.1.

In addition, to measure habitat fragmentation inside 500m, 1000m, and 1500m site buffers, I sourced FRAGSTATS version four (McGarigal et al. 2012) landscape metrics- specifically edge density and mean connectivity- from a related study (Tawril 2020). Edge density is the sum of habitat edge within a buffer. Connectivity (CONNECT) is the percentage of possible joinings between patches of the same type that actually exist in a site buffer (as in Martin et al. 2016). CONNECT and edge density data for all buffers was used to analyze differences between habitat types. Only 1500m buffer CONNECT and edge density variables were used as predictors for butterfly community characteristics and foraging activity data.

As part of a related study, floral resources at each site were characterized as total bloom cover and species richness (Tawril 2020). In order to obtain floral resource characteristics representative of an entire habitat, ten ten-by-two meter transects were haphazardly placed throughout each site on each survey day and percentage bloom cover of each flowering species was estimated within them. In addition, overall plant richness was calculated using a sitewide census of all flowering species present each survey month, and the number of native and exotic flowering species at each site was recorded as well. From these data, I calculated the average bloom cover and plant richness over August and September 2019 and the average native proportions of bloom cover and plant richness for each site.

Butterfly Survey and Identification Methods

Over August and September of 2019, I conducted butterfly surveys across sites, assisted by a team of Oakland University students. All surveys were conducted on sunny, warm days (>15.5 ℃) with low wind speeds (<3 m/s). We laid out five transects of 25 m^2 (5 x 5 m) to be surveyed at each site. During a five minute period at each transect, we observed butterflies and

moths with the goal of identifying each to species-level, recording those that landed on flowers as well as those that flew in and out of the transect without landing (deemed "flybys"). For those that visited flowers, the species of butterfly observed was recorded as well as the flower species it landed on and how many times it visited that flower species within a transect. We did not track individual butterfly organisms; individuals of the same species were grouped together into one observation per flower species within a transect. A maximum of five butterfly species visits per floral species per transect were recorded to encourage observations of less common butterflies. During each time period, we collected butterfly species for identification and educational purposes. While handling specimens during surveys and placing them in glassine envelopes, we paused the timer. Approximately 50 butterflies were collected over the survey weeks for identification, examination, and pinning for display. While in the field, butterfly observations for species not seen during survey periods (labelled "transect 0") were also recorded for site richness and diversity calculations. As sites were not surveyed the same number of times, I normalized observation data by survey effort- visitation and flyby counts were divided by the number of surveys at each site.

Characterizing Butterfly Community Metrics

To describe the butterfly communities at each survey site, I calculated several community-based metrics. As only a handful of butterflies observed were collected, and visitations recorded were tracked on a species-level and not an organism-level, site and species abundances were approximated based on the sum of visits and flybys recorded across all surveys. Site richness included the butterflies that could be identified to species level, as well as unidentifiable but unique observations; for example, while seven butterfly species were

identified at Charles Illsley, richness was recorded as nine due to the additional observations of a unique fritillary (subtribe *Argynnini*) and Clouded/Orange Sulphur (*Colias* species that often hybridize in Michigan). I calculated and rarefied Shannon Diversity in Rstudio 1.2.5042 using the "vegan: Community Ecology" package, v. 2.5-6 (Oksanen et al. 2019). Plant visitation richness was calculated using only the number of plant species visited by butterflies at each site, and the native and exotic proportion of this metric was also calculated.

To examine varying responses to environmental attributes based on the influence of functional traits, the butterfly functional groups of larval diet preference, wingspan, voltinism, and migratory status were also included in butterfly community calculations. I sourced larval diet preference and migratory status for each identified species from Scott (1986). A species' diet preference was deemed "specialist" if its larval hosts consisted of one family or several closely-related families and "generalist" if its larvae consumed the plant matter of two or more distantly-related families (Scott 1986). Migratory status was listed as either "nonmigratory" or "migratory". In addition, I sourced voltinism, or the number of generations per season, and wingspan from Daniels (2005). Wingspan was listed as the median of the range reported by Daniels, and voltinism was listed as "univoltine" if only one brood is produced per season and "multivoltine" if more than one brood is produced per season.

Interaction Maps and Specialization (H2)

In order to model plant-pollinator interactions at surveyed green spaces, plant-pollinator network maps were produced in Rstudio using the "bipartite" package (Dormann et al. 2009). A network map was created for each site, farms collectively, parks collectively, and all sites collectively using plant and butterfly species data, as well as for farms, parks, and all sites

collectively using plant and butterfly families data. I also used the bipartite package to calculate specialization (H2), a 0 to 1 value in which 1 indicates a network with the highest degree of specialization, or the greatest partitioning of floral resources by butterfly species within the network (Blüthgen et al. 2006).

Butterfly Community Comparison with "iNaturalist.org" Observations

Observations of *Lepidoptera* made in Oakland, Macomb, and Wayne counties from August 15, 2019 to September 23, 2019 (the dates in which we conducted the field research for this study) were downloaded from iNaturalist.org, an interactive website for users to report organism sightings and identify species for research purposes. All observations were used to count butterfly, moth, and total Lepidoptera observations for each county, but only research-grade observations (which have the same identifications from multiple users) were used to create iNaturalist county species lists. To compare county totals between the iNaturalist data and the data from this study, I standardized total observations from this study by county survey effort (the number of surveys performed across all sites in each county, in which Macomb was surveyed four times, Oakland was surveyed 29 times, and Wayne was surveyed five times).

Statistical and Graphical Analyses

Statistical analyses were performed in JMP® Pro 14.2.0 using the "Fit Model" tool (personality: Standard Least Squares, emphasis: Effect Leverage). This included an ANOVA analysis for differences in response variables between habitat types as well as regression plots for continuous relationships, such as in response to urbanization, habitat fragmentation metrics, and native plant abundance and richness. Relationships were considered significant if p, or Prob>|t|,

was less than 0.05. Studentized residuals were used to check the normality of residuals; after a continuous normal curve was fitted to the studentized residuals, I performed a Shapiro-Wilks test, and relationships were then deemed insignificant if Prob>W was less than 0.05 (residuals were not normally distributed).

I created bar graphs and linear regression plots in JMP Pro 14.2.0. Bar graphs were created using the average response variable of sites in each habitat type and the standard error for error bars. Linear regression plots included the R2 value, and site area was the only predictor variable logarithmically-transformed to more clearly display relationships to response variables. "★" in the upper or lower right corner of a graph indicates a significant relationship; otherwise, the trend was deemed insignificant.

Results

Landscape Characteristics Across Habitat Types

Parks generally had a greater total area than farms, but not significantly ($F_1 = 2.57$, $p = 0.140$), as well as a greater variability in size. Within the 1500m buffer, farm sites had an average of 36% (±0.38) impervious surface, while park sites had an average of 34% (±0.27) impervious surface. Edge density was generally higher in farms than parks- this difference was significant inside smaller buffers (at 500m: $F_1 = 6.11$, $p = 0.0331$, and 1000m: $F_1 = 5.33$, $p = 0.0436$), but not inside the 1500m buffer ($F_1 = 4.85$, $p = 0.0523$). Site area and connectivity in any buffer did not exhibit significant differences between habitat types.

Plant Richness & Bloom Cover Across Habitat Types

In a sitewide census, farms had an average plant richness of 37.3 (SD=±5.2), of which 17.8 (SD=±4.1) plant species were native and 19.5 (±5.3) were exotic. Parks averaged 27.3 (SD=±3.0) plant species, with 19.7 (SD=±2.9) native and 7.7 (SD=±1.1) exotic. Over August and September 2019, the proportion of native bloom cover was higher in parks than in farms (F_1 = 5.86, p = 0.0360); parks contained about 86% (SD=±8) native bloom cover in comparison to 55% (SD=±10) at farms (Figure 3). I found no significant difference between total bloom cover for the months of August and September between habitat types.

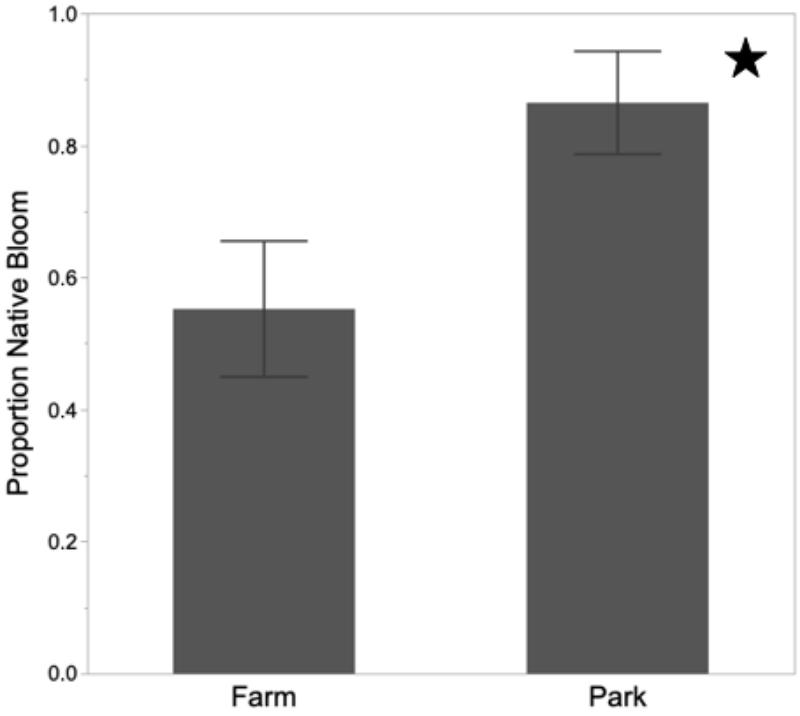


Figure 3: Average proportion native bloom over the full survey period for farm and park sites. F_1 = 5.86, p = 0.0360.

Summary of Butterfly Community Characteristics Across Sites

Across sites, we observed and identified a total of 25 butterfly species, with site level species richness ranging from 5 to 11 species (mean=8.58 SD=±1.88; Figure 4). We recorded 1078 butterfly floral visits and flybys across all sites and survey periods. The Cabbage White (*Pieris rapae*) was found at all 12 survey sites, while the Monarch (*Danaus plexippus*) was found at 11 and the Silver-Spotted Skipper (*Epargyreus clarus*) was found at ten. Additionally, we identified only one moth species - the hummingbird moth (*Macroglossum stellatarum*), observed at the Oakland University Student Organic Farm.

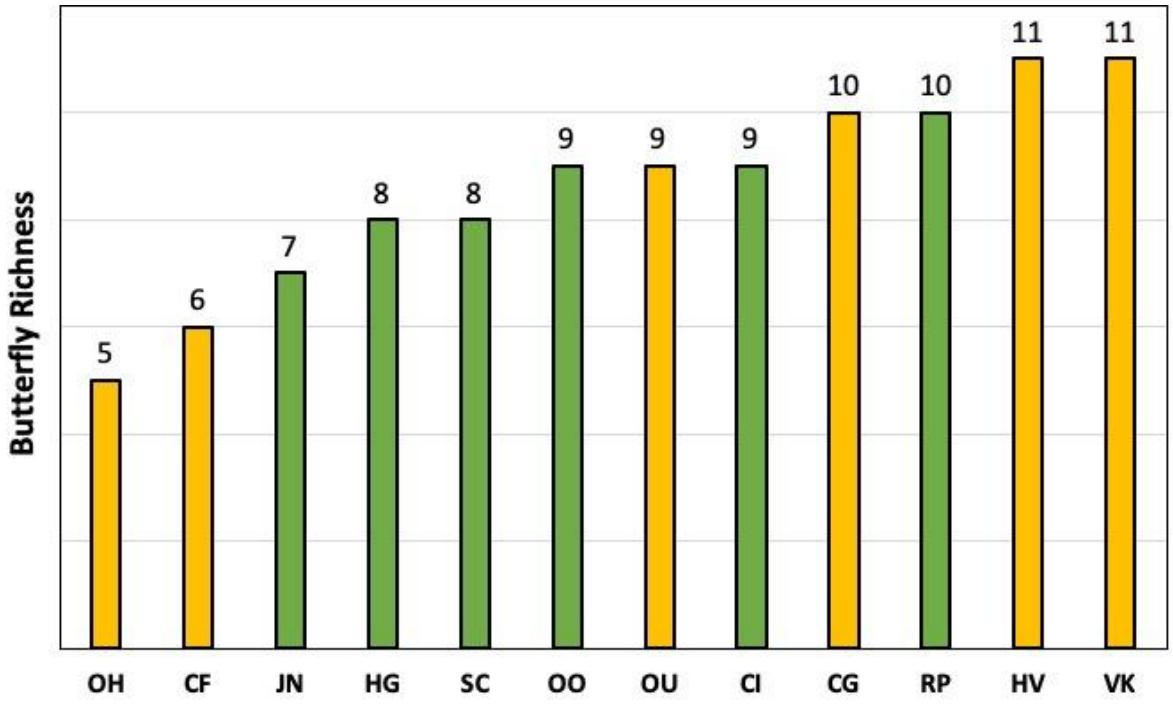


Figure 4: Butterfly species at each survey site. Green bars represent parks, while yellow bars represent farms. Site names represented by each acronym can be found in the Appendices in Table A.1.

The dominant butterfly family observed was Pieridae; Nymphalidae and Hesperiidae were also observed greatly. In addition, while many members of Hesperiidae were observed, we were not able to identify several species on-wing; species without confident identification were listed only as “Hesperiidae”. The most observed butterfly species was the Cabbage White (*Pieris*

rapae), followed by the Pearl Crescent (*Phyciodes tharos)* , and then the Monarch (*Danaus plexippus*; Figure 5).

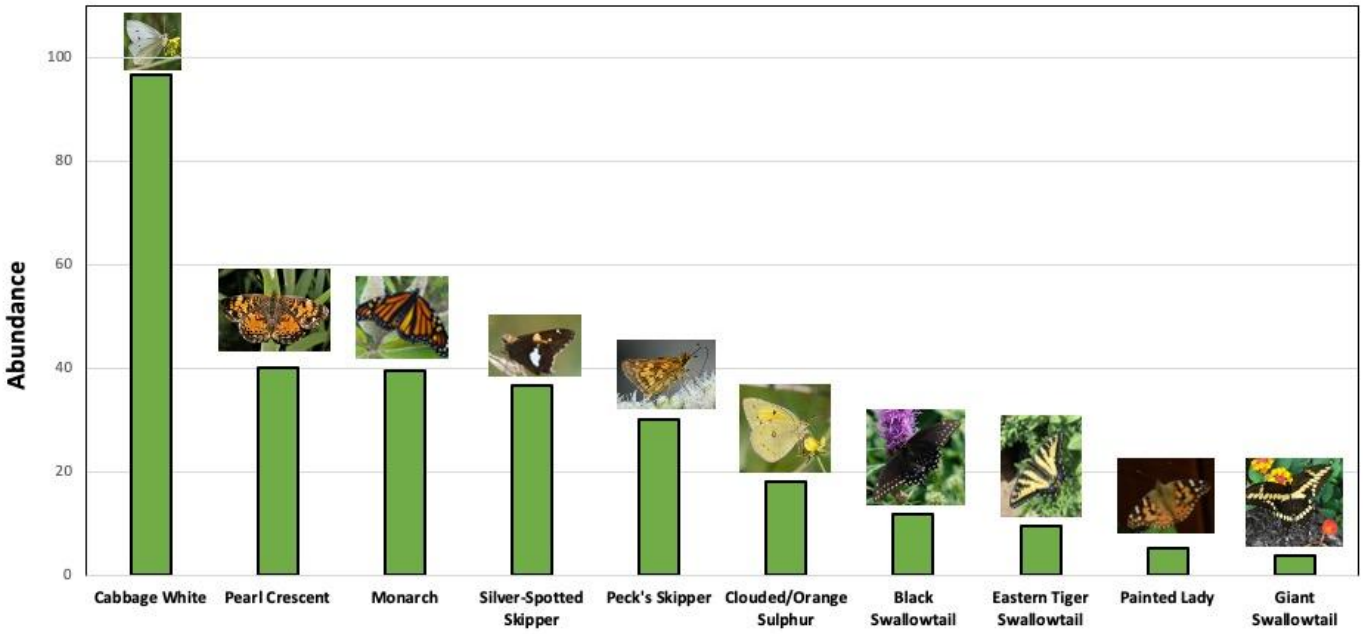


Figure 5: The ten most observed butterfly species across all sites and survey periods. Research-grade pictures sourced from inaturalist.org

Of the butterfly species identified, 13 were deemed larval generalists, and the other 11 larval specialists; both diet breadth groupings were found in similar abundances. In addition, 20 species produce multiple broods per season and were observed at about 40 times the rate as univoltine species. Only four species were considered completely migratory (*Vanessa atalanta, Vanessa cardui, Danaus plexippus, and Junonia coenia*); most butterflies observed were overwintering species. Butterfly wingspans ranged from 0.85 to five inches; the average wingspan of all observed butterflies was 2.14 inches. The smallest observed butterfly was the Least Skipper (*Ancyloxypha numitor*; 0.85in), and the largest was the Giant Swallowtail (*Papilio cresphontes*; 5in).

