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Not All Pollinator Gardens are Created Equally: Determining Factors Pertinent to Improving
Pollinator Garden Effectiveness

A thesis

presented to

the faculty of the Department of Biological Sciences

East Tennessee State University

In partial fulfillment

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Master of Science in Biology

by

Travis Watson

May 2021

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Dr. Darrell Moore

Keywords: floral diversity, native status, land-use, pollinators, functional groups

ABSTRACT

Not All Pollinator Gardens are Created Equally: Determining Factors Pertinent to Improving Pollinator Garden Effectiveness

by

Travis Watson

Increasing evidence documenting the decline of insect populations, resulting from increasing human disturbances has resulted in efforts to establish pollinator gardens to provide additional resources for insect populations. However, our understanding of biotic and abiotic garden characteristics important for attracting and sustaining pollinator diversity is limited. Here, we evaluated 17 pollinator gardens to evaluate the effect of five biotic and three abiotic garden characteristics on pollinator species richness, abundance, and proportional representation of four pollinator functional groups. Plant species richness positively influenced pollinator richness and negatively influenced flower visitation. *Bombus* proportional abundance responded to several variables (distance to vegetation, plant species richness, floral symmetry, floral native status, habitat type) and decreases in their proportional representation were accompanied by increasing proportions of other insect groups. Our results suggest any size, diverse, native pollinator gardens can improve pollinator diversity, and small-scale pollinator gardens should favor functional groups adapted for the habitat type.

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CHAPTER 1. INTRODUCTION

Introduction

Ecosystem services, such as pollination, are under growing threat in recent years, due to increasing human influence on natural ecosystems (Foley et al. 2005; Reid et al. 2005; Hooper et al. 2012). Growing demand for agricultural land, urbanization, and pesticide use have all been associated with alarming declines in global insect populations, especially bees (Potts et al. 2010; Valiente-Banuet et al. 2015; Loh et al. 2020). The pollination services provided by insect pollinators are critical to the reproductive success of 80% of angiosperms (Ollerton et al. 2011; Loh et al. 2020). Additionally, 75% of the world's primary food crops depend on insect pollination to enhance crop yields (Bell et al. 2005; Potts et al. 2010) making pollination critical to human health. In recent years, conservation groups, ecologists, and individuals have become increasingly concerned with mitigating insect declines in an effort to preserve this critical ecosystem service.

Pollinator Garden Movement. 'Pollinator Gardens' have become a popular means of providing floral resources for pollinator insects. One conservation group alone currently has >1,000,000 pollinator gardens registered in the United States (National Pollinator Garden Network 2020). These gardens are characterized by mass plantings of wildflowers intended to attract and support pollinators by providing additional food sources in areas of low resource availability (Cane 2013; Widows and Drake 2014; Salisbury et al. 2015). However, despite the increase in pollinator garden installation, our understanding of their effectiveness at mitigating pollinator declines is limited. Determining how the biotic and abiotic characteristics of pollinator

gardens influence the abundance and diversity of the pollinators they attract is critical to maximizing the effectiveness of these gardens at mitigating pollinator population declines.

Limits of Understanding. Our current understanding of the garden characteristics important to attracting and supporting a diverse and abundant pollinator community are largely shaped by studies focused on one particular plant or insect species (Totland and Matthews 1998; Avarguès-Weber and Chittka 2014; Quistberg et al. 2016; Plascencia and Philpott 2017; Boyle et al. 2019), or specific aspects of the landscape (edge density, land-use type, floral density) (Matteson and Langelloto 2011; Beans and Roach 2015; LaPoint et al. 2015; Plascencia and Philpott 2017; Simao et al. 2018). Few studies have focused specifically on ‘Pollinator Gardens’ and the functional characteristics that have the greatest influence over pollinator community composition (Hanley et al. 2014; Salisbury et al. 2015; Davis et al. 2017; Johnson et al. 2017; Simao et al. 2018; Rollings and Goulson 2019). Lack of consensus among design guidelines and the number of individuals planting pollinator gardens has resulted in much variation in garden size, plant species composition, floral density, and habitat type (personal observation) across the region.

Diversity of Insect Groups. Much of the focus for the pollinator garden movement has been on a select few insects, such as Honeybees or Monarch butterflies (Avarguès-Weber and Chittka 2014; Boyle et al. 2019). However, insect pollinators are a diverse group of organisms that span multiple orders (coleoptera, diptera, hymenoptera, hemiptera, lepidoptera) and have a broad range of foraging and habitat requirements (Padyšáková et al. 2013; Rader et al. 2016; Ollerton 2017; Arce et al. 2018; Harrison et al. 2018). Research has shown that different groups of insects respond differently to local and landscape scale factors based on differences in insect functional traits (Couvillon et al. 2015; Quistberg et al. 2016; Harrison et al. 2018). Therefore,

common metrics such as, abundance, richness, and diversity, may not provide a clear picture as to how the insect community responds to the additional floral resources (Plascencia and Philpott 2017; Harrison et al. 2018; Simao et al. 2018). Generalist pollinators such as Honeybee and Bumblebee feed on a wide range of plant species and may benefit from additional resources of any type. However, many other insect groups, such as small bees, flies, and beetles, have more specialized floral associations and may not benefit from flowers adapted for more generalist pollination syndromes (Fenster et al. 2004; Gong and Huang 2009; Padyšáková et al. 2013).

In order to better understand what characteristics of pollinator gardens are most important to attracting an abundant and diverse community of pollinators, this study aims to evaluate 1) the functional traits and, 2) plant species characteristics of pollinator gardens with the greatest influence on the diversity and proportional abundance of five pollinator functional groups (Bumblebees, Honeybees, small bees, lepidopteran, other insects).

CHAPTER 2. FLORAL DIVERSITY, NATIVE STATUS, AND LAND-USE SHAPE POLLINATOR COMMUNITY ASSEMBLAGE IN POLLINATOR GARDENS.