Butterfly Community Characteristics Across Habitat Types

After standardization by survey effort, farm sites averaged 31.9 (±5.4) total observations of butterflies, while parks averaged 23.6 (SD=±3.7); there was no significant difference in observations between habitat types. While farms had an average butterfly richness of 9.0 (±1.2), parks displayed a richness only slightly higher at 9.3 (SD=±0.3). Rarefied Shannon Diversity was significantly higher in parks (mean=8.09, SD=±0.34) than in farms (mean=6.07, SD=±0.56) ($F_1 = 9.41$, $p = 0.0119$; Figure 6).

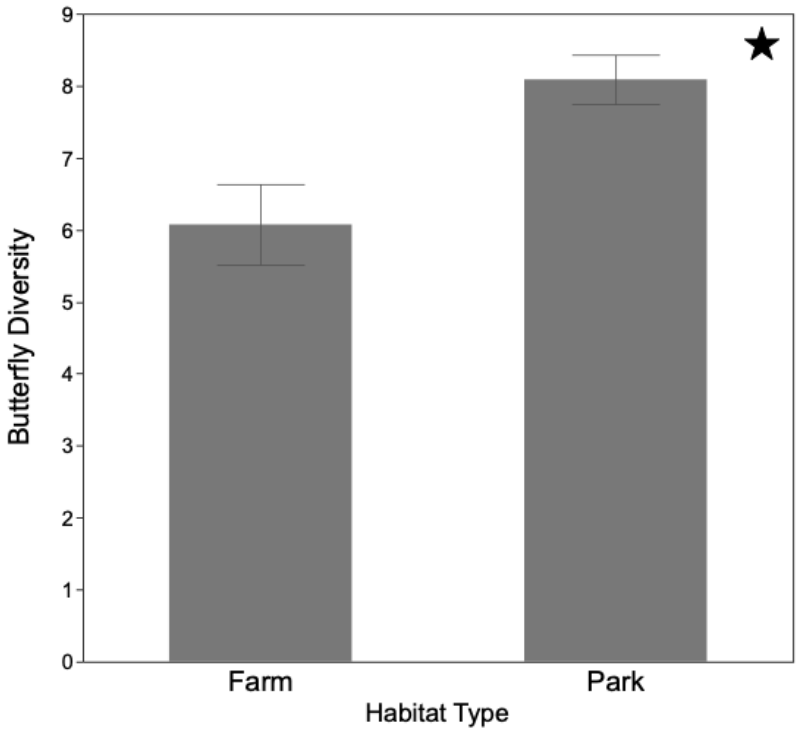


Figure 6: Average butterfly (Rarefied Shannon) diversity for farm and park sites. $F_1 = 9.41$, $p = 0.0119$.

There was no significant difference in total butterfly observations (abundance) between habitat types. Nymphalidae and Hesperiidae were the dominant butterfly families seen at parks, while Pieridae was observed most at farms. The top 3 observed butterfly species at parks were *Danaus plexippus, Pieris rapae, and Epargyreus clarus*. The top 3 at farms were *Pieris rapae,*

Phyciodes tharos, and Polites peckius. 7 species appear on the top 10 observed butterfly species list for both parks and farms (Table 1).

	Parks		Farms	
1.		***Danaus plexippus***		***Pieris rapae***
2.		***Pieris rapae***		***Phyciodes tharos***
3.		***Epargyreus clarus***		***Polites peckius***
4.		***Phyciodes tharos***		***Epargyreus clarus***
5.		***Polites peckius***		***Danaus plexippus***
6.		***Papilio glaucus***		***Colias spp***
7.		***Colias spp***		*Papilio polyxenes*
8.		*Papilio cresphontes*		***Papilio glaucus***
9.		*Ancyloxypha numitor*		*Cupido comyntas*
10.		*Vanessa cardui*		*Junonia coenia*

Table 1: Top 10 most observed butterflies at parks and farms. Bolded species appear on the top 10 lists for both habitat types. Research-grade pictures from inaturalist.org

Generalist butterfly species made up a greater proportion of observations at farms (F_1 = 6.72, p = 0.0268), while specialists made up a greater proportion at parks (F_1 = 6.72, p = 0.0268; Figure 7). The average observed butterfly wingspan was lower at farms, at 1.98 in (±0.13), than parks, at 2.35 in (±0.13). In addition, there was no significant difference between habitat types in the proportional abundances of migratory status and voltinism.

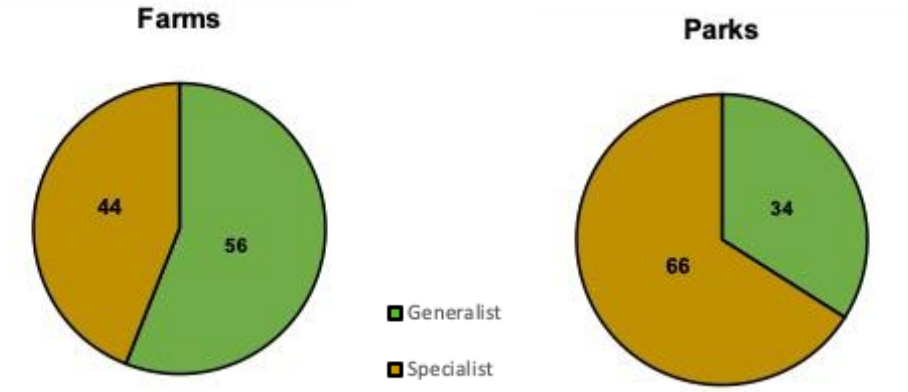


Figure 7: Average proportion (%) of observations consisting of specialist and generalist butterfly species at each habitat type. F_1 = 6.72, p = 0.0268.

Summary of Butterfly Foraging Activity Across Sites

We saw butterflies visiting floral hosts 970 times, among 59 flower species. The most visited plant species across all sites was Iron Weed (*Vernonia missurica*), followed by Canada Goldenrod (*Solidago canadensis*), and then Frost Aster (*Symphyotrichum pilosum*). Of the ten most visited plant species, seven were native wildflower species and three were exotic weeds (Figure 8). The most visited plant family was overwhelmingly Asteraceae (Figure 9).

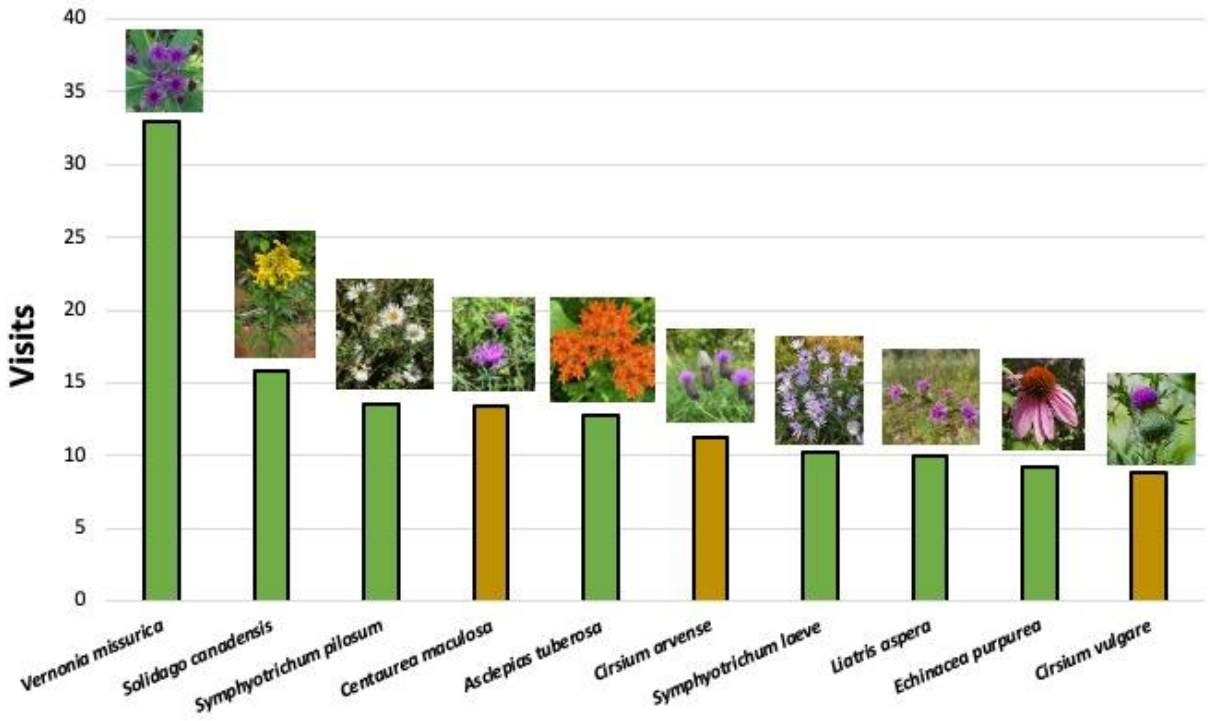


Figure 8: The ten most visited plant species across all sites and survey periods. Green bars represent native species, while brown bars represent exotic species. Research-grade pictures sourced from inaturalist.org.

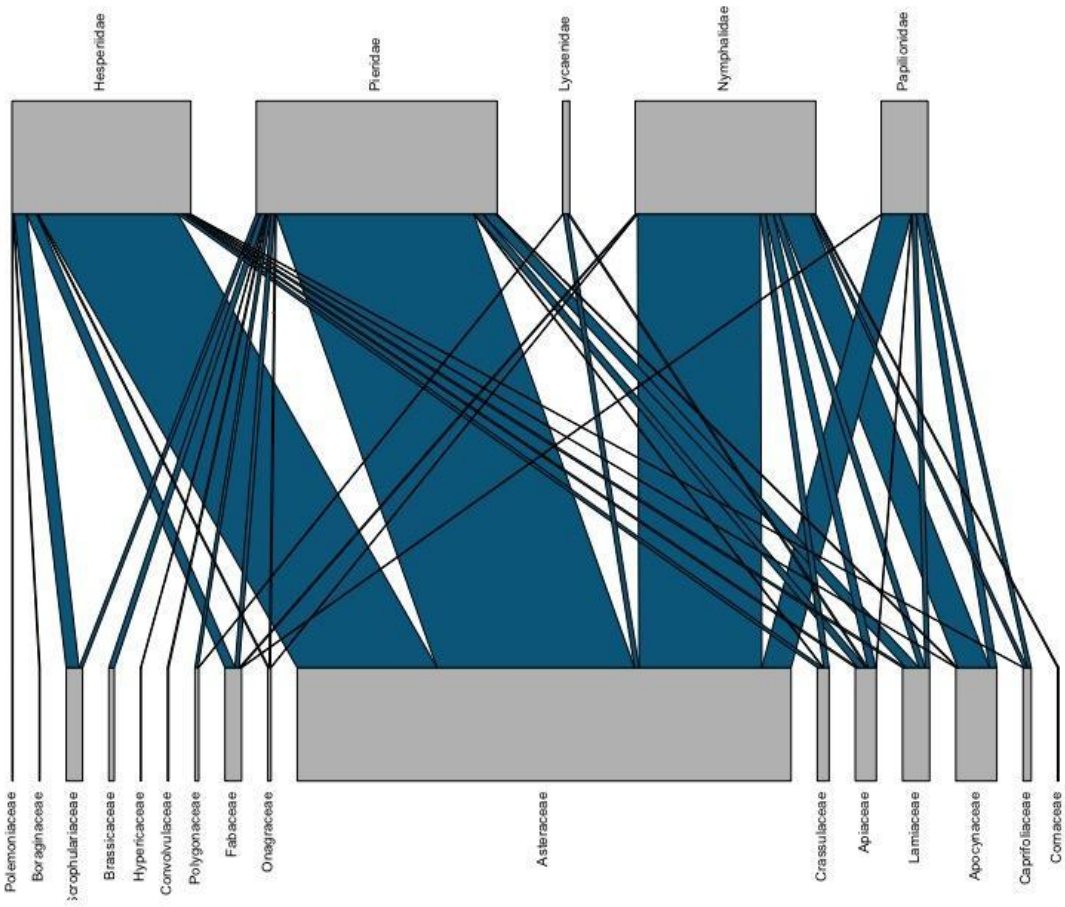


Figure 9: Plant-pollinator interaction map across all sites and survey periods. The top row contains butterfly families, while the bottom row contains plant families. Larger family boxes (gray) indicate greater abundances, while larger interaction pathways (blue) indicate a greater amount of interactions, or butterfly landings (visitations) on plants.

In a visitations by bloom cover analysis, Canada Thistle (*Cirsium arvense*) was the most visited plant per flower surface area, followed by Hoary Alyssum (*Berteroa incana*), and then Bull Thistle (*Cirsium vulgare*).

Native plants were visited at about two times the rate of exotic plants. Of the top ten visited plants overall, seven species were native wildflowers, including the top three, while only three were exotics (Figure 9). In the visitations by bloom cover analysis, however, exotics were visited at about three times the rate per flower surface area, and the top five plants visited per surface area were all exotics.

Butterfly Foraging Activity Across Habitat Types

I found no significant difference in total butterfly visits between habitat types. On average, butterflies visited 8.3 plant species at parks, while at farms, butterflies visited 14.2 plant species. The top three visited plant species by butterflies at parks were *Vernonia missurica*, *Solidago canadensis*, and *Cirsium vulgare*. The top three at farms were *Asclepias tuberosa*, *Symphyotrichum pilosum*, and *Cirsium arvense*. Only two species, *Centaurea maculosa* & *Rudbeckia hirta*, appear on the top 10 visited plant species list for both parks and farms (Table 2). Only two species were exotic in both the parks' and farms' top ten.

Of overall butterfly visits to flowers at farms, 58% were made to native plant species, compared to 81% at parks, and so a greater proportion of visits were to native plants at parks ($F_1 = 8.43$, $p = 0.0158$). Farms had a greater number of visits to exotic plants ($F_1 = 5.67$, $p = 0.0386$), despite no significant difference between total visitations. A greater number of exotic species were visited at farms when compared to parks ($F_1 = 6.22$, $p = 0.0318$).

	Parks		Farms	
1.		*Vernonia missurica* (N)		*Asclepias tuberosa* (N)
2.		*Solidago canadensis* (N)		*Symphyotrichum pilosum* (N)
3.		*Cirsium vulgare* (E)		*Cirsium arvense* (E)
4.		*Eupatorium maculatum* (N)		*Liatris aspera* (N)
5.		*Monarda fistulosa* (N)		***Centaurea maculosa*** (E)
6.		*Silphium integrifolium* (N)		*Symphyotrichum laeve* (N)
7.		***Centaurea maculosa*** (E)		*Echinacea purpurea* (N)
8.		*Solidago juncea* (N)		*Daucus carota* (N)
9.		*Asclepias syriaca* (N)		***Rudbeckia hirta*** (N)
10.		***Rudbeckia hirta*** (N)		*Symphyotrichum novae-angliae* (N)

Table 2: Top 10 most visited plants at parks and farms. Bolded species appear on the top 10 lists for both habitat types. (N) indicates a Michigan native species, while (E) indicates a species exotic to Michigan. Research-grade pictures from inaturalist.org

Butterflies visited ten plant families at parks and 14 plant families at farms. Asteraceae was the most visited plant family at both parks and farms (Figure 10). Parks often had higher specialization than farms, but not significantly ($F_1 = 3.29$, $p = 0.0999$).

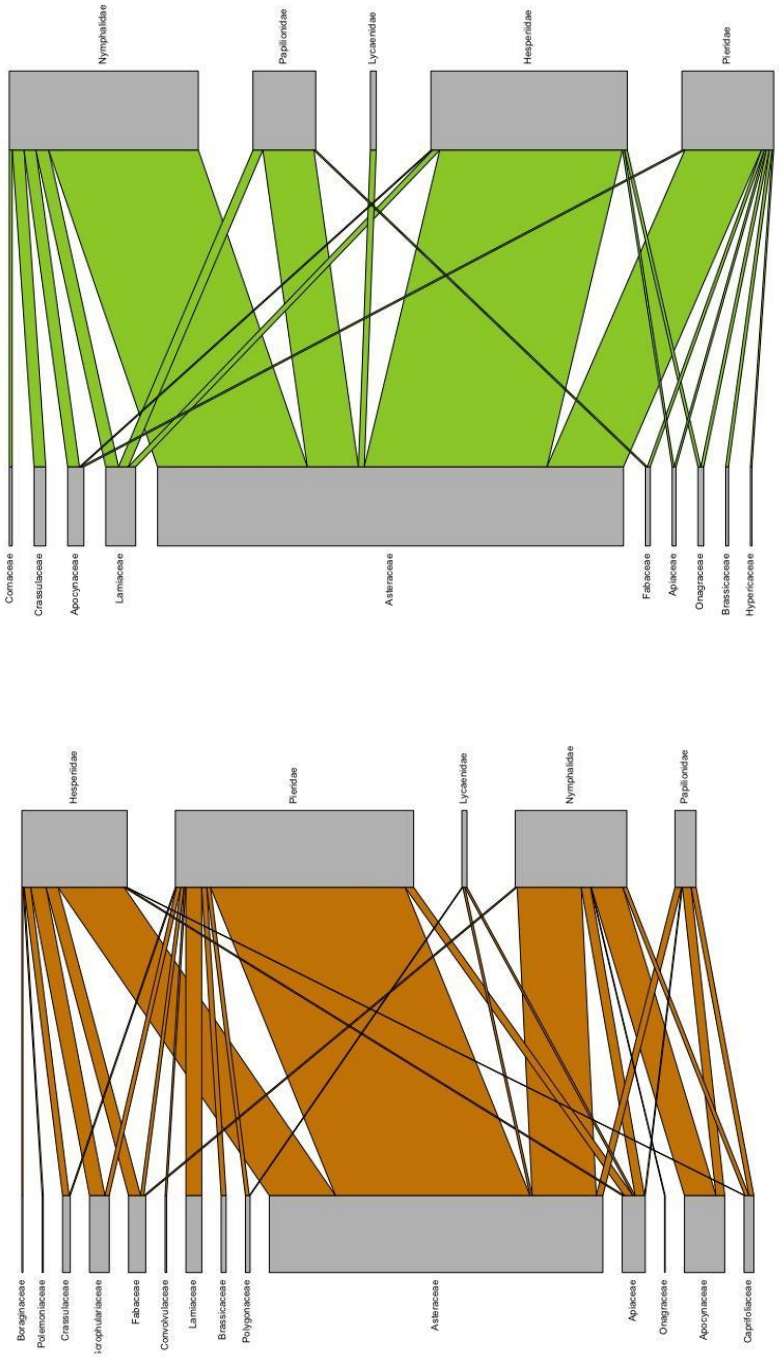


Figure 10: Plant-pollinator interactions maps for parks (green) and farms (tan).