ABSTRACT

Increasing evidence is accumulating documenting the decline of insect populations globally. Mainly resulting from increasing human disturbances. This has resulted in increasing efforts to mitigate pollinator losses by establishing pollinator gardens to provide additional resources for insect populations. However, we still have very limited understanding of the biotic and abiotic garden characteristics that are important for attracting and sustaining pollinator diversity. Here, we surveyed 17 pollinator gardens across the Appalachian-Blue ridge mountain ecoregion to evaluate the effect of five biotic and three abiotic garden characteristics on pollinator species richness, abundance, and the proportional representation of four pollinator functional groups. We recorded 149 plant species and 3114 insect-plant interactions. Small bees (other than *Apis*) and *Bombus* were the most abundant visitors (75%) followed by lepidopterans (16%). Asteraceae family plants were most common (40% of species) followed by Lamiaceae (9%). Plant species richness had a positive influence on pollinator richness and negative influence on flower visitation rate. *Bombus* proportional abundance responded to several variables (distance to vegetation, plant species richness, floral symmetry, floral native status, habitat type). However, a decrease in their proportional representation was typically accompanied by increasing proportions of other insect groups (small bees, other insects). Our results suggest diverse, native pollinator gardens of any size can improve pollinator diversity, and that small-scale pollinator garden designs should favor functional groups adapted for the habitat type over those that are not well suited.

Key words: Pollinator Garden, pollinators, land-use, urban, rural, functional diversity.

INTRODUCTION

Human-mediated disturbances to natural ecosystems are one of the greatest threats to biodiversity and ecosystem services (Foley et al., 2005; Reid et al., 2005; Hooper et al., 2012). Recently, an increase in urbanization, demand for agricultural land, and pesticide use have been particularly associated with a global decrease in insect populations (Potts, Biesmeijer, et al., 2010; Valiente-Banuet et al., 2015; Loh et al., 2020). A recent study showed that insect populations have declined globally by more than 8% every decade for the past 95 years (Loh et al., 2020). In central Europe and the US in particular, bee populations have declined by 25% and 59% respectively (Potts, Biesmeijer, et al., 2010; Potts, Roberts, et al., 2010). The decline in pollination services resulting from insect biodiversity loss can have alarming economic consequences, as these are valued at more than \$235 billion dollars globally (Food and Agriculture Organisation of the United Nations, 2016). Furthermore, 75% of all major food crops that are critical to meet the demands of an increasing human population depend on insect pollination (Bell et al., 2005; Potts, Biesmeijer, et al., 2010). The ecological consequences are also distressing, as it is estimated that 80% of angiosperm biodiversity depends partially or completely on insect pollination (Ollerton et al., 2011; Loh et al., 2020) and insects play a foundational role in multiple food webs (Kenneth Schoenly, 2016). As a result, preserving pollination services has become the subject of growing public and scientific interest in recent years (Jaffé et al., 2010; Bates et al., 2011; Hall et al., 2017; Plascencia and Philpott, 2017) and a major goal in Ecology and Conservation Biology (Potts, Biesmeijer, et al., 2010; Gill et al., 2016).

The ‘pollinator garden’ movement (Mitchell, 2016), characterized by mass planting of wildflowers in urban areas, has emerged as a major conservation strategy aimed to increase the amount resources available to pollinators and mitigate their decline (Johnson et al., 2017). At the forefront of this movement is the Pollinator Partnership, a collaboration between conservation groups, federal agencies, garden clubs, and private citizens, which currently has over one million pollinator gardens registered across the United States (National Pollinator Garden Network, 2020). Pollinator gardens are expected to provide additional sources of food (pollen and nectar) for pollinators, and thus contribute to slowing their decline (Cane, 2013; Widows and Drake, 2014; Salisbury et al., 2015). Despite the increasing use of pollinator gardens however, little is known about the specific characteristics (e.g. garden size, plant diversity) that mediate their success in hosting high levels of pollinator density and diversity (Matteson and Langelloto, 2011; Simao et al., 2018; Seitz et al., 2020). In fact, to date, little empirical evidence exists on the overall success of pollinator gardens in attracting and sustaining a broad diversity of pollinator populations (Simao et al., 2018). Understanding the effects that biotic (e.g. species composition) and abiotic (e.g. size and location) pollinator garden characteristics can have on pollinator abundance and diversity is thus critical for mitigating further pollinator declines.

Current research suggests that variation in habitat characteristics at both, small spatial scales and across a spectrum of land-use types, can influence pollinator richness and abundance (Bates et al., 2011; Quistberg et al., 2016; Banaszak-Cibicka et al., 2018). For example, the number of open flowers at a local scale determines the quantity of available floral resources and may be an indicator of the maximum pollinator ‘load’ (abundance) a site can support. Thus, we could expect an increase in overall pollinator abundance with increasing pollinator garden flower density (Davis et al., 2017; Simao et al., 2018). On the other hand, the number of different plant

species (species richness) may determine the diversity of floral rewards available, potentially influencing the diversity of pollinators attracted to a garden. For instance, species in the Asteraceae family (present in most pollinator gardens) are typically generalists and attract a broad range of pollinator species (Gong and Huang, 2009). However, these plant species may fail to provide critical resources for more specialized insects (Havens and Vitt, 2016), which experience greater rates of decline than generalists (Loh et al., 2020). For example, a study showed Monarch butterfly (*Danaus plexippus*) populations have declined by 80% in recent years (Boyle et al., 2019). These butterflies however depend strongly on the presence of *Asclepias* spp. and thus they would not benefit from Aster dominated gardens (Boyle et al., 2019). Gardens with a greater number of plant species are also more likely to include specialized plants, hence promoting higher niche partitioning and support a more diverse pollinator community (Kephart, 1983; Blüthgen and Klein, 2011; Hanley et al., 2014; Salisbury et al., 2015). Garden size (independent of flower density) could also play an important role in its ability to attract and support an abundant and diverse pollinator community (Sih and Baltus, 1987; Simao et al., 2018). For instance, flowers distributed over larger areas may increase long-distance pollinator attraction and hence pollinator visitation compared to smaller gardens (Sih and Baltus, 1987). Additionally, larger gardens may increase the number of suitable nesting sites/structures for pollinators (Davis et al., 2017). For instance, patches of bare ground are favorable nesting sites for many solitary bees while logs, rocks, and grass provide cover and shelter for other pollinator groups (Pardee and Philpott, 2014; Quistberg et al., 2016). In this sense, studies have also shown that the proximity to woodland areas can significantly influence the assemblage of pollinators within a site (Theodorou et al., 2020). While bumblebees, honeybees, and butterflies can travel relatively long distances when foraging, the vast majority of flying insects (e.g. small native

bees) have more limited flight distances (Quistberg et al., 2016), which in turn may limit their frequency in gardens located far away from woodlands.

Intrinsic plant species characteristics can also be important in mediating pollinator garden potential to attract a large and diverse pollinator community. For instance, radial floral symmetry is often associated with high levels of pollinator generalization (Fenster et al., 2004; Krishna and Keasar, 2018), while bilateral flowers tend to attract more specialist pollinators (Fenster et al., 2004; Shimizu et al., 2014). If we can assume that radial flowers attract a similar pool of generalist pollinators, then increasing the number of plant species with bilateral flowers (i.e. specialized) would be more likely to lead to an increase in pollinator diversity at a garden (Ollerton et al., 2011; Padyšáková et al., 2013). Furthermore, native pollinators often rely on native flowering plants for reproduction (Ollerton et al., 2011). It is thus possible that pollinator gardens can contain a high density and diversity of flowers and yet provide little to no resources for the local pollinator community, if these are dominated by cultivars or non-native species. Thus, we can further expect an increase in pollinator diversity with increasing proportion of native plant species present in pollinator gardens. Overall, understanding how pollinator garden physical characteristics and plant species composition can influence pollinator abundance and diversity is critical if we aim to maximize their effectiveness as a conservation strategy to minimize pollinator declines.

The specific surrounding context where pollinator gardens are located can also influence the abundance and diversity of pollinators a garden can sustain, and thus its effectiveness as a conservation tool (Cane, 2001; Bates et al., 2011; Quistberg et al., 2016). For instance, urban areas are characterized by a higher proportion of asphalt and concrete structures and a lower proportion of plants compared to rural areas that are characterized by large swathes of

agricultural crops, hay fields, and undeveloped land (Pozzi and Small, 2005; Ratcliffe et al., 2016; Homer et al., 2020). Thus, we could predict that pollinator abundance and richness will be greater in rural areas due to the higher availability of floral resources. However, current evidence has shown that some features of agricultural land such as large expanses of monoculture crops, may also present foraging barriers to some insect groups (Quinn et al., 2017). Likewise, it could be expected that urban environments would be less suitable habitats to sustain pollinator populations. However, it has been found that many small native bees can take advantage of cracks and crevices in urban habitats for nesting (Pardee and Philpott, 2014; Kratschmer et al., 2018). Many solitary bees have also been shown to nest in bare ground, a characteristic more often associated with urban environments (Harrison et al., 2018). The few studies to date that have evaluated pollinator populations along a gradient of land-use type have shown that overall species richness and abundance varies little from urban to rural habitats, while the composition of insect communities varies greatly. (Plascencia and Philpott, 2017; Harrison et al., 2018; Simao et al., 2018). However, studies that evaluate the potential impacts of land use type (urban vs rural) on the effectiveness of pollinator gardens in attracting a large and diverse pollinator community are still very limited.

Pollinators are a diverse group of organisms that vary in their foraging and nesting requirements (Ollerton, 2017). For instance, studies investigating how bee abundance varies with varying habitat characteristics (e.g. floral abundance/density, floral diversity, garden size) have found species-specific responses to such changes (Samnegård et al., 2011; Quistberg et al., 2016; Kratschmer et al., 2018). Similar species-specific responses have been observed in other insect groups such as hoverflies (Bates et al., 2011; Matteson and Langelloto, 2011; Rader et al., 2016; Woodcock et al., 2019; Theodorou et al., 2020). A study across nine insect groups along an

urbanization gradient showed that the proportion of visits from each pollinator functional group was differentially affected by habitat type (Geslin et al., 2013). While flies and beetles were negatively impacted by an increase in urbanization, *Bombus* and *Apis mellifera* showed no response to land use change. (Geslin et al., 2013). Understanding the influence of pollinator garden characteristics on the behavior and abundance of specific insect pollinator groups is hence critical for understanding their efficacy in minimizing pollinator declines. For instance, butterflies and bumblebees can travel relatively long distances and thus may be less likely to be affected by land use change at large spatial scales (Vidal and Rendón-Salinas, 2014; Quistberg et al., 2016) compared to small solitary bees, which have very limited flight ranges and typically nest in proximity to floral resources (Langellotto et al., 2018). In addition to overall estimates of pollinator diversity, studies should also evaluate individual responses across insect groups in order to more fully understand how changes in pollinator garden characteristics may impact pollinator communities.

In this study we evaluate the effects of pollinator garden characteristics including size, floral density, distance to vegetation, and land use type (rural versus urban), as well as characteristics associated with plant species composition (species diversity, proportion of radial and native species) on the overall diversity and proportional abundance of five functional pollinator groups (Bumblebees, Honeybees, small bees, lepidopteran, other insects).

MATERIALS AND METHODS

Region—The study was conducted in the Appalachian Highlands in the Eastern United States. This area encompasses the greater Tri-cities metropolitan area including Bristol TN/VA, Kingsport TN and Johnson City TN. These three major cities contain high-density residential, commercial, and industrial land use typical of urban environments with population densities decreasing in surrounding municipalities and rural areas (TNSDC, 2019). This region is part of the Appalachian-Blue Ridge mountain ecoregion and is one of the most biologically diverse regions of temperate deciduous forest in the world hosting over twenty plant species and at least three rare/endangered butterfly species (Stephenson et al., 1993), among many other important insect pollinators.