Comparison with "iNaturalist.org" Butterfly Observations

Moths made up a greater proportion of Lepidoptera observations in iNaturalist than in this study's field work; among iNaturalist observations, more moths were sighted than butterflies in Macomb and Oakland counties, while in our field study, moths were sighted less than butterflies in Oakland county and not at all in Macomb and Wayne. iNaturalist and our field study both agreed that butterfly observations were greatest in Wayne County and lowest in Macomb County (Figure 11).

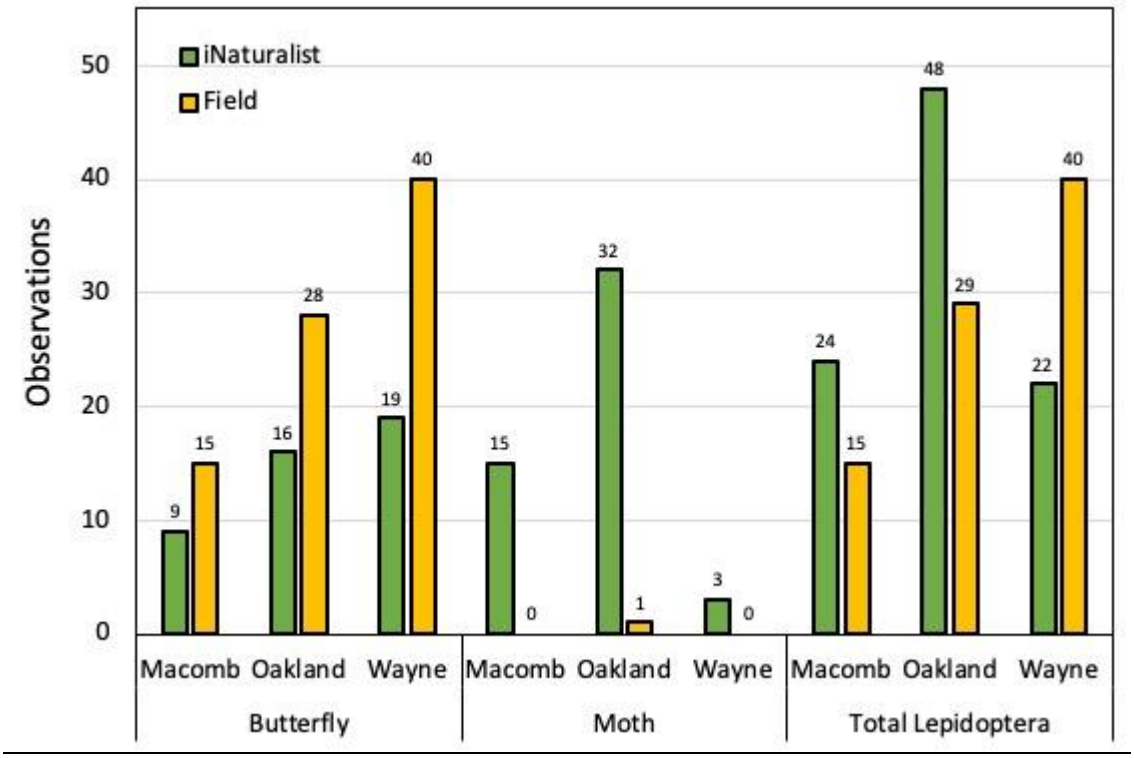


Figure 11: Observations of *Lepidoptera* for both iNaturalist sightings and this study's field surveys.

iNaturalist observers reported five butterfly species that we did not observe during our surveys (Table 3). In Wayne County, iNaturalist observers spotted the Common-Checkered Skipper (*Pyrgus communis*) twice, which was not observed in our field study. In Oakland County, three butterfly species not found in our study were spotted by iNaturalist members: the

Mourning Cloak (*Nymphalis antiopa*), Eastern Comma (*Polygonia comma*), and Question Mark (*Polygonia interrogationis*) butterflies. Finally, in Macomb County, iNaturalist observers identified one additional species, the Hackberry Emperor (*Asterocampa celtis*).

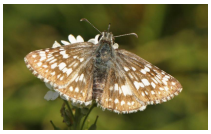
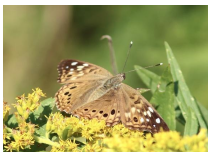
Picture	Common Name	Scientific Name	Observed County
	Common- Checkered Skipper	*Pyrgus communis*	Wayne
	Mourning Cloak	*Nymphalis antiopa*	Oakland
	Eastern Comma	*Polygonia comma*	Oakland
	Question Mark	*Polygonia interrogationis*	Oakland
	Hackberry Emperor	*Asterocampa celtis*	Macomb

Table 3: Butterfly species found in Wayne, Oakland, and Macomb counties during this study's survey months that were not sighted in this study's field surveys.

The average butterfly richness per county was 16.3 (SD=± 6.1) without iNaturalist observations and 19.0 (SD=±6.2) with iNaturalist observations. In both cases, county butterfly richness was highest in Oakland and lowest in Macomb (Figure 12). iNaturalist observations increased this study's Macomb and Oakland richness data by three and Wayne richness data by two.

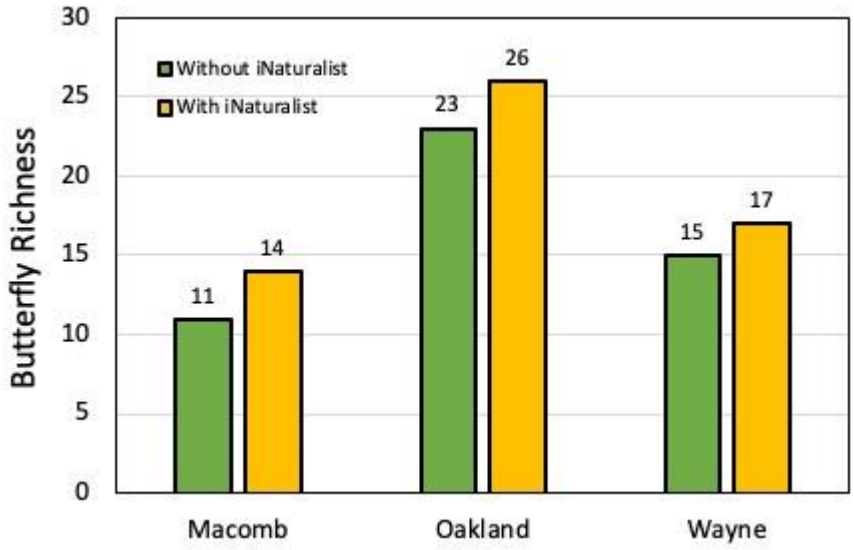


Figure 12: Butterfly richness over this study's survey months based on this study's field surveys (green) as well as including both this study's field surveys and additional species sighted on iNaturalist during the survey months (yellow).

Butterfly Community Metrics Across Landscape Characterizations

Butterfly richness increased with urbanization ($F_1 = 5.62$, $p = 0.0393$; Figure 13). I found no significant relationship between urbanization and butterfly diversity or abundance (Figure 13). I also found no significant relationships between site butterfly abundance, richness, and diversity and edge density or patch connectivity.

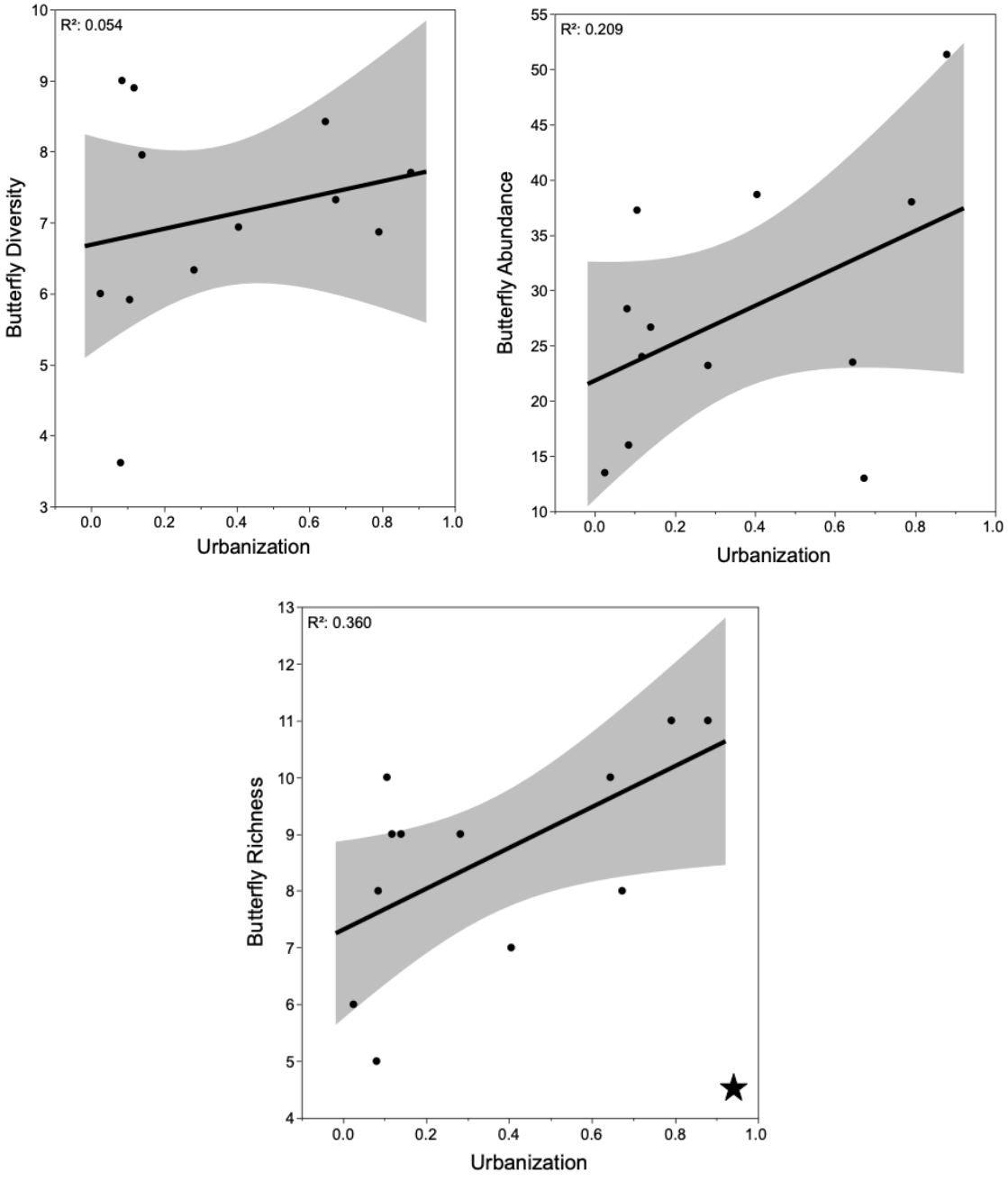


Figure 13: Linear regressions of butterfly diversity ($F_1 = 0.566$, $p = 0.470$), abundance ($F_1 = 2.63$, $p = 0.136$), and richness ($F_1 = 5.62$, $p = 0.0393$) against urbanization (proportion impervious surface).

The proportion of observations consisting of generalist butterfly species, however, increased with both edge density ($F_1 = 6.05$, $p = 0.0336$; Figure 14a) and site area ($F_1 = 5.01$, $p = 0.0492$; Figure 14b). The proportion of observations consisting of butterfly species producing a single generation per season also increased with edge density ($F_1 = 52.3$, $p < .0001$; Figure 14a). I found no other significant trends between functional group abundances and land-use metrics.

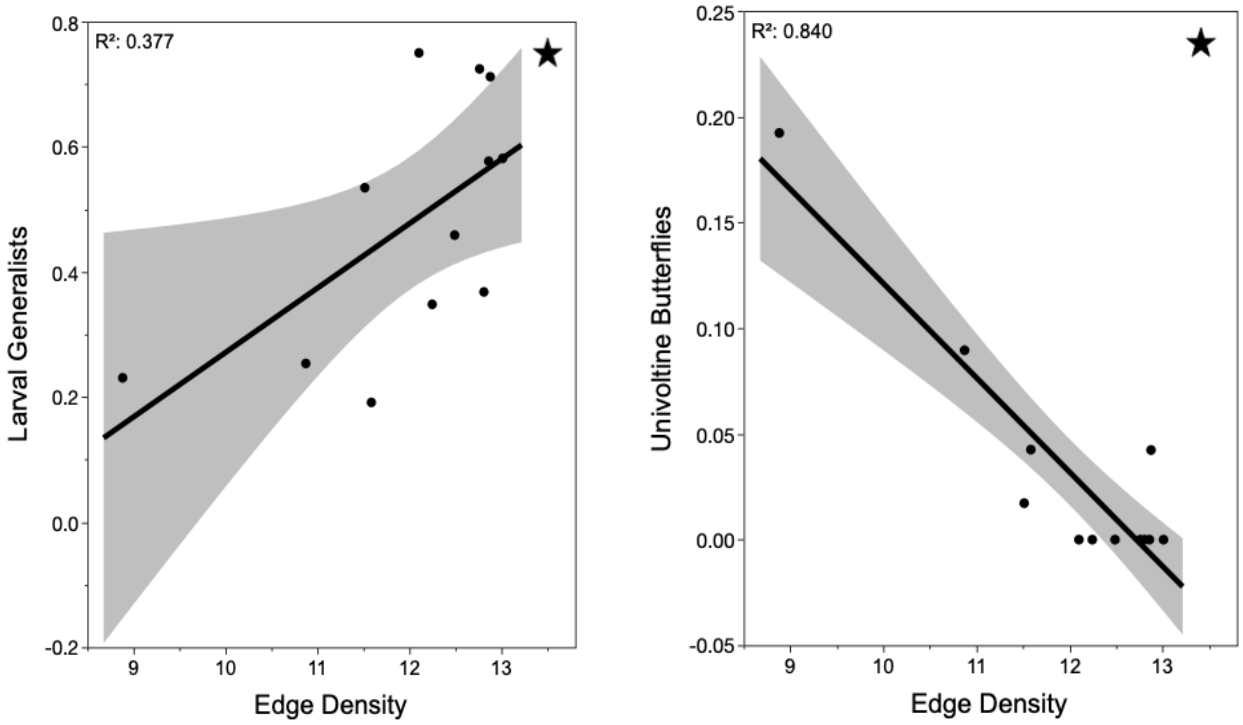


Figure 14a: Linear relationships between proportion generalist ($F_1 = 6.05$, $p = 0.0336$) and single generation species ($F_1 = 52.3$, $p < .0001$) and edge density.

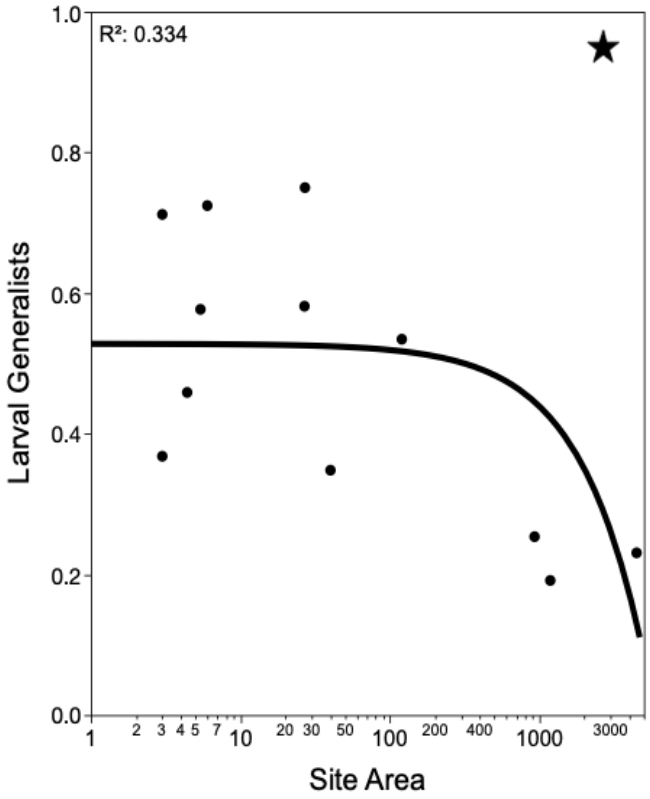


Figure 14b: Log-transformed relationship between proportion generalist species and site area (ac) ($F_1 = 5.01$, $p = 0.0492$).