To evaluate how pollinator-garden characteristics (e.g., size, floral density, diversity, native status, floral symmetry) affect the diversity, visitation rate, and assemblage of insect pollinators seventeen pollinator gardens were selected. Sites were initially identified using the Million Pollinator Garden Challenge interactive map of registered pollinator gardens in the United States. Additional sites were selected from private individuals who volunteered for the study through regional Master Gardener programs and Conservation groups. The primary criteria for site selection was that the garden was intended as a pollinator garden with the aim to provide floral resources, habitat, and support for pollinator populations. Sites that included beekeeping activities were excluded.

Data collection—Site visits were performed between 9am and 5pm from May to August during sunny, warm, non-rainy days. Each site was visited 1-2 days at two different times to account for time of day (morning and afternoon). However, we were only able to sample two times at six sites. A regression between time of sampling (across all sites) and all our response

variables however was not significant ($t = (-1.81 - 1.84)$, $df = 1$, $P = (0.096 - 0.923)$), suggesting no effect of time of day on the results observed. For the six sites that were visited twice data on insect visitation, number of open flowers, floral density, and plant richness data was averaged. For each site the following site characteristics were recorded, 1) garden size (m^2), 2) proximity to undeveloped woodlands (estimated with ArcGIS Pro) and 3) habitat type. Garden size was measured on site for small gardens and using ArcGIS Pro with a standard georeferenced basemap for larger gardens. Habitat type was determined using 2016 National Land Cover Data and sites were classified using ArcGIS Pro based on the percentage of land classified as ‘developed’ within a 5km buffer centered on the GPS coordinates of the garden. We used a 30m resolution USGS NLCD data (MRLC, 2016) to determine the number of pixels per class within the 5km buffer intended to encompass the average foraging distance of bumblebees (Osborne et al., 1999, 2008; Rao and Strange, 2012). Values were combined for all ‘developed’ land-use classes to determine the proportion of developed land surrounding the site. These values were then used to classify habitats as Urban (>20% developed), or Rural (<20% developed) based on thresholds established in previous studies (Pozzi and Small, 2005; Ratcliffe et al., 2016).

In addition, we collected data on total flower number and floral density (number of flowers per m^2) by conducting flower counts for each species in bloom during each visit. In cases where flower numbers were too large these were estimated by counting the number of flowers on 1-5 inflorescences and multiplying average flower number by the number of inflorescences per plant. Common lawn weeds such as white clover (*Trifolium repens*), red clover (*Trifolium pratense*), dandelion (*Taraxacum officinale*), and narrowleaf plantain (*Plantago lanceolata*) were present in the surroundings at all gardens but only counted at two gardens where these were intentionally added within garden beds. We recorded the total number of plant species within

each garden and identified them to the species level with the aid of identification guides (e.g. Ladybird Johnson Wildflower Center, Tennessee Native Wildflowers) and ETSU herbarium specimens and personnel. We further recorded the proportion of species with radial/bilateral flower symmetry and the proportion of native species based on their origin status (native/not native to the region) in the USDA Plant Database.

Insect visitation was recorded by direct visual observations conducted by a two-member team for 20-30 minutes per visit at each site (40-60 min total per site) depending on garden size. A subset of the visiting insects was collected via hand netting for later identification in the lab. Due to lack of uniformity in garden shape, observations were made while systematically walking at a constant pace around the perimeter of the garden beds. Insects observed contacting floral reproductive organs were broadly identified in the field (sweatbee, butterfly, bumblebee, honeybee, hoverfly, beetle, etc.) then later separated into distinct functional groups (butterfly, bumblebee, honeybee, small bees, and other insects) for analysis, as it has been done in previous studies (Geslin et al., 2013). The identity of the plant being visited was also recorded. It is important to note that because it is possible that the same insects were counted twice during floral observations our data only reflects visitation frequencies and may not directly correlate with overall insect species abundance at a site.

ANALYSIS

We evaluated the effects of all predictor variables (plant species richness, garden size, total number of open flowers, floral density, distance to vegetation, proportion of native flowers, proportion of radial flowers) on the following response variables: pollinator richness and total visitation (total number of visits), average number of visits per flower, proportion of *Bombus* visits, proportion of small bee visits (i.e. all other bees except *Bombus*), proportion of

Lepidopteran visits and proportion of other pollinator visits (e.g. beetles and flies). We evaluated the effects of each predictor variable on all response variables via multiple regression analysis. Pollinator richness reflects the total number of unique insect types (eg. sweat bee, hoverfly, skipper, beetle) observed visiting flowers at the site, while total visitation represents the total number of observed floral visits at a site. Average visits per flower was calculated for each site by dividing the average number of open flowers by the average number of insect visits (number of open flowers/total number of pollinator visits). We evaluated both because while total visitation reflects the overall number of pollinators attracted to the site, average visits per flower accounts for floral density. We evaluated differences in the proportion of visits from each pollinator functional group instead of the total number of visits in order to better illustrate the compositional dynamics of pollinators in response to our predictors irrespective of changes in total pollinator visitation to a site. For this study we treated *Bombus* as a separate group from other bee Genera because *Bombus* species typically have much larger foraging ranges and elicit social behaviors that are not present in most bees that may lead them to respond differently than other native bee species (Geslin et al., 2013; Koski et al., 2015; Harrison et al., 2018).

Lepidopterans (butterflies and moths) are dependent on floral nectar for survival, many are migratory, are highly dependent on specific plant species for survival (Ghazanfar et al., 2016; Rader et al., 2016; Woodcock et al., 2019). All other pollinators include flies, wasps, and beetles. This group represents the insect pollinators from multiple Orders that have been understudied in previous research but provide substantial contributions to pollination success in many pollination networks (Rader et al., 2016; Woodcock et al., 2019; Theodorou et al., 2020). Members of this functional group can be highly specialized during at least one life stage, tend to have shorter flight distances, and tend to be less adapted for moving large volumes of pollen than bee species

(Rader et al., 2016). *Apis mellifera* was excluded from the analyses as it only comprised 3% of all observations, and >50% of observations came from a single site. All models met assumptions of normality of residuals (Shapiro-Wilk $P > 0.05$) except for proportion of *Lepidopteran* which was log transformed ($\log^{10}(\text{value} + 0.5)$).