Butterfly Foraging Activity Across Landscape Characterizations

No significant relationship was found between butterfly visits to flowers and any environmental attributes. Network specialization (H2), however, was found to increase with site area ($F_1 = 14.9$, $p = 0.0031$; Figure 15a). Specialization was also found to decrease with edge density ($F_1 = 19.2$, $p = 0.0014$; Figure 15b).

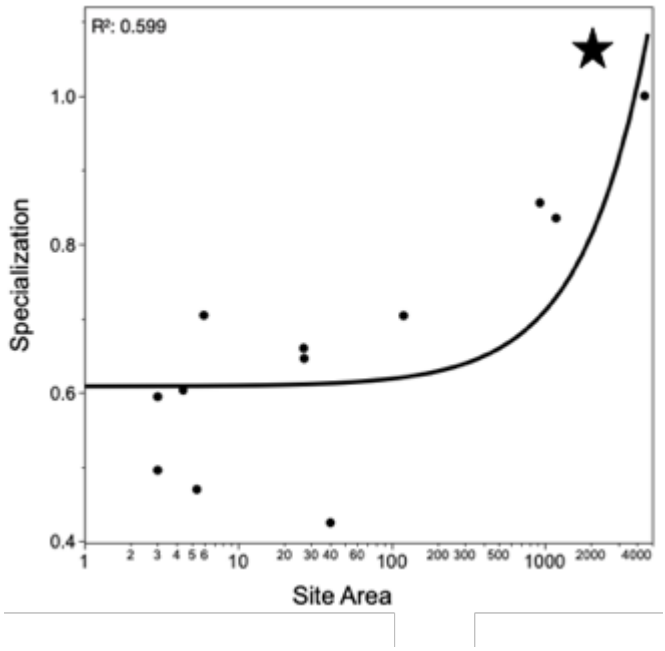


Figure 15a: Log-transformed relationship between specialization (H2) and site area (ac); ($F_1 = 14.9$, $p = 0.0031$).

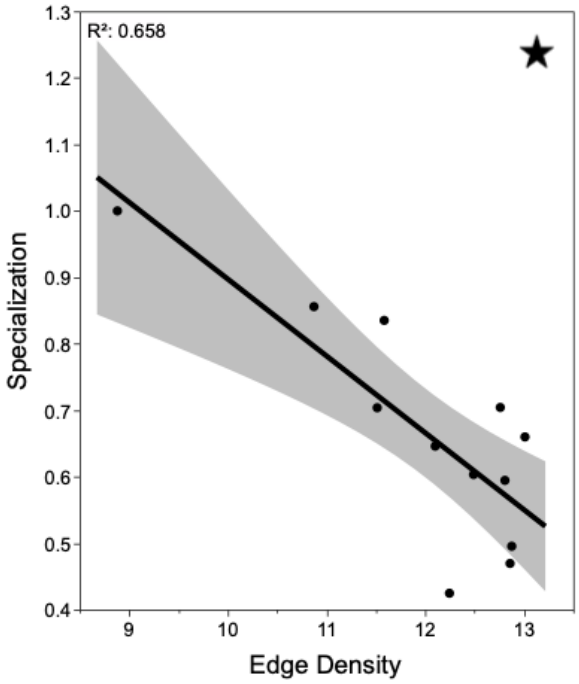


Figure 15b: Linear regression of specialization (H2) against edge density; $F_1 = 19.2$, $p = 0.0014$.

Butterfly Community Metrics Across Native Plant Abundance and Richness

I found no significant relationship between native proportion of bloom cover and butterfly abundance, diversity, richness, or functional group abundances.

A significant positive correlation was found between native proportion of plant richness and butterfly diversity ($F_1 = 9.18$, $p = 0.0127$; Figure 16).

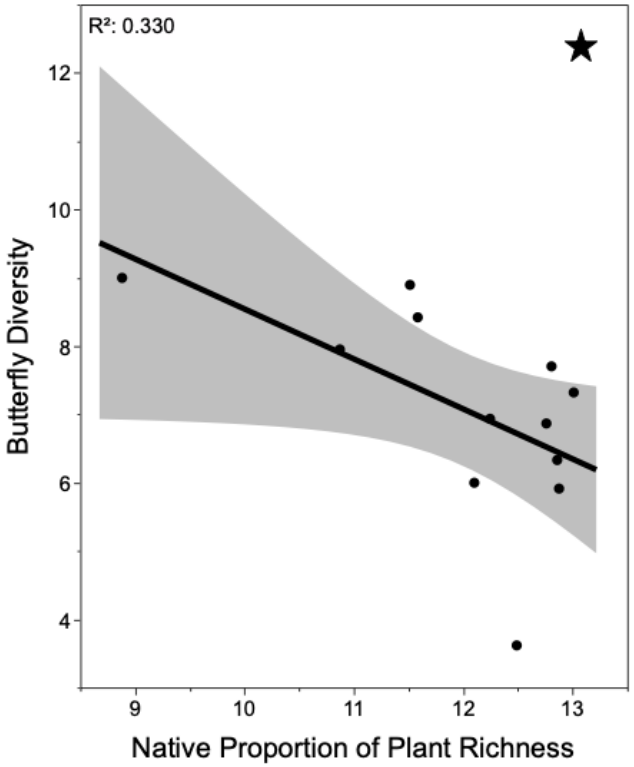


Figure 16: Linear regression of butterfly (Rarefied Shannon) diversity against native proportion of site plant richness; $F_1 = 9.18$, $p = 0.0127$.

Discussion

Habitat Type as a Predictor for Site Attributes and Butterfly Community Metrics

My study's first goal was to identify key differences between parks and farms and determine if one habitat type better supports butterfly-plant communities than the other. Habitat types did not differ in terms of adjacent urbanization (within a 1500 meter radius), though this

may not be surprising considering the extent and variability of urbanization of the metro-Detroit area, as seen in Figure 2, especially since site spatial pairs consisted of one farm and one park site. The two habitat types did differ in the edge density of their patches, with farms having greater edge area than parks. Overall, habitat types seem to mainly be distinguished by a difference in their plant communities; in late summer, parks had more native flower bloom than farms, and a correlating greater amount of butterfly visits to native plants ($r = 0.821$). These findings call into question if parks and farms are efficient categories to describe habitat type, or if categorization should be centered around other factors other than anthropogenic purpose, like urbanization and native plant abundance. In addition, it would be interesting to investigate why patch connectivity did not differ between habitat types, and if this either points to healthy patch management by farmers or neglect by park managers.

There were several differences between parks and farms in terms of their observed butterfly community compositions. While the top ten observed butterflies in both parks and farms were very similar, the top ten plants they visited were not; only 2 species were shared (*Centaurea maculosa and Rudbeckia hirta*) between the habitat types. Overall, parks supported more butterfly diversity than farms, indicating more stable butterfly populations at park sites. In addition, larval specialist species were found to be in greater abundance at parks than at farms, which is often a large contributor to increased biodiversity (Perovic et al. 2015, Habel et al. 2016). This bodes well for current park management, indicating its natural pollinator populations are more stable than those at farms, which are stereotypically more altered by anthropogenic practices (in the form of agricultural intensification).

Effect of Landscape-Scale Factors on Butterfly Communities

The second objective of this study was to determine if human impact in the form of urbanization and habitat fragmentation affects butterfly-plant communities in southeastern Michigan. Unexpectedly, I found butterfly richness to increase at sites with a greater extent of urbanization, contradicting the findings of previous studies (Warren et al. 2001, Winfree et al. 2011, Ricketts et al. 2008, Kurylo et al. 2020). Fahrig et al. 2017 disputes that most studies show that effects of increased land use are positive, though this report's findings have been questioned (Fletcher et al. 2018). Urban spaces with adequate green space have been shown to support stable butterfly populations, though this is often highly dependent on patch quality (Dylewski et al. 2019, Lizée et al. 2012). This finding could be attributed to an induced concentration of butterfly populations in more urban and therefore smaller habitats (resulting in a greater likelihood of seeing all the species living in that habitat during survey periods). No correlation between site area and urbanization was found ($r = -0.241$), meaning more urban sites are not necessarily smaller in total green space, but, as urban sites exist within more inhospitable matrices, butterflies could be quite restricted to the patch they originate from, since dispersal may be riskier (Baguette et al. 2003, Nowicki et al. 2014). It is a possibility that this finding is mainly due to a small sample size, and a greater number of surveys (most importantly more time spent surveying larger sites) could help to stabilize this survey concentration effect. Urbanization has been found to increase richness in certain cases for some pollinators, like *Hymenoptera*, but not yet for butterflies (Theodorou et al. 2020).

While I did not find site area and percent urbanization to be correlates, I did find site area to increase with the amount of specialist butterflies found at each site, as well as with greater degrees of network specialization. This could expand on a resource concentration hypothesis,

implying that larger green spaces have more stable resources to support specialist butterfly populations, as shown in several other studies (Steffan-Dewenter & Tscharntke 2000, Hämback et al. 2007, Brückmann et al. 2010). Larger greenspaces may consist of more plant resources to allow for more resource partitioning between larval generalists. In addition, smaller green spaces are often more easily and intensively managed, which disrupts vegetation and diminishes plant diversity (Öckinger et al. 2009); this is particularly harmful to sensitive specialist species (Warren et al. 2001, Schweiger et al. 2008, Brito et al. 2014, Brückmann et al. 2010, Habel et al. 2019).

Contrastingly, abundance of specialist butterflies and network specialization was found to decrease as edge density increased. Generalist herbivores have been shown to benefit from increased habitat edge, especially at farms (M'Gonigle et al. 2015, Kuussaari et al. 2007). Perovic et al. (2015), however, found that greater suitable edge was shown to favor larval specialist butterfly species. It has also been shown that increasing habitat edge, especially when that edge separates the habitat from urban and agricultural land, can foster very diverse communities of pollinators (Chacoff and Aizen 2006), and that diverse and stable communities of butterflies are best promoted by increasing populations of specialist species (Perovic et al. 2015). This study did find a strong negative correlation between site area and edge density ($r = -0.918$), however, and so conflicting effects between increased site area and edge density on network specialization may explain these results. In addition, large edges without the necessary plant species to support larval specialists' restricted diets will cause them to avoid edges, and so the specific quality of plant resources in edges is important as well.

I also found that multivoltine butterfly species were found in higher abundances in sites with greater edge density, aligning with the increased number of generalist species with greater

edge, as multi-voltinism and wide feeding preferences are often related functional traits (Börschig et al. 2013, Gámez-Virués et al. 2015). As species producing multiple generations per season have increased rates of population growth and therefore a quicker ability to adapt to changing environmental conditions (Altermatt 2010), multivoltine species may be found in increasing abundance around edges because of their ability to survive in the face of encroaching urban areas, especially if the studied sites are not large enough to support specialist, and therefore likely univoltine, species (Perovic et al. 2015). Only four of the 24 species we observed were univoltine, however, and so results may be skewed bc of the low amount of univoltine butterflies observed overall. More research is necessary to investigate the relationship between patch and overall habitat size, amount of habitat edge, and butterfly functional diversity.

Importance of Native Plants to Butterfly Communities

The third goal of this study was to determine if the commonly supported idea that a diversity of native plants is beneficial for pollinator communities rings true for butterfly communities of southeastern Michigan. I did not find native proportion of total bloom cover to be a good predictor of butterfly abundance, richness, or diversity. Visitations to flower species, however, did show differences between exotic and native plants. While native plants were visited by mature butterflies at about two times the rate of exotic plants, exotics were visited at about three times the rate of natives per flower surface area (resulting from the visitations by bloom cover analysis). So, it seems to be ambiguous whether adult butterflies prefer to obtain nectar from native or exotic species of flowers. Again, this discussion may be less valuable when considering that most adult butterflies are generalist feeders (even when they had specialist diets at their larval stage), and so introduced species may not affect their mature diets (Richardson et

al. 2000, Staab et al. 2020). If exotic flower species are allowed to persist in the plant population and be pollinated, however, they will only continue to spread and outcompete native species (Barnett et al. 2016, Gioria & Osborne 2014), damaging butterfly species when they are at their larval stage.

Sites with a greater native proportion of plant richness supported more diverse butterfly communities. This further supports the common effort of supporting stable pollinator communities by increasing plant richness (Potts et al. 2003, Ebeling et al. 2008), preferably with native species (Ries et al. 2001, Burghardt et al. 2009, Solis-Gabriel et al. 2017). Greater native plant richness in comparison to exotic richness could support greater butterfly diversity by supporting more vulnerable species like larval specialists (Warren et al. 2001, Swengel et al. 2011, Cusser & Goodell 2013).

Informing Conservation Strategies for Butterflies in Urban Areas

The overall aim of this study was to use its findings to inform conservation strategies for park planners and farmers to support butterfly communities in southeastern Michigan and urban areas like it. Based on the findings of this study and the examined literature, three main focuses for butterfly conservation are being proposed:

1) Expand and create larger green spaces with highly suitable habitat edges: Green spaces with a higher density of habitat edge (often accomplished through creating many small patches) have been shown to support vulnerable specialist species (Perovic et al. 2015, Filgueiras et al. 2016); through my study, however, it was suggested that too small of an overall habitat size may counter this ability. Urban green spaces need to be large enough to allow for stable resources and habitat for vulnerable butterfly populations (Brückmann

et al. 2010), and high-quality edge with diverse plant resources between close patches could allow for a greater recolonization ability in the case of patch metapopulation extinction.

2) Increase wildflower and vegetation diversity with native plant species: Through this study, I reported more diverse, and therefore more stable, butterfly communities in habitats with a greater dominance of richness by native plant species. Both native and exotic flowers seem to be prime candidates for adult butterfly foraging, but this is expected as most adult butterflies have generalist diets (Richardson et al. 2000, Staab et al. 2020). Heavy management of exotic plant species should therefore be prioritized to decrease exotic spread rate, thereby decreasing their potential to outcompete native species that caterpillars rely on to survive (Barnett et al. 2016, Gioria & Osborne 2014). Members of *Asteraceae*, like *Vernonia missurica*, *Solidago canadensis*, and *Symphyotrichum* species, seem to be most effective for adult butterfly foraging, though a diverse set of native flowers from several plant families should allow for stable mature diet availability. In addition, most the species we observed were non-migratory and require overwintering habitats, so a native vegetation diversity of flowers, trees, shrubs, and grasses is also beneficial to support all stages of a butterfly's life (Haddad et al. 2001, Aguirre-Gutiérrez et al. 2017, USDA Natural Resources Conservation Service 2000, Kurlyo et al. 2020).
3) Focus conservation efforts on caterpillar specialists: From the literature and this study's findings, patch management, in terms of habitat quality and distribution, especially from the effects of habitat fragmentation, affects the ability of certain butterfly functional groups to survive and support overall butterfly diversity (Warren et al. 2001, Gámez-

Virués et al. 2015, Swengel et al. 2011, Eskildsen et al. 2015). Those leading green space management should identify the species found in their green space, especially those that feed on only a few species of plants or less in their larval stage, since these species are extremely vulnerable to disturbance; they should then attempt to conserve and increase the native plant species that those larvae feed on (Swengel et al. 2011). In addition to active pollinator surveys, citizen science programs, like iNaturalist, as seen in this study as well as Prudic et al. 2018, can also be beneficial in identifying the species found in urban parks and gardens. A full list of the specialist caterpillar species observed in this study and the plant families that they feed on can be found in Appendix Table A.6.

While human land-use is intensifying rapidly in the U.S. as well as globally, research-supported conservation strategies can be implemented by scientists and communities alike to combat its negative effects on pollinators and their habitats. My study identifies three general focuses on conservation to improve butterfly diversity and support ecosystems at parks and farms affected by varying levels of urbanization. Pollinators and other insects may face threats from human land-use, but it is increasingly important to understand how they can be supported both inside and outside human-dominated environments.

Appendices

Table A.1: List and characteristics of survey sites

Site Code	Site	County	Habitat Type	Site Area (Ac)	*Proportion Impervious Surface (Urbanization)	*Edge Density	*CONNECT
CF	Cold Frame Farm	Macomb	Farm	27	0.024965	12.101	24.7619
CG	Clarkston Community Garden	Oakland	Farm	3	0.105575	12.876	29.4872
CI	Charles Illsley Park	Oakland	Park	120	0.117678	11.513	40
HG	Harding Greenspace	Oakland	Park	26.8	0.672362	13.01	12.7282
HV	HAVEN	Oakland	Farm	6	0.790955	12.76	11.5421
JN	Johnson Nature Center	Oakland	Park	40	0.405014	12.245	14.8815
OH	Oakland Hills Community Garden	Oakland	Farm	4.4	0.080584	12.489	45
OO	Orion Oaks County Park	Oakland	Park	927	0.139547	10.872	22.3044
OU	Oakland University Student Organic Farm	Oakland	Farm	5.4	0.282503	12.859	18.6869
RP	Rouge Park	Wayne	Park	1181	0.643915	11.584	12.1678
SC	Stony Creek Metropark	Macomb	Park	4461	0.084443	8.881	22.6263
VK	Votrobeck Playground	Wayne	Farm	3	0.878948	12.807	12.813

*Proportion impervious surface, edge density, and CONNECT all calculated within a 1500m buffer, using ArcGIS 10.7.1 and FRAGSTATS

Table A.2: Identified butterfly species list, including functional traits

Species	**Common Name**	**Family**	**Larval Feeding Preference** *(Scott 1986)*	**Wing Length (In)** *(Daniels 2005)*	**Voltinism** *(Daniels 2005)*	**Migratory** *(Scott 1986)*	**# Sites Seen At**
Anatrytone logan	Delaware Skipper	Hesperiidae	Specialist	1.2	Univoltine	No	1
Ancyloxypha numitor	Least Skipper	Hesperiidae	Specialist	0.85	Multivoltine	No	2
Celastrina neglecta	Summer Azure	Lycaenidae	Generalist	1.025	Multivoltine	No	2
Cercyonis pegala	Common Wood Nymph	Nymphalidae	Specialist	2.3	Univoltine	No	2
Coenonympha tullia	Common ringlet	Pieridae	Specialist	1.89	Univoltine	No	2
Cupido comyntas	Eastern-tailed Blue	Lycaenidae	Generalist	0.875	Multivoltine	Somewhat	6
Danaus plexippus	Monarch	Nymphalidae	Specialist	3.75	Multivoltine	Yes	11
Epargyreus clarus	Silver-Spotted Skipper	Hesperiidae	Specialist	2.075	Multivoltine	No	10
Junonia coenia	Common Buckeye	Nymphalidae	Generalist	2.1	Multivoltine	Yes	2
Limenitis archippus	Viceroy	Nymphalidae	Generalist	2.9	Multivoltine	No	1
Limenitis arthemis astyanax	Red Spotted Purple	Lycaenidae	Generalist	3.25	Multivoltine	No	1
Lycaena phlaeas	American Copper	Lycaenidae	Specialist	1.15	Multivoltine	No	2
Papilio cresphontes	Giant Swallowtail	Papilionidae	Generalist	5	Multivoltine	Somewhat	2
Papilio glaucus	Eastern Tiger Swallowtail	Papilionidae	Generalist	4.5	Multivoltine	No	6
Papilio polyxenes	Black Swallowtail	Papilionidae	Generalist	3.35	Multivoltine	No	6
Phyciodes batesii	Tawny Crescent	Nymphalidae	Specialist	1.525	Univoltine	No	2
Phyciodes tharos	Pearl Crescent	Nymphalidae	Specialist	1.5	Multivoltine	Somewhat	8
Pieris rapae	Cabbage White	Pieridae	Generalist	1.75	Multivoltine	No	12
Polites peckius	Peck's Skipper	Hesperiidae	Specialist	1.125	Multivoltine	No	8
Polites themistocles	Tawny-Edged Skipper	Hesperiidae	Generalist	1.75	Multivoltine	No	1
Strymon melinus	Gray Hairstreak	Lycaenidae	Generalist	1.25	Multivoltine	No	1

Table A.2 (continued): Identified butterfly species list, including functional traits

Species	**Common Name**	**Family**	**Larval Feeding Preference (Scott 1986)**	**Wing Length (In) (Daniels 2005)**	**Voltinism (Daniels 2005)**	**Migratory (Scott 1986)**	**# Sites Seen At**
Vanessa atalanta	Red Admiral	Nymphalidae	Specialist	2.125	Multivoltine	Yes	1
Vanessa cardui	Painted Lady	Nymphalidae	Generalist	2.075	Multivoltine	Yes	4
Vanessa virginiensis	American Painted Lady	Nymphalidae	Generalist	2.075	Multivoltine	Somewhat	2

Table A.3: Butterfly species by survey site

Site	Common Name	Species	Site	Common Name	Species
CF			**OH**		
	Common Buckeye	*Junonia coenia*		Painted Lady	*Vanessa cardui*
	Eastern Tiger Swallowtail	*Papilio glaucus*		Silver-Spotted Skipper	*Epargyreus clarus*
	Monarch	*Danaus plexippus*		Eastern Tiger Swallowtail	*Papilio glaucus*
	Cabbage White	*Pieris rapae*		Peck's Skipper	*Polites peckius*
	Clouded/Orange Sulphur	*Colias spp*		Cabbage White	*Pieris rapae*
	Pearl Crescent	*Phyciodes tharos*			
CG			**OO**		
	Tawny Crescent	*Phyciodes batesii*		Eastern-tailed Blue	*Cupido comyntas*
	Silver-Spotted Skipper	*Epargyreus clarus*		Summer Azure	*Celastrina neglecta*
	Eastern-tailed Blue	*Cupido comyntas*		Least Skipper	*Ancyloxypha numitor*
	Eastern Tiger Swallowtail	*Papilio glaucus*		Common Wood Nymph	*Cercyonis pegala*
	Delaware Skipper	*Anatrytone logan*		Monarch	*Danaus plexippus*
	Peck's Skipper	*Polites peckius*		Cabbage White	*Pieris rapae*
	Monarch	*Danaus plexippus*		Common Ringlet	*Coenonympha tullia*
	Cabbage White	*Pieris rapae*		Clouded/Orange Sulphur	*Colias spp*
	Clouded/Orange Sulphur	*Colias spp*		Pearl Crescent	*Phyciodes tharos*
	Pearl Crescent	*Phyciodes tharos*			
CI			**OU**		
	Tawny Crescent	*Phyciodes batesii*		Red Spotted Purple	*Limenitis arthemis*
	Silver-Spotted Skipper	*Epargyreus clarus*		Silver-Spotted Skipper	*Epargyreus clarus*
	Eastern-tailed Blue	*Cupido comyntas*		Eastern Tiger Swallowtail	*Papilio glaucus*
	Giant Swallowtail	*Papilio cresphontes*		Peck's Skipper	*Polites peckius*
	Monarch	*Danaus plexippus*		American Copper	*Lycaena phlaeas*
	Black Swallowtail	*Papilio polyxenes*		Monarch	*Danaus plexippus*
	Cabbage White	*Pieris rapae*		Black Swallowtail	*Papilio polyxenes*
	Clouded/Orange Sulphur	*Colias spp*		Cabbage White	*Pieris rapae*
				Hummingbird Moth	*Macroglossum stellatarum*
				Clouded/Orange Sulphur	*Colias spp*

Table A.3 (continued): Butterfly species by survey site

Site	Common Name	Species	Site	Common Name	Species
HG			**RP**		
	Silver-Spotted Skipper	*Epargyreus clarus*		Silver-Spotted Skipper	*Epargyreus clarus*
	Eastern-tailed Blue	*Cupido comyntas*		Eastern Tiger Swallowtail	*Papilio glaucus*
	Gray Hairstreak	*Strymon melinus*		Summer Azure	*Celastrina neglecta*
	Peck's Skipper	*Polites peckius*		Least Skipper	*Ancyloxypha numitor*
	Monarch	*Danaus plexippus*		Common Wood Nymph	*Cercyonis pegala*
	Cabbage White	*Pieris rapae*		American Copper	*Lycaena phlaeas*
	Tawny-Edged Skipper	*Polites themistocles*		Monarch	*Danaus plexippus*
	Clouded/Orange Sulphur	*Colias spp*		Black Swallowtail	*Papilio polyxenes*
				Cabbage White	*Pieris rapae*
HV			**SC**		
	Viceroy	*Limenitis archippus*		Red Admiral	*Vanessa atalanta*
	Painted Lady	*Vanessa cardui*		Silver-Spotted Skipper	*Epargyreus clarus*
	Silver-Spotted Skipper	*Epargyreus clarus*		Peck's Skipper	*Polites peckius*
	Eastern-tailed Blue	*Cupido comyntas*		Monarch	*Danaus plexippus*
	Giant Swallowtail	*Papilio cresphontes*		Black Swallowtail	*Papilio polyxenes*
	Peck's Skipper	*Polites peckius*		Cabbage White	*Pieris rapae*
	Monarch	*Danaus plexippus*		Common Ringlet	*Coenonympha tullia*
	Black Swallowtail	*Papilio polyxenes*		Pearl Crescent	*Phyciodes tharos*
	Cabbage White	*Pieris rapae*			
	Clouded/Orange Sulphur	*Colias spp*			
	Pearl Crescent	*Phyciodes tharos*			

Table A.3 (continued): Butterfly species by survey site

Site	Common Name	Species	Site	Common Name	Species
JN			**VK**		
	Painted Lady	*Vanessa cardui*		Painted Lady	*Vanessa cardui*
	Silver-Spotted Skipper	*Epargyreus clarus*		Silver-Spotted Skipper	*Epargyreus clarus*
	Eastern Tiger Swallowtail	*Papilio glaucus*		Common Buckeye	*Junonia coenia*
	Peck's Skipper	*Polites peckius*		Eastern-tailed Blue	*Cupido comyntas*
	Monarch	*Danaus plexippus*		Peck's Skipper	*Polites peckius*
	Cabbage White	*Pieris rapae*		Monarch	*Danaus plexippus*
	American Painted Lady	*Vanessa virginiensis*		Black Swallowtail	*Papilio polyxenes*
				Cabbage White	*Pieris rapae*
				American Painted Lady	*Vanessa virginiensis*
				Clouded/Orange Sulphur	*Colias spp*
				Pearl Crescent	*Phyciodes tharos*

Table A.4: Plant species visited per butterfly species

Butterfly Species	Plant Code	Butterfly Species	Plant Code	Butterfly Species	Plant Code
Limenitis archippus	DauCar	*Junonia coenia*	DauCar	*Polites peckius (cont)*	TriPra
Limenitis arthemis	OenBie	*Cupido comyntas*	CicInt		VerMis
Phyciodes batesii	CirVul		DauCar	*Lycaena phlaeas*	SolCan
	CirArv		EchPur	*Danaus plexippus*	AscSyr
Vanessa cardui	CenMac		PolPen		AscTub
	DipFul	*Papilio cresphontes*	CirVul		CenMac
	MonFis		VerMis		CirVul
	VerMis	*Papilio glaucus*	CirVul		CirArv
Epargyreus clarus	BorOff		CirArv		CosBip
	BudDav		EchPur		DauCar
	CenMac		EupMac		DipFul
	CicInt		LiaAsp		EchPur
	CirVul		MonFis		EupMac
	DauCar		TagEre		HelHel
	DipFul		VerMis		HylSpe
	EchPur	*Anatrytone logan*	SymPil		LiaAsp
	EriAnn				SilTer
	EupMac	*Celastrina neglecta*	EupMac		SolCan
	HelAut	*Ancyloxypha numitor*	CenMac		SolJun
	HelHel	*Polites peckius*	AscTub		SolSpe
	HylSpe		BudDav		SilInt
	LiaAsp		CenMac		SymPil
	MonFis		CicInt		TriPra
	OenGau		CirVul		VerMis
	PhlPan		CirArv		ZinEle
	RatPin		DauCar	*Papilio polyxenes*	AscTub
	RudHir		EchPur		DauCar
	SilInt		EriAnn		DipFul
	SilPer		HelHel		SymLae
	SolCan		LiaAsp		TriPra
	SolJun		MonFis	*Pieris rapae*	AscVer
	SymNov		RudHir		BerInc
	TriPra		SymNov		CenMac
	VerMis		SymPil		CicInt

Table A.4 (continued): Plant species visited per butterfly species

Butterfly Species	Plant Code	Butterfly Species	Plant Code	Butterfly Species	Plant Code
Pieris rapae (cont)	CirArv	*Pieris rapae (cont)*	PolPen	*Colias spp* (cont)	TagEre
	ConArv		RudHir		TriRep
	DauCar		SilInt		ZinEle
	EchPur		SolCan	*Phyciodes tharos*	AscTub
	EriAnn		SolRid		CenMac
	EriCan		SolRig		CirArv
	EupMac		SonAsp		CorSpp
	HelAnn		SymLae		EchPur
	HelHel		SymNov		EriAnn
	HylSpe		SymPil		HelHel
	HypPer		TagEre		PycVir
	LacSer		BudDav		RudHir
	LavAng		TarOff		SolCan
	LeuVul		TriRep		SolJun
	LiaAsp		VerMis		SymLae
	SymLae	*Colias spp*	CirArv		TriPra
	LiaSpi		HelHel	*Polites themistocles*	EchPur
	MelOff		SolCan		HelHel
	MenSpi		SolJun		VerMis
	NepCat		SolRig	*Vanessa virginiensis*	VerMis
	OenGau		SymLae		
	PhaSpp		SymNov		

Table A.5: Plant species codes with native status

Plant Code	Common Name	Family	Species	Native Status
AscSyr	Common Milkweed	Apocynaceae	*Asclepias syriaca*	Native
AscTub	Butterfly Milkweed	Apocynaceae	*Asclepias tuberosa*	Native
AscVer	Whorled Milkweed	Apocynaceae	*Asclepias verticillata*	Native
BerInc	Hoary Alyssum	Brassicaceae	*Berteroa incana*	Exotic
BorOff	Borage	Boraginaceae	*Borage officinalis*	Exotic
BudDav	Butterfly Bush	Scrophulariaceae	*Buddleja davidii*	Exotic
CenMac	Spotted Knapweed	Asteraceae	*Centaurea maculosa*	Exotic
CicInt	Chicory	Asteraceae	*Cichorium intybus*	Exotic
CirArv	Canada Thistle	Asteraceae	*Cirsium arvense*	Exotic
CirVul	Bull Thistle	Asteraceae	*Cirsium vulgare*	Exotic
ConArv	Field Bindweed	Convolvulaceae	*Convolvulus arvensis*	Exotic
CorSpp	Dogwood (unknown species)	Cornaceae	*Cornus spp*	Native
CosBip	Common Cosmo	Asteraceae	*Cosmos bipinnatus*	Exotic
DauCar	Queen Anne's Lace	Apiaceae	*Daucus carota*	Exotic
DipFul	Wild Teasel	Caprifoliaceae	*Dipsacus fullonum*	Exotic
EchPur	Purple Cone	Asteraceae	*Echinacea purpurea*	Native
EriAnn	Annual Fleabane	Asteraceae	*Erigeron annuus*	Native
EriCan	Horseweed	Asteraceae	*Conyza canadensis*	Native
EupMac	Spotted Joe Pye Weed	Asteraceae	*Eupatorium maculatum*	Native
HelAnn	Annual Sunflower	Asteraceae	*Helianthus annuus*	Native
HelAut	Sneezeweed	Asteraceae	*Helenium autumnale*	Native
HelHel	Heliopsis (False Sunflower)	Asteraceae	*Heliopsis helianthoides*	Native
HylSpe	Showy Stonecrop	Crassulaceae	*Hylotelephium spectabile*	Exotic
HypPer	Goat Weed	Hypericaceae	*Hypericum perforatum*	Exotic
LacSer	Prickly Lettuce	Asteraceae	*Lactuca serriola*	Exotic
LavAng	English Lavender	Lamiaceae	*Lavandula angustifolia*	Exotic
LeuVul	Ornamental Daisy	Asteraceae	*Leucanthemum vulgare*	Exotic
LiaAsp	Rough Blazing Star	Asteraceae	*Liatris aspera*	Native
LiaSpi	Dense Blazing Star	Asteraceae	*Liatris spicata*	Native
MelOff	Lemon Balm	Fabaceae	*Melilotus officinalis*	Exotic
MenSpi	Spearmint	Lamiaceae	*Mentha spicata*	Exotic
MonFis	Bee Balm (Wild Bergamot)	Lamiaceae	*Monarda fistulosa*	Native
NepCat	Catmint	Lamiaceae	*Nepeta cataria*	Exotic
OenBie	Common Evening-Primrose	Onagraceae	*Oenothera biennis*	Native

Table A.5 (continued): Plant species codes with native status

Plant Code	Common Name	Family	Species	Native Status
OenGau	Biennial Bee Blossom	Onagraceae	*Oenothera gaura*	Native
PhaSpp	Pole Beans (species unknown)	Fabaceae	*Phaseolus spp*	Exotic
PhlPan	Garden Phlox	Polemoniaceae	*Phlox paniculata*	Exotic
PolPen	Smartweed	Polygonaceae	*Polygonum pensylvanicum*	Native
PycVir	Mountain Mint	Lamiaceae	*Pycnanthemum virginianum*	Native
RatPin	Prairie Coneflower	Asteraceae	*Ratibida pinnata*	Native
RudHir	Black-Eyed Susan	Asteraceae	*Rudbeckia hirta*	Native
SilInt	Rosin Weed	Asteraceae	*Silphium integrifolium*	Native
SilPer	Cup-Plant	Asteraceae	*Silphium perfoliatum*	Native
SilTer	Prairie Dock	Asteraceae	*Silphium terebinthinaceum*	Native
SolCan	Canada Goldenrod	Asteraceae	*Solidago canadensis*	Native
SolJun	Early Goldenrod	Asteraceae	*Solidago juncea*	Native
SolRid	Riddell's goldenrod	Asteraceae	*Solidago riddellii*	Native
SolRig	Stiff Goldenrod	Asteraceae	*Solidago rigida*	Native
SolSpe	Showy Goldenrod	Asteraceae	*Solidago speciosa*	Native
SonAsp	Prickly Sow thistle	Asteraceae	*Sonchus asper*	Exotic
SymLae	Smooth Aster	Asteraceae	*Symphyotrichum laeve*	Native
SymNov	New England Aster	Asteraceae	*Symphyotrichum novae-angliae*	Native
SymPil	Frost Aster	Asteraceae	*Symphyotrichum pilosum*	Native
TagEre	Mexican Marigold (Tall)	Asteraceae	*Tagetes erecta*	Exotic
TarOff	Dandelion	Asteraceae	*Taraxacum officinale*	Exotic
TriPra	Red Clover	Fabaceae	*Trifolium pratense*	Exotic
TriRep	White Clover	Fabaceae	*Trifolium repens*	Exotic
VerMis	Iron Weed	Asteraceae	*Vernonia missurica*	Native
ZinEle	Common Zinnia	Asteraceae	*Zinnia spp*	Exotic