To evaluate the effect of habitat type on all response variables we used a mixed model with habitat type (nine urban and eight rural) as fixed effects and individual site as a random factor. For this analysis, the proportion of *Lepidopteran* was combined with the proportion of other insects because these were not observed to respond differently from other insect groups (see results below). This grouping also better reflects how characteristics inherent to urban and rural environments may influence bees compared to other insect groups. Residuals for all models met assumptions of normality (Shapiro-Wilk $P > 0.05$) except total visits per flower which was transformed ($\sqrt[3]{\text{value}}$) to meet assumptions of normality. We checked for correlations between predictor variables using Pearson's correlation test. All analyses were conducted in SASTM 9.4 (2016).

RESULTS

We recorded 149 unique plant species and observed 3114 total insect-plant interactions across all pollinator gardens. Overall, there was wide among-site variation in each of the predictor variables including average number of flowers (14-246,852), plant species richness (2-31), garden size (8-1198 m²), distance to vegetation m (3-640 m), floral density (1.26-378.35), proportion of native (0.17-1.0) and radially symmetrical species (0.56-1.0). All major Orders of insect pollinators were represented including hymenoptera, diptera, lepidoptera, and coleoptera. Small bees and *Bombus* were the most abundant floral visitors (75%) followed by lepidopterans (16%). Plants in the Asteraceae family were the most common (40% of species) followed by

Lamiaceae (9%). Asclepiadaceae, Ranunculaceae, and Fabaceae were also common but represented much smaller portions of the flowering community (11% combined). 76% of all plant species observed had radial floral symmetry and nearly 60% were native.

Neither overall pollinator richness nor their total visitation was significantly affected by any of the pollinator garden characteristics evaluated (Table 1), although pollinator richness tended to marginally increase ($t = 0.7$, $df = 1$, $P = 0.06$) with increasing plant species richness (Fig. 1A). Flower visitation rate (visits/flower) on the other hand was negatively affected by plant species richness (Table 1; Fig. 1B). The proportion of *Bombus* was significantly affected by pollinator garden's characteristics including distance to woody vegetation, proportion of radial and native flowers (Table 1). Specifically, the proportion of *Bombus* visits increased with increasing distance to woodland vegetation (Fig. 2A) and with increasing proportion of radial flowers in the garden (Fig. 2B). The proportion of native flowers had a negative effect on the proportion of *Bombus* visits at a site (Fig. 3A). The proportion of native flowers however, tended to have a positive effect on the proportion of visits from all other insects, although this effect was only marginally significant (Table 1; Fig. 3B). Plant species richness also had a marginal ($t = -1.99$, $df = 1$, $P=0.07$) negative effect on the proportion of *Bombus* visits (Fig. 2C). No other significant effects were observed for other pollinator groups (Table 1).

Table 1: Showing results from six linear regression analyses. Independent variables are listed in left column below the full model and dependent variables are listed in top row. Degrees of freedom for the full model for all independent variables = 7. Degrees of freedom for each dependent variable = 1. * Variable is significant $P < 0.05$ ** Variable is significant $p < 0.01$

	Pollinator Richness		Pollinator Frequency (site)		Visitation Frequency (flower)		Prop. of Bombus		Prop. of other bees		Prop. of Lepidopteran		Prop. of Other insects	
	Test Statistic	P value	Test Statistic	P value	Test Statistic	P value	Test Statistic	P value	Test Statistic	P value	Test Statistic	P value	Test Statistic	P value
Full Model	F = 1.56	0.263	F = 2.08	0.151	F = 4.07	*0.027	F = 3.89	*0.031	F = 3.02	0.063	F = 0.44	0.851	F = 1.65	0.237
Flower Abundance	t = 0.7	0.503	t = 1.29	0.228	t = -0.92	0.383	t = 0.61	0.558	t = 0.41	0.692	t = -0.03	0.977	t = -1.09	0.303
Plant Species Richness	t = 0.7	0.063	t = -0.2	0.844	t = -3.96	**0.003	t = -1.99	0.078	t = 1.27	0.236	t = 0.87	0.408	t = -0.84	0.424
Size	t = -0.82	0.434	t = 1.16	0.274	t = 2.02	0.074	t = 0.58	0.575	t = 0.36	0.728	t = -0.69	0.505	t = 0.03	0.979
Distance to Vegetation	t = 0.72	0.482	t = 0.22	0.833	t = 1.3	0.226	t = 2.45	*0.037	t = -0.52	0.617	t = -0.54	0.604	t = -1.73	0.117
Floral Density	t = -1.1	0.301	t = 1.05	0.322	t = 0.46	0.656	t = 0.26	0.798	t = 1.51	0.165	t = -1.1	0.298	t = -0.78	0.454
Average Proportion Radial	t = -0.29	0.775	t = 0.7	0.504	t = 0.94	0.374	t = 2.61	*0.028	t = -1.97	0.080	t = 0.26	0.801	t = -0.88	0.402
Average Proportion Native	t = 0.93	0.376	t = -0.23	0.826	t = 0.66	0.524	t = -2.72	*0.023	t = 0.16	0.875	t = 1.05	0.323	t = 2.07	0.069

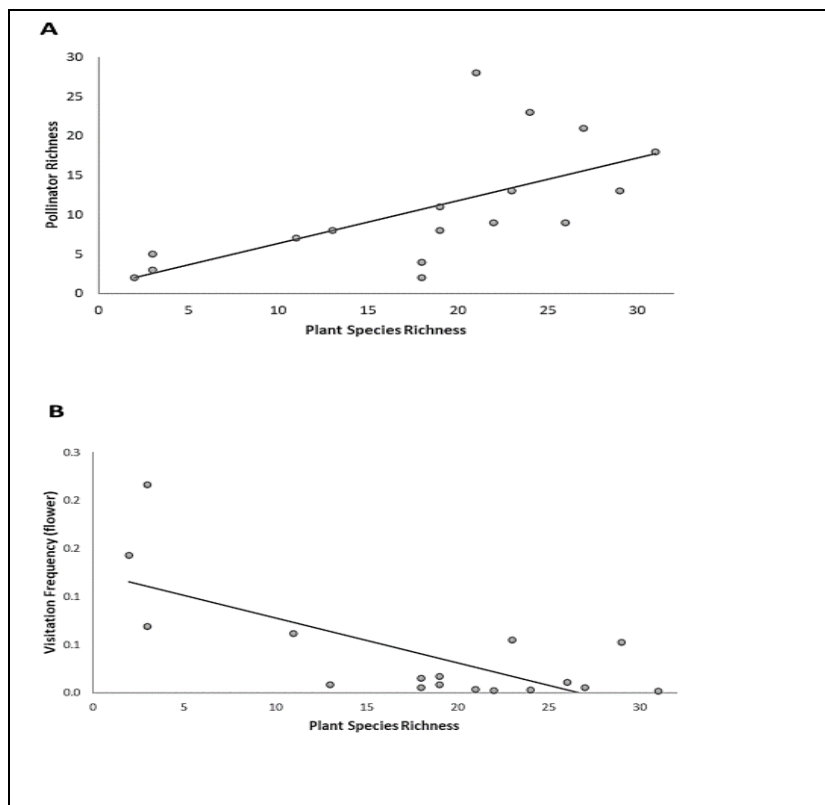


Figure 1: Relationship between A) pollinator richness and B) pollinator visits per flower and plant species richness across 17 pollinator gardens studied. A is marginally significant ($t = 0.7$, $df = 1$, $P = 0.06$) and B is significant ($t = -3.96$, $df = 1$, $P = 0.003$).

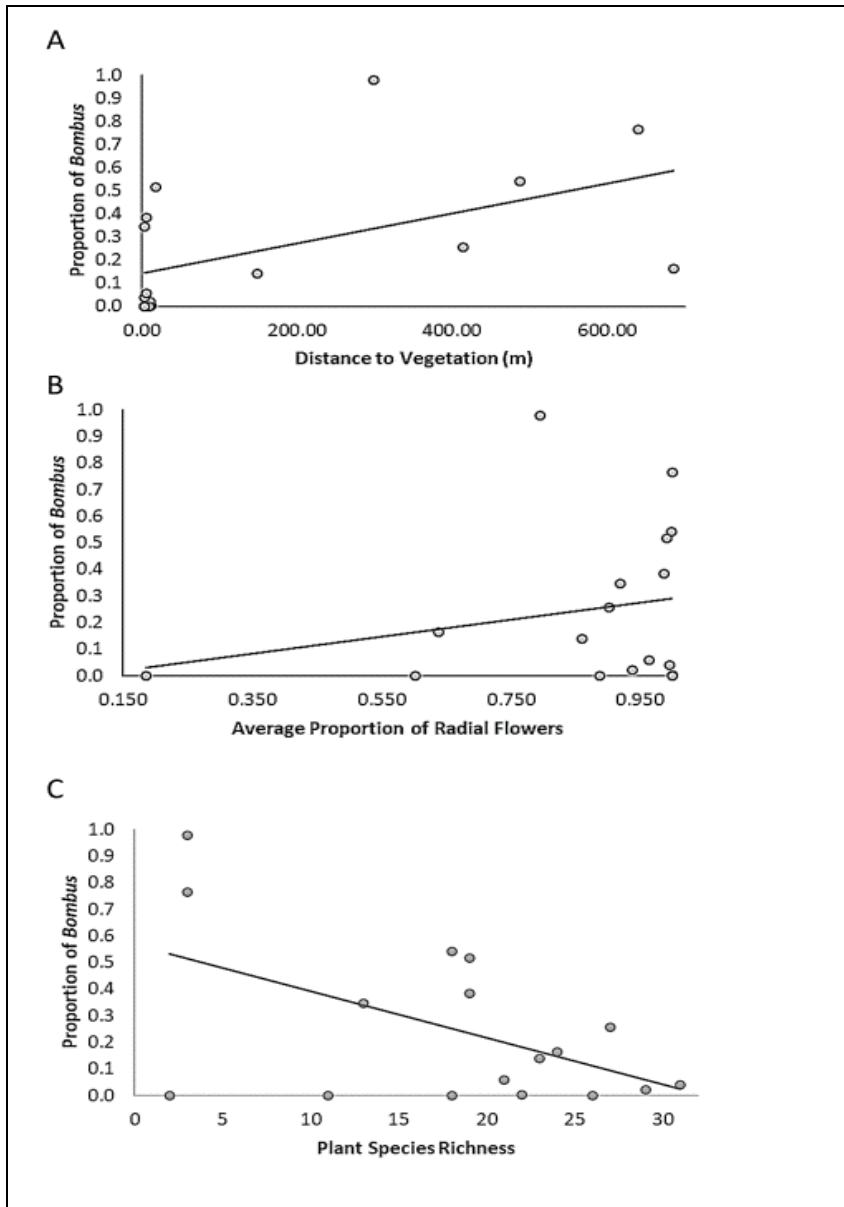


Figure 2: Relationship between proportion of *Bombus* genera and A) distance to vegetation in meters, B) average proportion of native flowers, and C) plant species richness across 17 pollinator gardens studied. A and B were significant ($t = 2.45$, $df = 1$, $P = 0.04$) $t = 2.61$, $df = 1$, $P=0.03$, respectively), C was marginally significant ($t = -1.99$, $df = 1$, $P=0.08$).