Table A.6: Identified larval specialist butterfly species and their preferred plant resources (Scott 1986)

Butterfly Species	**Common Name**	**Family**	**Preferred Plant Resources at Larval Stage**
Anatrytone logan	Delaware Skipper	Hesperiidae	Grasses: *Andropogon gerardii, Erianthus divaricatus, Panicum virgatum*
Ancyloxypha numitor	Least Skipper	Hesperiidae	Grasses: *Zizaniopsis miliacea, Oryza sativa, Leersia oryzoides, Spartina, Setaria, Panicum, Zea mays*
Cercyonis pegala	Common Wood Nymph	Nymphalidae	Grasses: *Andropogon, Tridens flavus, Avena fatua, Stipa spartea, Puccinellia, Poa Pratensis*
Coenonympha tullia	Common ringlet	Pieridae	Grasses: *Stipa, Poa pratensis, Festuca, Agrostis*
Danaus plexippus	Monarch	Nymphalidae	Milkweeds*: Asclepias* species
Epargyreus clarus	Silver-Spotted Skipper	Hesperiidae	Legumes: *Fabaceae*, including *Gleditsia triacanthos*
Lycaena phlaeas	American Copper	Lycaenidae	Buckwheats: *Polygonaceae* species
Phyciodes batesii	Tawny Crescent	Nymphalidae	*Asteraceae*, including *Symphyotrichum* species
Phyciodes tharos	Pearl Crescent	Nymphalidae	*Asteraceae*, including *Symphyotrichum* species
Polites peckius	Peck's Skipper	Hesperiidae	Grasses, preferably *Leersia oryzoides, Poa pratensis*
Vanessa atalanta	Red Admiral	Nymphalidae	Nettles: *Urticaceae* species

Table A.7: ANOVA test results for all predictor and response variables

Response	**Predictor**	**Df**	**Sum Sq.**	**F**	**P-value**	**Shapiro-Wilks (Prob<W)***
Site Area	Habitat Type	1	3748654.1	2.5737	0.1397	
Proportion Impervious Surface	Habitat Type	1	0.00084288	0.0078	0.9313	
CONNECT (500m)	Habitat Type	1	56.544564	1.1897	0.301	
CONNECT (1000m)	Habitat Type	1	255.90278	1.2723	0.2857	
CONNECT (1500m)	Habitat Type	1	25.763198	0.1939	0.6691	
Edge Density (500m)	Habitat Type	1	132.34849	6.1052	**0.0331***	0.5883
Edge Density (1000m)	Habitat Type	1	18.172024	5.3286	**0.0436***	0.108
Edge Density (1500m)	Habitat Type	1	5.0531141	4.8489	0.0523	
Proportion Native Bloom Cover	Habitat Type	1	0.29273582	5.8624	**0.0360***	0.4498
Rarefied Shannon Diversity	Habitat Type	1	12.18426	9.4126	**0.0119***	0.5644
Butterfly Visits	Habitat Type	1	192.5337	1.4593	0.2548	
Exotic Plant Visits	Habitat Type	1	228.37688	5.6673	**0.0386***	0.2372
Native Plant Visits	Habitat Type	1	1.3222454	0.0127	0.9126	
Exotic Plant Visit Richness	Habitat Type	1	75	6.2155	**0.0318***	0.7445
Native Plant Visit Richness	Habitat Type	1	2.0833333	0.4448	0.5199	
Proportion Visits Native	Habitat Type	1	0.16104712	8.4271	**0.0158***	0.2535
Butterfly Abundance	Habitat Type	1	206.53169	1.6171	0.2323	
Butterfly Richness	Habitat Type	1	0.08333333	0.0215	0.8864	
Plant Richness	Habitat Type	1	300	2.802	0.1251	
Exotic Plant Richness	Habitat Type	1	420.08333	4.7909	0.0534	
Native Plant Richness	Habitat Type	1	10.083333	0.133	0.7229	
Butterfly Generalist Abundance	Habitat Type	1	233.3478	10.4938	**0.0089***	0.5682
Butterfly Specialist Abundance	Habitat Type	1	6.428912	0.0881	0.7727	
Butterfly Average Wingspan	Habitat Type	1	0.07444434	0.7292	0.4131	
Migratory Butterfly Abundance	Habitat Type	1	12.066759	0.9907	0.343	
Nonmigratory Butterfly Abundance	Habitat Type	1	262.8912	3.5231	0.09	
Univoltine Butterfly Abundance	Habitat Type	1	1.7505787	2.5037	0.1447	
Multivoltine Butterfly Abundance	Habitat Type	1	197.77613	1.6407	0.2291	
Proportion Abundance Generalist	Habitat Type	1	0.17520681	6.7217	**0.0268***	0.3614
Proportion Abundance Specialist	Habitat Type	1	0.17520681	6.7217	**0.0268***	0.3614

Response	**Predictor**	**Df**	**Sum Sq.**	**F**	**P-value**	**Shapiro-Wilks (Prob<W)***
Proportion Abundance Migratory	Habitat Type	1	0.02365075	2.4545	0.1483	
Proportion Abundance Nonmigratory	Habitat Type	1	0.03310492	2.7139	0.1305	
Proportion Abundance Univoltine	Habitat Type	1	0.00746412	2.5605	0.1406	
Proportion Abundance Multivoltine	Habitat Type	1	0.00746412	2.5605	0.1406	
Network Specialization (H2)	Habitat Type	1	0.07783096	3.2883	0.0999	
Rarefied Shannon Diversity	Edge Density (1500m)	1	8.2930563	4.9258	0.0507	
Butterfly Visits	Edge Density (1500m)	1	320.0705	2.6855	0.1323	
Proportion Native Bloom Cover	Edge Density (1500m)	1	0.05265533	0.7121	0.4185	
Exotic Plant Visits	Edge Density (1500m)	1	90.941939	1.6828	0.2237	
Native Plant Visits	Edge Density (1500m)	1	133.61868	1.4681	0.2535	
Proportion Visits Native	Edge Density (1500m)	1	0.05228634	1.7437	0.2161	
Butterfly Abundance	Edge Density (1500m)	1	227.42307	1.8103	0.2082	
Butterfly Richness	Edge Density (1500m)	1	0.56343227	0.1469	0.7095	
Plant Richness	Edge Density (1500m)	1	43.54425	0.3281	0.5794	
Butterfly Generalist Abundance	Edge Density (1500m)	1	192.55166	7.3168	**0.0221***	0.9998
Butterfly Specialist Abundance	Edge Density (1500m)	1	0.31403451	0.0043	0.9492	
Butterfly Average Wingspan	Edge Density (1500m)	1	0.17859364	1.9482	0.193	
Migratory Butterfly Abundance	Edge Density (1500m)	1	0.17567371	0.0131	0.911	
Nonmigratory Butterfly Abundance	Edge Density (1500m)	1	220.69541	2.7993	0.1252	
Univoltine Butterfly Abundance	Edge Density (1500m)	1	5.8753731	20.4924	**0.0011***	**0.0494***
Multivoltine Butterfly Abundance	Edge Density (1500m)	1	284.27994	2.5406	0.142	
Network Specialization (H2)	Edge Density (1500m)	1	0.20693089	19.2329	**0.0014***	0.5859
Proportion Abundance Generalist	Edge Density (1500m)	1	0.16437833	6.0547	**0.0336***	0.7657
Proportion Abundance Specialist	Edge Density (1500m)	1	0.16437833	6.0547	**0.0336***	0.7657
Proportion Abundance Migratory	Edge Density (1500m)	1	0.01821786	1.7898	0.2106	
Proportion Abundance Nonmigratory	Edge Density (1500m)	1	0.01821786	1.7898	0.2106	
Proportion Abundance Univoltine	Edge Density (1500m)	1	0.03074094	52.3281	**<.0001***	0.7795
Proportion Abundance Multivoltine	Edge Density (1500m)	1	0.03074094	52.3281	**<.0001***	0.7795
Rarefied Shannon Diversity	CONNECT (1500m)	1	3.8923957	1.8329	0.2056	

Response	Predictor	Df	Sum Sq.	F	P-value	Shapiro-Wilks (Prob<W)*
Butterfly Visits	CONNECT (1500m)	1	23.919551	0.1608	0.6969	
Proportion Native Bloom Cover	CONNECT (1500m)	1	0.09284428	1.3278	0.276	
Exotic Plant Visits	CONNECT (1500m)	1	75.917257	1.3668	0.2695	
Native Plant Visits	CONNECT (1500m)	1	133.55944	1.4673	0.2536	
Proportion Visits Native	CONNECT (1500m)	1	0.06804197	2.3949	0.1528	
Butterfly Abundance	CONNECT (1500m)	1	41.839692	0.2902	0.6019	
Butterfly Richness	CONNECT (1500m)	1	10.243119	3.5723	0.0881	
Plant Richness	CONNECT (1500m)	1	93.548595	0.7325	0.4121	
Butterfly Generalist Abundance	CONNECT (1500m)	1	0.00111819	0	0.9961	
Butterfly Specialist Abundance	CONNECT (1500m)	1	43.488169	0.6275	0.4467	
Butterfly Average Wingspan	CONNECT (1500m)	1	0.09390236	0.9377	0.3557	
Migratory Butterfly Abundance	CONNECT (1500m)	1	9.7919487	0.7892	0.3952	
Nonmigratory Butterfly Abundance	CONNECT (1500m)	1	12.241506	0.1228	0.7333	
Univoltine Butterfly Abundance	CONNECT (1500m)	1	0.02597009	0.0298	0.8664	
Multivoltine Butterfly Abundance	CONNECT (1500m)	1	46.092527	0.3396	0.5729	
Network Specialization (H2)	CONNECT (1500m)	1	0.00048366	0.0154	0.9037	
Proportion Abundance Generalist	CONNECT (1500m)	1	0.0103482	0.2432	0.6326	
Proportion Abundance Specialist	CONNECT (1500m)	1	0.0103482	0.2432	0.6326	
Proportion Abundance Migratory	CONNECT (1500m)	1	0.00137941	0.1163	0.7402	
Proportion Abundance Nonmigratory	CONNECT (1500m)	1	0.00137941	0.1163	0.7402	
Proportion Abundance Univoltine	CONNECT (1500m)	1	0.00005026	0.0137	0.909	
Proportion Abundance Multivoltine	CONNECT (1500m)	1	0.00005026	0.0137	0.909	
Rarefied Shannon Diversity	Site Area	1	6.7534602	3.6753	0.0842	
Butterfly Visits	Site Area	1	267.98066	2.1543	0.1729	
Proportion Native Bloom Cover	Site Area	1	0.08872652	1.2615	0.2876	
Exotic Plant Visits	Site Area	1	74.840588	1.3448	0.2731	
Native Plant Visits	Site Area	1	100.31758	1.0633	0.3268	
Proportion Visits Native	Site Area	1	0.04286734	1.386	0.2663	
Butterfly Abundance	Site Area	1	192.33942	1.4895	0.2503	
Butterfly Richness	Site Area	1	0.02161396	0.0056	0.942	
Plant Richness	Site Area	1	16.156734	0.1193	0.737	

Response	Predictor	Df	Sum Sq.	F	P-value	Shapiro-Wilks (Prob<W)*
Butterfly Generalist Abundance	Site Area	1	147.60528	4.7907	0.0534	
Butterfly Specialist Abundance	Site Area	1	1.1953705	0.0163	0.9011	
Butterfly Average Wingspan	Site Area	1	0.03085626	0.2899	0.6021	
Migratory Butterfly Abundance	Site Area	1	1.4740867	0.1113	0.7455	
Nonmigratory Butterfly Abundance	Site Area	1	144.68485	1.6738	0.2248	
Univoltine Butterfly Abundance	Site Area	1	5.6973462	18.7097	**0.0015***	**0.0038***
Multivoltine Butterfly Abundance	Site Area	1	5.0339912	16.2252	**0.0024***	0.7264
Network Specialization (H2)	Site Area	1	0.18845588	14.9488	**0.0031***	0.2703
Proportion Abundance Generalist	Site Area	1	0.14540712	5.0061	**0.0492***	0.4254
Proportion Abundance Specialist	Site Area	1	0.14540712	5.0061	**0.0492***	0.4254
Proportion Abundance Migratory	Site Area	1	0.0028374	0.2422	0.6333	
Proportion Abundance Nonmigratory	Site Area	1	0.0028374	0.2422	0.6333	
Proportion Abundance Univoltine	Site Area	1	0.03284645	87.1454	**<.0001***	**0.0004***
Proportion Abundance Multivoltine	Site Area	1	0.03284645	87.1454	**<.0001***	**0.0004***
Rarefied Shannon Diversity	Proportion Impervious Surface	1	1.3452117	0.5656	0.4693	
Butterfly Visits	Proportion Impervious Surface	1	297.76361	2.4525	0.1484	
Proportion Native Bloom Cover	Proportion Impervious Surface	1	0.00885687	0.1131	0.7436	
Exotic Plant Visits	Proportion Impervious Surface	1	6.0739651	0.0971	0.7617	
Native Plant Visits	Proportion Impervious Surface	1	192.97811	2.2682	0.163	
Proportion Visits Native	Proportion Impervious Surface	1	0.00040515	0.0115	0.9167	
Butterfly Abundance	Proportion Impervious Surface	1	309.36964	2.6345	0.1356	
Butterfly Richness	Proportion Impervious Surface	1	13.999697	5.6185	**0.0393***	0.2128
Plant Richness	Proportion Impervious Surface	1	0.00076817	0	0.9982	
Butterfly Generalist Abundance	Proportion Impervious Surface	1	38.841302	0.9317	0.3572	
Butterfly Specialist Abundance	Proportion Impervious Surface	1	131.17162	2.1667	0.1718	
Butterfly Average Wingspan	Proportion Impervious Surface	1	0.24478436	2.878	0.1207	
Migratory Butterfly Abundance	Proportion Impervious Surface	1	1.8611261	0.141	0.7151	

Response	**Predictor**	**Df**	**Sum Sq.**	**F**	**P-value**	**Shapiro-Wilks (Prob<W)***
Nonmigratory Butterfly Abundance	Proportion Impervious Surface	1	266.3772	3.5866	0.0875	
Univoltine Butterfly Abundance	Proportion Impervious Surface	1	1.3115215	1.7649	0.2135	
Multivoltine Butterfly Abundance	Proportion Impervious Surface	1	354.58826	3.3814	0.0958	
Network Specialization (H2)	Proportion Impervious Surface	1	0.00192379	0.0615	0.8091	
Proportion Abundance Generalist	Proportion Impervious Surface	1	0.00278957	0.0644	0.8048	
Proportion Abundance Specialist	Proportion Impervious Surface	1	0.00278957	0.0644	0.8048	
Proportion Abundance Migratory	Proportion Impervious Surface	1	0.00864894	0.7767	0.3988	
Proportion Abundance Nonmigratory	Proportion Impervious Surface	1	0.00864894	0.7767	0.3988	
Proportion Abundance Univoltine	Proportion Impervious Surface	1	0.00488817	1.5407	0.2428	
Proportion Abundance Multivoltine	Proportion Impervious Surface	1	0.00488817	1.5407	0.2428	
Rarefied Shannon Diversity	Proportion Native Bloom	1	4.2799366	2.0528	0.1824	
Butterfly Visits	Proportion Native Bloom	1	167.16969	1.2431	0.2909	
Butterfly Abundance	Proportion Native Bloom	1	239.69222	1.9268	0.1953	
Butterfly Richness	Proportion Native Bloom	1	1.0710469	0.283	0.6064	
Proportion Abundance Generalist	Proportion Native Bloom	1	0.11699157	3.6689	0.0844	
Proportion Abundance Specialist	Proportion Native Bloom	1	0.11699157	3.6689	0.0844	
Proportion Abundance Migratory	Proportion Native Bloom	1	0.00239379	0.2035	0.6615	
Proportion Abundance Nonmigratory	Proportion Native Bloom	1	0.00239379	0.2035	0.6615	
Proportion Abundance Univoltine	Proportion Native Bloom	1	0.00113028	0.3185	0.5849	
Proportion Abundance Multivoltine	Proportion Native Bloom	1	0.00113028	0.3185	0.5849	
Rarefied Shannon Diversity	Proportion Native Plant Richness	1	12.025747	9.1778	**0.0127***	0.7142
Butterfly Visits	Proportion Native Plant Richness	1	89.560457	0.6297	0.4459	
Butterfly Abundance	Proportion Native Plant Richness	1	85.9819	0.6152	0.451	
Butterfly Richness	Proportion Native Plant Richness	1	2.8602263	0.7933	0.394	
Proportion Abundance Generalist	Proportion Native Plant Richness	1	0.07353611	2.0295	0.1847	
Proportion Abundance Specialist	Proportion Native Plant Richness	1	0.07353611	2.0295	0.1847	

Response	**Predictor**	**Df**	**Sum Sq.**	**F**	**P-value**	**Shapiro-Wilks (Prob<W)***
Proportion Abundance Migratory	Proportion Native Plant Richness	1	0.00292348	0.2497	0.6281	
Proportion Abundance Nonmigratory	Proportion Native Plant Richness	1	0.00292348	0.2497	0.6281	
Proportion Abundance Univoltine	Proportion Native Plant Richness	1	0.00128322	0.3632	0.5602	
Proportion Abundance Multivoltine	Proportion Native Plant Richness	1	0.00128322	0.3632	0.5602	

*Shapiro-Wilks Prob<W results only reported for parameter-responses with significant p-values. **Bold** p-values indicate significant trends, while **bold** Prob<W values render significant p-values obsolete.