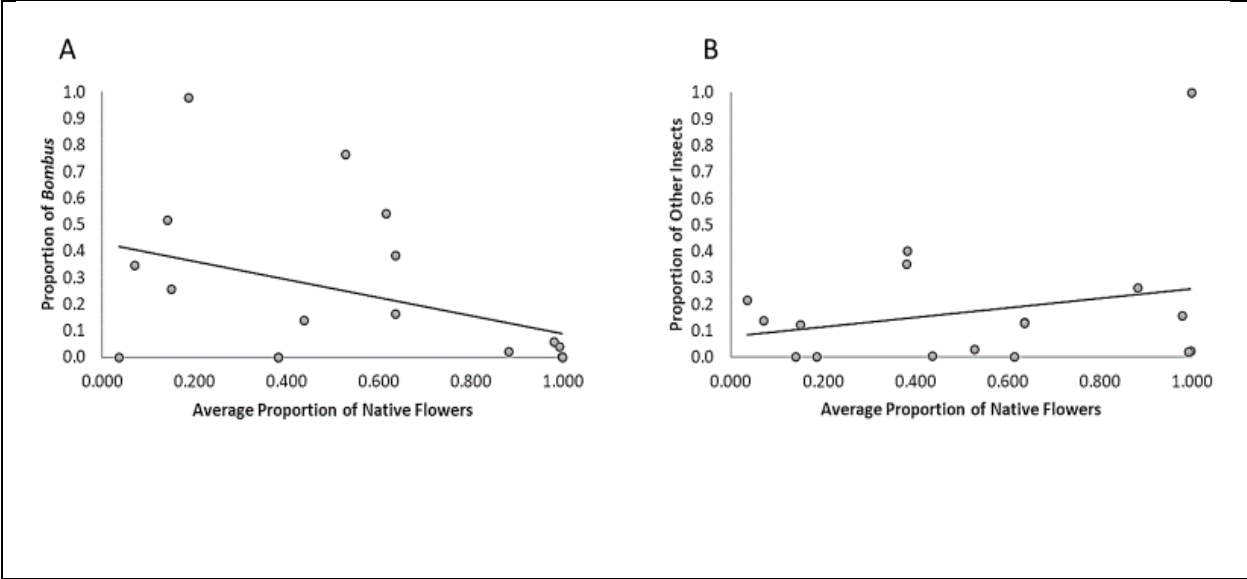
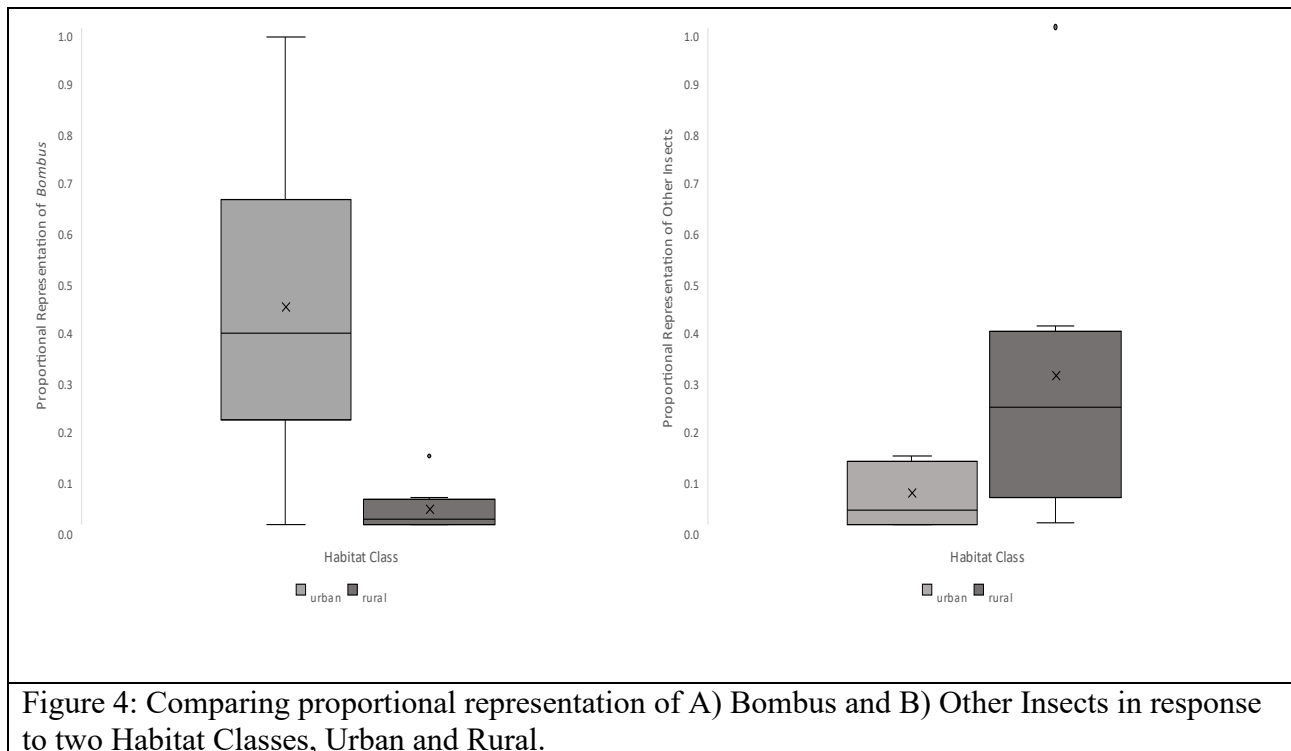


Figure 3: Relationship between A) proportion of *Bombus* and B) proportion of other insects, and average proportion of native flowers. A is significant ($t = -2.72$, $df = 1$, $P = 0.02$), B is marginally significant ($t = 2.07$, $df = 1$, $P = 0.07$).

Habitat type did not have an effect on pollinator richness, total visitation or visitation rate per flower, nor did it affect the proportion of non-*Bombus* bee visits. However, the proportion of visits from *Bombus* ($F_{7,9}=14.16$, $P = 0.002$) and from other insects ($F_{7,9}= 6.43$, $P = 0.02$) were significantly affected by habitat type. *Bombus* visits represented a higher proportion of the total visits in urban settings while ‘other insects’ visited flowers in greater proportions in rural settings (Fig. 4).



Pearson’s test showed a significant correlation between the average proportion of native flowers with the total number of flowers ($r = 0.53$, $P = 0.03$) and the proportion of radial flowers ($r = 0.48$, $P = 0.05$) at a site. However, number of flowers and proportion of radial flowers were not correlated with each other. Additionally, plant species richness was positively correlated with garden size ($r = 0.75$, $P < 0.001$).