Literature Cited

Aguirre-Gutiérrez, J., WallisDeVries, M. F., Marshall, L., van't Zelfde, M., Villalobos-Arámbula, A. R., Boekelo, B., Bartholomeus, H., Franzén, M., & Biesmeijer, J. C. (2017). Butterflies show different functional and species diversity in relationship to vegetation structure and land use. *Global Ecology and Biogeography*, *26*(10), 1126–1137. https://doi.org/10.1111/geb.12622

Aizen, M. A., Garibaldi, L. A., Cunningham, S. A., & Klein, A. M. (2009). How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. *Annals of Botany*, *103*(9), 1579–1588. https://doi.org/10.1093/aob/mcp076

Altermatt, F. (2010). Tell me what you eat and I'll tell you when you fly: Diet can predict phenological changes in response to climate change. *Ecology Letters*, *13*(12), 1475–1484. https://doi.org/10.1111/j.1461-0248.2010.01534.x

Baguette, M., Mennechez, G., Petit, S., & Schtickzelle, N. (2003). Effect of habitat fragmentation on dispersal in the butterfly Proclossiana eunomia. *Comptes Rendus - Biologies*, *326*(SUPPL. 1), 200–209. https://doi.org/10.1016/s1631-0691(03)00058-1

Barnett, J. M., Hudak, P. F., & Dick, G. O. (2016). Removing Chinese Privet (*Ligustrum sinense* Lour.) and Establishing Native Plants in a Flooded Riparian Corridor in North-Central Texas, USA. *Environmental Quality Management*, *26*(2), 121–129. https://doi.org/10.1002/tqem.21489

Barrios-O'Neill, D., Kelly, R., Dick, J. T. A., Ricciardi, A., MacIsaac, H. J., & Emmerson, M. C. (2016). On the context-dependent scaling of consumer feeding rates. *Ecology Letters*, *19*(6), 668–678. https://doi.org/10.1111/ele.12605

Biesmeijer, J. C., Roberts, S. P. M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., Schaffers, A. P., Potts, S. G., Kleukers, R., Thomas, C. D., Settele, J., & Kunin, W. E. (2006). Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science*. https://doi.org/10.1126/science.1127863

Börschig, C., Klein, A. M., von Wehrden, H., & Krauss, J. (2013). Traits of butterfly communities change from specialist to generalist characteristics with increasing land-use intensity. *Basic and Applied Ecology*, *14*(7), 547–554. https://doi.org/10.1016/j.baae.2013.09.002

Breed, G. A., Stichter, S., & Crone, E. E. (2013). Climate-driven changes in northeastern US butterfly communities. *Nature Climate Change*. https://doi.org/10.1038/nclimate1663

Brito, M. M., Ribeiro, D. B., Raniero, M., Hasui, É., Ramos, F. N., & Arab, A. (2014). Functional composition and phenology of fruit-feeding butterflies in a fragmented landscape: Variation of seasonality between habitat specialists. *Journal of Insect Conservation*, *18*(4), 547–560. https://doi.org/10.1007/s10841-014-9650-8

Brittain, C., Kremen, C., & Klein, A. M. (2013). Biodiversity buffers pollination from changes in environmental conditions. *Global Change Biology*. https://doi.org/10.1111/gcb.12043

Brückmann, S. V., Krauss, J., & Steffan-Dewenter, I. (2010). Butterfly and plant specialists suffer from reduced connectivity in fragmented landscapes. *Journal of Applied Ecology*, *47*(4), 799–809. https://doi.org/10.1111/j.1365-2664.2010.01828.x

Brückmann, S. V., Krauss, J., van Achterberg, C., & Steffan-Dewenter, I. (2011). The impact of habitat fragmentation on trophic interactions of the monophagous butterfly Polyommatus coridon. *Journal of Insect Conservation*, *15*(5), 707–714. https://doi.org/10.1007/s10841-010-9370-7

Bukovinszky, T., Potting, R. P. J., Clough, Y., Van Lenteren, J. C., & Vet, L. E. M. (2005). The role of pre- and post- alighting detection mechanisms in the responses to patch size by specialist herbivores. *Oikos*, *109*(3), 435–446. https://doi.org/10.1111/j.0030-1299.2005.13707.x

Burghardt, K. T., Tallamy, D. W., & Gregory Shriver, W. (2009). Impact of native plants on bird and butterfly biodiversity in suburban landscapes. *Conservation Biology*, *23*(1), 219–224. https://doi.org/10.1111/j.1523-1739.2008.01076.x

Center for Sustainable Systems, University of Michigan. 2020. "U.S. Cities Factsheet." Pub. No. CSS09-06.

Chacoff, N. P., & Aizen, M. A. (2006). Edge effects on flower-visiting insects in grapefruit plantations bordering premontane subtropical forest. *Journal of Applied Ecology*, *43*(1), 18–27. https://doi.org/10.1111/j.1365-2664.2005.01116.x

Cusser, S., & Goodell, K. (2013). Diversity and Distribution of Floral Resources Influence the Restoration of Plant-Pollinator Networks on a Reclaimed Strip Mine. *Restoration Ecology*, *21*(6), 713–721. https://doi.org/10.1111/rec.12003

Cutler, G. C., Reeh, K. W., Sproule, J. M., & Ramanaidu, K. (2012). Berry unexpected: Nocturnal pollination of lowbush blueberry. *Canadian Journal of Plant Science*. https://doi.org/10.4141/CJPS2012-026

Daniels, J. C. (2005). Butterflies of Michigan. Cambridge, MN: Adventure Publications.

de Araújo, L. D. A., Quirino, Z. G. M., & Machado, I. C. (2014). High specialisation in the pollination system of Mandevilla tenuifolia (J.C. Mikan) Woodson (Apocynaceae) drives the effectiveness of butterflies as pollinators. *Plant Biology*. https://doi.org/10.1111/plb.12152

Dewitz, J. (2019). National Land Cover Database (NLCD) 2016 Products: U.S. Geological Survey data release, https://doi.org/10.5066/P96HHBIE.

Dormann, C. F., J. Fründ, N. Blüthgen, and B. Gruber (2009). Indices, Graphs and Null Models: Analyzing Bipartite Ecological Networks. Page The Open Ecology Journal.

Dylewski, Ł., Maćkowiak, Ł., & Banaszak-Cibicka, W. (2019). Are all urban green spaces a favourable habitat for pollinator communities? Bees, butterflies and hoverflies in different urban green areas. *Ecological Entomology*, *44*(5), 678–689. https://doi.org/10.1111/een.12744

Ebeling, A., Klein, A. M., Schumacher, J., Weisser, W. W., & Tscharntke, T. (2008). How does plant richness affect pollinator richness and temporal stability of flower visits? *Oikos*, *117*(12), 1808–1815. https://doi.org/10.1111/j.1600-0706.2008.16819.x

Eilers, E. J., Kremen, C., Smith Greenleaf, S., Garber, A. K., & Klein, A.-M. (2011). Contribution of Pollinator-Mediated Crops to Nutrients in the Human Food Supply. *PLoS ONE*, *6*(6), e21363. https://doi.org/10.1371/journal.pone.0021363

Eskildsen, A., Carvalheiro, L. G., Kissling, W. D., Biesmeijer, J. C., Schweiger, O., & Høye, T. T. (2015). Ecological specialization matters: long-term trends in butterfly species richness and assemblage composition depend on multiple functional traits. *Diversity and Distributions*, *21*(7), 792–802. https://doi.org/10.1111/ddi.12340

Fahrig, L. (2017). Ecological Responses to Habitat Fragmentation Per Se. *Annual Review of Ecology, Evolution, and Systematics*, *48*(1), 1–23. https://doi.org/10.1146/annurev-ecolsys-110316-022612

Fenster, C. B., Armbruster, W. S., Wilson, P., Dudash, M. R., & Thomson, J. D. (2004). Pollination Syndromes and Floral Specialization. *Annual Review of Ecology, Evolution, and Systematics*, *35*(1), 375–403. https://doi.org/10.1146/annurev.ecolsys.34.011802.132347

Filgueiras, B. K. C., Melo, D. H. A., Leal, I. R., Tabarelli, M., Freitas, A. V. L., & Iannuzzi, L. (2016). Fruit-feeding butterflies in edge-dominated habitats: community structure, species persistence and cascade effect. *Journal of Insect Conservation*, *20*(3), 539–548. https://doi.org/10.1007/s10841-016-9888-4

Filz, K. J., Wiemers, M., Herrig, A., Weitzel, M., & Schmitt, T. (2013). A question of adaptability: Climate and habitat change lower trait diversity in butterfly communities in south-western Germany. *European Journal of Entomology*, *110*(4), 633–642. https://doi.org/10.14411/eje.2013.086

Finkbeiner, S. D., Briscoe, A. D., & Reed, R. D. (2012). The benefit of being a social butterfly: Communal roosting deters predation. *Proceedings of the Royal Society B: Biological Sciences*. https://doi.org/10.1098/rspb.2012.0203

Flanders, A. A., Kuvlesky, W. P., Ruthven, D. C., Zaiglin, R. E., Bingham, R. L., Fulbright, T. E., Hernández, F., & Brennan, L. A. (2006). Effects of Invasive Exotic Grasses on South Texas Rangeland Breeding Birds. *The Auk*, *123*(1), 171–182. https://doi.org/10.1093/auk/123.1.171

Fletcher, R. J., Didham, R. K., Banks-Leite, C., Barlow, J., Ewers, R. M., Rosindell, J., Holt, R. D., Gonzalez, A., Pardini, R., Damschen, E. I., Melo, F. P. L., Ries, L., Prevedello, J. A., Tscharntke, T., Laurance, W. F., Lovejoy, T., & Haddad, N. M. (2018). Is habitat fragmentation good for biodiversity? In *Biological Conservation* (Vol. 226, pp. 9–15). Elsevier Ltd. https://doi.org/10.1016/j.biocon.2018.07.022

Frankie, G., Pawelek, J., Chase, M. H., Jadallah, C. C., Feng, I., Rizzardi, M., & Thorp, R. (2019). Native and non-native plants attract diverse bees to urban gardens in California. *Journal of Pollination Ecology*, *25*(3), 16–23.

Frost, C. J., & Hunter, M. D. (2004). Insect canopy herbivory and frass deposition affect soil nutrient dynamics and export in oak mesocosms. *Ecology*, *85*(12), 3335–3347. https://doi.org/10.1890/04-0003

Funamoto, D. (2019). Precise sternotribic pollination by settling moths in adenophora maximowicziana (Campanulaceae). *International Journal of Plant Sciences*. https://doi.org/10.1086/701734

Gallai, N., Salles, J. M., Settele, J., & Vaissière, B. E. (2009). Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics*, *68*(3), 810–821. https://doi.org/10.1016/j.ecolecon.2008.06.014

Gámez-Virués, S., Perović, D. J., Gossner, M. M., Börschig, C., Blüthgen, N., de Jong, H., Simons, N. K., Klein, A.-M., Krauss, J., Maier, G., Scherber, C., Steckel, J., Rothenwöhrer, C., Steffan-Dewenter, I., Weiner, C. N., Weisser, W., Werner, M., Tscharntke, T., & Westphal, C. (2015). Landscape simplification filters species traits and drives biotic homogenization. *Nature Communications*, *6*(1), 8568. https://doi.org/10.1038/ncomms9568

Gioria, M., & Osborne, B. A. (2014). Resource competition in plant invasions: Emerging patterns and research needs. In *Frontiers in Plant Science* (Vol. 5, Issue SEP, p. 501). Frontiers Media S.A. https://doi.org/10.3389/fpls.2014.00501

Habel, J. C., Segerer, A., Ulrich, W., Torchyk, O., Weisser, W. W., & Schmitt, T. (2016). Butterfly community shifts over two centuries. *Conservation Biology*, *30*(4), 754–762. https://doi.org/10.1111/cobi.12656

Habel, J. C., Ulrich, W., & Schmitt, T. (2019). Butterflies in corridors: quality matters for specialists. *Insect Conservation and Diversity*. https://doi.org/10.1111/icad.12386

Haddad, N. M., Tilman, D., Haarstad, J., Ritchie, M., & Knops, J. M. H. (2001). Contrasting effects of plant richness and composition on insect communities: A field experiment. *American Naturalist*, *158*(1), 17–35. https://doi.org/10.1086/320866

Haddad, N. M., Brudvig, L. A., Clobert, J., Davies, K. F., Gonzalez, A., Holt, R. D., Lovejoy, T. E., Sexton, J. O., Austin, M. P., Collins, C. D., Cook, W. M., Damschen, E. I., Ewers, R. M., Foster, B. L., Jenkins, C. N., King, A. J., Laurance, W. F., Levey, D. J., Margules, C. R., … Townshend, J. R. (2015). Habitat fragmentation and its lasting impact on Earth's ecosystems. *Science Advances*, *1*(2), e1500052. https://doi.org/10.1126/sciadv.1500052

Haddad, N. M., Crutsinger, G. M., Gross, K., Haarstad, J., Knops, J. M. H., & Tilman, D. (2009). Plant species loss decreases arthropod diversity and shifts trophic structure. *Ecology Letters*, *12*(10), 1029–1039. https://doi.org/10.1111/j.1461-0248.2009.01356.x

Hallmann, C. A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., Stenmans, W., Müller, A., Sumser, H., Hörren, T., Goulson, D., & de Kroon, H. (2017). More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLOS ONE*, *12*(10), e0185809. https://doi.org/10.1371/journal.pone.0185809

Hambäck, P. A., Summerville, K. S., Steffan-Dewenter, I., Krauss, J., Englund, G., & Crist, T. O. (2007). Habitat specialization, body size, and family identity explain lepidopteran density-area relationships in a cross-continental comparison. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(20), 8368–8373. https://doi.org/10.1073/pnas.0611462104

Hanski, I. A. (2011). Eco-evolutionary spatial dynamics in the Glanville fritillary butterfly. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(35), 14397–14404. https://doi.org/10.1073/pnas.1110020108

Hanspach, J., Loos, J., Dorresteijn, I., Von wehrden, H., Moga, C. I., & David, A. (2015). Functional diversity and trait composition of butterfly and bird communities in farmlands of central romania. *Ecosystem Health and Sustainability*, *1*(10), 1–8. https://doi.org/10.1890/EHS15-0027.1

Hartley, S. E., & Jones, T. H. (2008). *Insect Herbivores, Nutrient Cycling and Plant Productivity*. *173*, 27–52. https://doi.org/10.1007/978-3-540-74004-9_2

Hermann, S. L., Blackledge, C., Haan, N. L., Myers, A. T., & Landis, D. A. (2019). Predators of monarch butterfly eggs and neonate larvae are more diverse than previously recognised. *Scientific Reports*. https://doi.org/10.1038/s41598-019-50737-5

Hill, J. K., Thomas, C. D., & Lewis, O. T. (1996). Effects of Habitat Patch Size and Isolation on Dispersal by Hesperia comma Butterflies: Implications for Metapopulation Structure. *The Journal of Animal Ecology*, *65*(6), 725. https://doi.org/10.2307/5671

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, I. (2016). *Assessment Report on Pollinators, Pollination and Food Production*. https://doi.org/10.5281/ZENODO.3402857

Kaukonen, M., Ruotsalainen, A. L., Wäli, P. R., Männistö, M. K., Setälä, H., Saravesi, K., Huusko, K., & Markkola, A. (2013). Moth herbivory enhances resource turnover in subarctic mountain birch forests? *Ecology*, *94*(2), 267–272. https://doi.org/10.1890/12-0917.1

Keitt, T. H. (2009). Habitat conversion, extinction thresholds, and pollination services in agroecosystems. *Ecological Applications*. https://doi.org/10.1890/08-0117.1

Klein Goldewijk, K., Beusen, A., & Janssen, P. (2010). Long-term dynamic modeling of global population and built-up area in a spatially explicit way: HYDE 3.1. *The Holocene*, *20*(4), 565–573. https://doi.org/10.1177/0959683609356587

Klein, A. M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. In *Proceedings of the Royal Society B: Biological Sciences*. https://doi.org/10.1098/rspb.2006.3721

Konvicka, M., & Kadlec, T. (2011). How to increase the value of urban areas for butterfly conservation? A lesson from Prague nature reserves and parks. *European Journal of Entomology*, *108*(2), 219–229. https://doi.org/10.14411/eje.2011.030

Krauss, J., Bommarco, R., Guardiola, M., Heikkinen, R. K., Helm, A., Kuussaari, M., Lindborg, R., Öckinger, E., Pärtel, M., Pino, J., Pöyry, J., Raatikainen, K. M., Sang, A., Stefanescu, C., Teder, T., Zobel, M., & Steffan-Dewenter, I. (2010). Habitat fragmentation causes immediate and time-delayed biodiversity loss at different trophic levels. *Ecology Letters*, *13*(5), 597–605. https://doi.org/10.1111/j.1461-0248.2010.01457.x

Kremen, C., Williams, N. M., & Thorp, R. W. (2002). Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences of the United States of America*, *99*(26), 16812–16816. https://doi.org/10.1073/pnas.262413599

Kurylo, J. S., Threlfall, C. G., Parris, K. M., Ossola, A., Williams, N. S. G., & Evans, K. L. (2020). Butterfly richness and abundance along a gradient of imperviousness and the importance of matrix quality. *Ecological Applications*, *30*(7). https://doi.org/10.1002/eap.2144

Kuussaari, M., Heliölä, J., Luoto, M., & Pöyry, J. (2007). Determinants of local species richness of diurnal Lepidoptera in boreal agricultural landscapes. *Agriculture, Ecosystems and Environment*, *122*(3), 366–376. https://doi.org/10.1016/j.agee.2007.02.008

Lister, B. C., & Garcia, A. (2018). Climate-driven declines in arthropod abundance restructure a rainforest food web. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(44), E10397–E10406. https://doi.org/10.1073/pnas.1722477115

Lizée, M. H., Manel, S., Mauffrey, J. F., Tatoni, T., & Deschamps-Cottin, M. (2012). Matrix configuration and patch isolation influences override the species-area relationship for urban butterfly communities. *Landscape Ecology*, *27*(2), 159–169. https://doi.org/10.1007/s10980-011-9651-x

M'Gonigle, L. K., Ponisio, L. C., Cutler, K., & Kremen, C. (2015). Habitat restoration promotes pollinator persistence and colonization in intensively managed agriculture. *Ecological Applications*, *25*(6), 1557–1565. https://doi.org/10.1890/14-1863.1

Martin, E. A., B. Seo, C.-R. Park, B. Reineking, and I. Steffan-Dewenter. 2016. Scale-dependent effects of landscape composition and configuration on natural enemy diversity, crop herbivory, and yields. *Ecological Applications 26*:448–462.

McGarigal, K., SA Cushman, and E Ene. 2012. FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer software program produced

by the authors at the University of Massachusetts, Amherst. Available at the following web site: http://www.umass.edu/landeco/research/fragstats/fragstats.html

McTavish, M. J., Smenderovac, E., Gunn, J., Murphy, S. D., & Brent, C. (2019). Insect Defoliators in Recovering Industrial Landscapes: Effects of Landscape Degradation and Remediation Near an Abandoned Metal Smelter on Gypsy Moth (Lepidoptera: Lymantriidae) Feeding, Frass Production, and Frass Properties. *Environmental Entomology*, *48*(5), 1187–1196. https://doi.org/10.1093/ee/nvz096

Mebs, D., Wunder, C., Pogoda, W., & Toennes, S. W. (2017). Feeding on toxic prey. The praying mantis (Mantodea) as predator of poisonous butterfly and moth (Lepidoptera) caterpillars. *Toxicon*, *131*, 16–19. https://doi.org/10.1016/j.toxicon.2017.03.010

Michigan Department of Natural Resources. (2009). MICHIGAN KARNER BLUE BUTTERFLY HABITAT CONSERVATION PLAN. Retrieved from https://www.michigan.gov/documents/dnr/2009_Michigan_Karner_Blue_Butterfly_Habitat_Conservation_Plan_Division_Report_number_3514_328672_7.pdf

Moré, M., Sérsic, A. N., & Cocucci, A. A. (2007). Restriction of pollinator assemblage through flower length and width in three long-tongued hawkmoth-pollinated species of Mandevilla (Apocynaceae, Apocynoideae). *Annals of the Missouri Botanical Garden*. https://doi.org/10.3417/0026-6493(2007)94[485:ROPATF]2.0.CO;2

Narango, D. L., Tallamy, D. W., & Marra, P. P. (2017). Native plants improve breeding and foraging habitat for an insectivorous bird. *Biological Conservation*, *213*, 42–50. https://doi.org/10.1016/j.biocon.2017.06.029

National Research Council. 2007. Status of Pollinators in North America. Washington, DC: The National Academies Press. https://doi.org/10.17226/11761.

Ne'eman, G., Jürgens, A., Newstrom-Lloyd, L., Potts, S. G., & Dafni, A. (2009). A framework for comparing pollinator performance: effectiveness and efficiency. *Biological Reviews*, *85*(3). https://doi.org/10.1111/j.1469-185X.2009.00108.x

Nowicki, P., Vrabec, V., Binzenhöfer, B., Feil, J., Zakšek, B., Hovestadt, T., & Settele, J. (2014). Butterfly dispersal in inhospitable matrix: Rare, risky, but long-distance. *Landscape Ecology*, *29*(3), 401–412. https://doi.org/10.1007/s10980-013-9971-0

Öckinger, E., Dannestam, Å., & Smith, H. G. (2009). The importance of fragmentation and habitat quality of urban grasslands for butterfly diversity. *Landscape and Urban Planning*. https://doi.org/10.1016/j.landurbplan.2009.05.021

Öckinger, E., & Smith, H. G. (2007). Semi-natural grasslands as population sources for pollinating insects in agricultural landscapes. *Journal of Applied Ecology*. https://doi.org/10.1111/j.1365-2664.2006.01250.x

Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.H.H., Szoecs, E., & Wagner, H. (2019). vegan: Community Ecology Package. R package version 2.5-6. Retrieved from https://CRAN.R-project.org/package=vegan

Perović, D., Gámez-Virués, S., Börschig, C., Klein, A. M., Krauss, J., Steckel, J., Rothenwöhrer, C., Erasmi, S., Tscharntke, T., & Westphal, C. (2015). Configurational landscape heterogeneity shapes functional community composition of grassland butterflies. *Journal of Applied Ecology*, *52*(2), 505–513. https://doi.org/10.1111/1365-2664.12394

Pleasants, J. M., & Oberhauser, K. S. (2013). Milkweed loss in agricultural fields because of herbicide use: Effect on the monarch butterfly population. *Insect Conservation and Diversity*, *6*(2), 135–144. https://doi.org/10.1111/j.1752-4598.2012.00196.x

Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: Trends, impacts and drivers. In *Trends in Ecology and Evolution* (Vol. 25, Issue 6, pp. 345–353). https://doi.org/10.1016/j.tree.2010.01.007

Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: Trends, impacts and drivers. In *Trends in Ecology and Evolution*. https://doi.org/10.1016/j.tree.2010.01.007

Rader, R., Bartomeus, I., Garibaldi, L. A., Garratt, M. P. D., Howlett, B. G., Winfree, R., Cunningham, S. A., Mayfield, M. M., Arthur, A. D., Andersson, G. K. S., Bommarco, R., Brittain, C., Carvalheiro, L. G., Chacoff, N. P., Entling, M. H., Foully, B., Freitas, B. M., Gemmill-Herren, B., Ghazoul, J., … Woyciechowski, M. (2016). Non-bee insects are important contributors to global crop pollination. *Proceedings of the National Academy of Sciences of the United States of America*, *113*(1), 146–151. https://doi.org/10.1073/pnas.1517092112

Raj, H. (2017). Various threatening factors to the biodiversity of insect pollinators in Himachal Himalaya , India. *International Journal of Sciences & Applied Research*.

Richardson, D. M., Allsopp, N., D'Antonio, C. M., Milton, S. J., & Rejmánek, M. (2000). Plant invasions – the role of mutualisms. *Biological Reviews of the Cambridge Philosophical Society*, *75*(1), 65–93. https://doi.org/10.1017/s0006323199005435

Ricketts, T. H., Regetz, J., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., Bogdanski, A., Gemmill-Herren, B., Greenleaf, S. S., Klein, A. M., Mayfield, M. M., Morandin, L. A., Ochieng', A., & Viana, B. F. (2008). Landscape effects on crop pollination services: Are there general patterns? *Ecology Letters*, *11*(5), 499–515. https://doi.org/10.1111/j.1461-0248.2008.01157.x

Ries, L., & Debinski, D. M. (2001). Butterfly responses to habitat edges in the highly fragmented prairies of Central Iowa. *Journal of Animal Ecology*, *70*(5), 840–852. https://doi.org/10.1046/j.0021-8790.2001.00546.x

Ries, L., Debinski, D. M., & Wieland, M. L. (2001). Conservation value of roadside prairie restoration to butterfly communities. In *Conservation Biology* (Vol. 15, Issue 2, pp. 401–411). https://doi.org/10.1046/j.1523-1739.2001.015002401.x

Rojas, B., Burdfield-Steel, E., Pakkanen, H., Suisto, K., Maczka, M., Schulz, S., & Mappes, J. (2017). How to fight multiple enemies: Target-specific chemical defences in an aposematic moth. *Proceedings of the Royal Society B: Biological Sciences*, *284*(1863). https://doi.org/10.1098/rspb.2017.1424

Salisbury, A., Armitage, J., Bostock, H., Perry, J., Tatchell, M., & Thompson, K. (2015). Enhancing gardens as habitats for flower-visiting aerial insects (pollinators): Should we plant native or exotic species? *Journal of Applied Ecology*, *52*(5), 1156–1164. https://doi.org/10.1111/1365-2664.12499

Sánchez-Bayo, F., & Wyckhuys, K. A. G. (2019). Worldwide decline of the entomofauna: A review of its drivers. In *Biological Conservation*. https://doi.org/10.1016/j.biocon.2019.01.020

Santos, J. dos, Varassin, I. G., & Muschner, V. C. (2018). Effects of neighborhood on pollination and seed dispersal of a threatened palm. *Acta Oecologica*, *92*, 95–101. https://doi.org/10.1016/j.actao.2018.08.010

Schweiger, O., Settele, J., Kudrna, O., Klotz, S., & Kühn, I. (2008). Climate change can cause spatial mismatch of trophically interacting species. *Ecology*, *89*(12), 3472–3479. https://doi.org/10.1890/07-1748.1

Scott, J. A. (1986). The butterflies of North America: A natural history and field guide. Stanford, CA: Stanford University Press.

Seibold, S., Gossner, M. M., Simons, N. K., Blüthgen, N., Müller, J., Ambarlı, D., Ammer, C., Bauhus, J., Fischer, M., Habel, J. C., Linsenmair, K. E., Nauss, T., Penone, C., Prati, D., Schall, P., Schulze, E. D., Vogt, J., Wöllauer, S., & Weisser, W. W. (2019).

Arthropod decline in grasslands and forests is associated with landscape-level drivers. *Nature*, *574*(7780), 671–674. https://doi.org/10.1038/s41586-019-1684-3

Settele, J., Kudrna, O., Harpke, A., Kühn, I., & Swaay, Van, C. (2008). *Climatic risk atlas of European butterflies. Biodiversity and ecosystem risk assessment 1*. http://books.google.hu/books?id=emxFAQAAIAAJ

Sirami, C., Gross, N., Baillod, A. B., Bertrand, C., Carrié, R., Hass, A., Henckel, L., Miguet, P., Vuillot, C., Alignier, A., Girard, J., Batáry, P., Clough, Y., Violle, C., Giralt, D., Bota, G., Badenhausser, I., Lefebvre, G., Gauffre, B., … Fahrig, L. (2019). Increasing crop heterogeneity enhances multitrophic diversity across agricultural regions. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(33), 16442–16447. https://doi.org/10.1073/pnas.1906419116

Solis-Gabriel, L., Mendoza-Arroyo, W., Boege, K., & del-Val, E. (2017). Restoring lepidopteran diversity in a tropical dry forest: Relative importance of restoration treatment, tree identity and predator pressure. *PeerJ*. https://doi.org/10.7717/peerj.3344

Spitzer, L., Benes, J., Dandova, J., Jaskova, V., & Konvicka, M. (2009). The Large Blue butterfly, Phengaris [Maculinea] arion, as a conservation umbrella on a landscape scale: The case of the Czech Carpathians. *Ecological Indicators*. https://doi.org/10.1016/j.ecolind.2008.12.006

Staab, M., Pereira-Peixoto, M. H., & Klein, A. M. (2020). Exotic garden plants partly substitute for native plants as resources for pollinators when native plants become seasonally scarce. *Oecologia*, *0123456789*. https://doi.org/10.1007/s00442-020-04785-8

Steffan-Dewenter, I., & Tscharntke, T. (2000). Butterfly community structure in fragmented habitats. *Ecology Letters*, *3*(5), 449–456. https://doi.org/10.1111/j.1461-0248.2000.00175.x

Swengel, S. R., Schlicht, D., Olsen, F., & Swengel, A. B. (2011). Declines of prairie butterflies in the midwestern USA. *Journal of Insect Conservation*, *15*(1), 327–339. https://doi.org/10.1007/s10841-010-9323-1

Tallamy, D. W., Ballard, M., & D'Amico, V. (2010). Can alien plants support generalist insect herbivores? *Biological Invasions*, *12*(7), 2285–2292. https://doi.org/10.1007/s10530-009-9639-5

Tawril, A.L. (2020). Environmental Factors Influencing Pollinator Communities in Human Dominated Ecosystems. [Master's thesis, Oakland University].

Tewksbury, J. J., Levey, D. J., Haddad, N. M., Sargent, S., Orrock, J. L., Weldon, A., Danielson, B. J., Brinkerhoff, J., Damschen, E. I., & Townsend, P. (2002). Corridors affect plants, animals, and their interactions in fragmented landscapes. *Proceedings of the National Academy of Sciences of the United States of America*, *99*(20), 12923–12926. https://doi.org/10.1073/pnas.202242699

Theodorou, P., Radzevičiūtė, R., Lentendu, G., Kahnt, B., Husemann, M., Bleidorn, C., Settele, J., Schweiger, O., Grosse, I., Wubet, T., Murray, T. E., & Paxton, R. J. (2020). Urban areas as hotspots for bees and pollination but not a panacea for all insects. *Nature Communications*, *11*(1), 1–13. https://doi.org/10.1038/s41467-020-14496-6

Thomas, J. A. (2005). Monitoring change in the abundance and distribution of insects using butterflies and other indicator groups. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *360*(1454), 339–357. https://doi.org/10.1098/rstb.2004.1585

Thomas, J. A., Telfer, M. G., Roy, D. B., Preston, C. D., Greenwood, J. J. D., Asher, J., Fox, R., Clarke, R. T., & Lawton, J. H. (2004). Comparative Losses of British Butterflies, Birds, and Plants and the Global Extinction Crisis. *Science*, *303*(5665), 1879–1881. https://doi.org/10.1126/science.1095046

Traveset, A., Tur, C., & Eguíluz, V. M. (2017). Plant survival and keystone pollinator species in stochastic coextinction models: Role of intrinsic dependence on animal-pollination. *Scientific Reports 7*(6915*).* https://doi.org/10.1038/s41598-017-07037-7

USDA Natural Resources Conservation Service. (2000). Butterflies (Order: Lepidoptera). Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_010038.pdf

Van Dyck, H., Van Strien, A. J., Maes, D., & Van Swaay, C. A. M. (2009). Declines in common, widespread butterflies in a landscape under intense human use. *Conservation Biology*, *23*(4), 957–965. https://doi.org/10.1111/j.1523-1739.2009.01175.x

van Swaay, C. A. M., & Warren, M. S. (2006). Prime Butterfly Areas of Europe: An initial selection of priority sites for conservation. *Journal of Insect Conservation*, *10*(1), 5–11. https://doi.org/10.1007/s10841-005-7548-1

Vanbergen, A. J., Hails, R. S., Watt, A. D., & Jones, T. H. (2006). Consequences for host-parasitoid interactions of grazing-dependent habitat heterogeneity. *Journal of Animal Ecology*. https://doi.org/10.1111/j.1365-2656.2006.01099.x

Vanengelsdorp, D., Hayes, J., Underwood, R. M., & Pettis, J. (2008). A Survey of Honey Bee Colony Losses in the U. *PLoS ONE*, *3*(12). https://doi.org/10.1371/journal.pone.0004071

Warren, M. S., Hill, J. K., Thomas, J. A., Asher, J., Fox, R., Huntley, B., Roy, D. B., Telfer, M. G., Jeffcoate, S., Harding, P., Jeffcoate, G., Willis, S. G., Greatorex-Davies, J. N., Moss, D., & Thomas, C. D. (2001). Rapid responses of British butterflies to opposing forces of climate and habitat change. *Nature*, *414*(6859), 65–69. https://doi.org/10.1038/35102054

Winfree, R., Bartomeus, I., & Cariveau, D. P. (2011). Native pollinators in anthropogenic habitats. *Annual Review of Ecology, Evolution, and Systematics*. https://doi.org/10.1146/annurev-ecolsys-102710-145042