DISCUSSION

Pollinator gardens are becoming a widely used tool to mitigate rising bee population declines (Salisbury et al., 2015; Coil, 2018; National Pollinator Garden Network, 2020). However, what attributes mediate the overall efficacy of pollinator-gardens is still unclear. Our results suggest that plant species richness, and their proximity to woody vegetation are two of the most important pollinator garden characteristics mediating their effectiveness at hosting high levels of pollinator abundance and richness. For instance, plant species richness had a negative effect on overall pollinator visitation per flower, even though it had no effect on total pollinator attraction to a site. Furthermore, plant species richness had a marginally positive effect on pollinator species richness (Fig. 1A). According to our observations, florally diverse pollinator gardens attract a more diverse pollinator community, with lower proportions of *Bombus* than less florally diverse gardens (Fig. 1&2). This result hence suggests that as plant diversity within a garden increases, the likelihood of including plants that support more specialized pollinator interactions also increases (Fenster et al., 2004; Rollings and Goulson, 2019). Thus, gardens that offer little floral diversity may attract a limited group of generalist pollinators, such as *Bombus*, and fail to support other critical specialist pollinators. Our results also suggest that floral diversity within a garden may be even more relevant than garden size for attracting pollinators, since the latter was not significant in any of our models. This, suggests that smaller areas can still contribute significantly to supporting pollinator populations by maximizing floral diversity within them. However, we did observe a positive correlation between garden size, and plant species richness and hence we cannot fully tease apart their individual effects in our study. Garden size may also be important for other important aspects such as ground cover, or other structural elements

known to benefit specific insect groups (Pardee and Philpott, 2014; Quistberg et al., 2016; Banaszak-Cibicka et al., 2018; Harrison et al., 2018).

The distance between a pollinator garden and undisturbed vegetation was also an important factor mediating pollinator diversity and species composition. In our study, pollinator gardens that were closer to woodlands hosted a lower proportion of *Bombus* pollinators than gardens further away (Fig. 2A). This result at first seems counterintuitive as woodland areas have been shown to provide nesting sites and cover necessary for many native insects including *Bombus* and other native bees (Hennig and Ghazoul, 2011). However, *Bombus* can travel long distances in search of resources and may not be impeded by large areas of low resource availability (Langellotto et al., 2018). While other bees such as *Halictids* have much shorter foraging ranges and may not be able to reach pollinator gardens far away from their nest site (Quistberg et al., 2016). Thus, the decrease in the proportion of bumblebees near woodland areas may in fact reflect an increase in the proportion of other pollinators with far more restricted foraging ranges. Overall, our results suggest that attributes such as plant species richness and location may be more important than attributes such as floral density and total flower abundance that are generally thought to strongly impact pollinator richness and abundance (Pardee and Philpott, 2014; Quistberg et al., 2016; Kratschmer et al., 2018). For instance, we did not observe a significant relationship between floral abundance and floral density with pollinator abundance or richness. Thus, plant diversity within pollinator gardens seems to be more important than overall floral abundance in order to increase pollinator richness and diversity. In fact, while our study did not compare pollinator abundance in gardens to areas without gardens, one study showed that increasing floral rewards in an area can improve pollinator abundance even at small scales (<10,000 flowers) (Simao et al., 2018).

While some studies have focused on garden attributes that influence pollinator diversity and community composition at the landscape and local levels (Matteson and Langelloto, 2011; Salisbury et al., 2015; Quistberg et al., 2016; Davis et al., 2017; Plascencia and Philpott, 2017; Mach and Potter, 2018), very few have evaluated the importance of intrinsic plant characteristics within pollinator gardens (Seitz et al., 2020). Our results suggest that these can have important effects on pollinator community composition. For example, our data shows that Bumblebee proportion increases with increasing proportion of radial flowers (Fig. 2A) and decreases with increasing proportion of native flowers (Fig. 3). *Bombus* can be considered generalist pollinators (Schweitzer et al., 2012) and radially symmetrical flowers, such as asters, are thought to favor generalists (Gong and Huang, 2009). Hence, a disproportionate representation of species with radial flowers within pollinator-gardens may help attract generalist pollinators such as *Bombus*. However, this increase may be at the expense of other important insect pollinators in the community. For instance, our results showed a weak, but negative relation between the proportion of radial flowers and the proportional abundance of small bees in the community ($P = 0.08$). On the other hand, the decrease in bumblebee proportion with increasing proportion of native flowers may reflect the fact that many native plant species tend to have specialized pollinator relationships (Hanley et al., 2014; Pardee and Philpott, 2014; Salisbury et al., 2015; Rollings and Goulson, 2019). For instance, plants in the *Asclepias* family (milkweeds) are a critical food source and egg laying site of Monarch butterflies (*Danaus plexippus*) and populations of the plant on butterfly are closely linked (Kephart, 1983; Boyle et al., 2019). This result is also supported by a weak but positive correlation between proportion of native flowers and proportion of ‘other insects’ in our study (Fig. 3). Thus, pollinator gardens that include native plants may be more likely to attract a diverse group of native pollinators than those

containing non-native plants. Overall, our results emphasize the importance of considering the composition of intrinsic plant characteristics within pollinator gardens, particularly floral symmetry and native status, in order to maximize their effectiveness in supporting a diverse pollinator community.

Our results support previous findings showing that some insect groups are better suited to succeed in urban environments (Geslin et al., 2013; Davis et al., 2017; Theodorou et al., 2020). In particular, we found that Bumblebees composed a significantly greater proportion of the pollinator community in urban than rural gardens. Our data also indicates that the community of ‘other insects’ have the opposite trend and are found in greater proportions in rural gardens. Because overall pollinator abundance was not different between habitat types, we suggest that each habitat type favors specific functional groups of insects. For instance, cracks, crevices, and bare ground associated with urban spaces can support some small bee species (Hall et al., 2017; Kratschmer et al., 2018; Theodorou et al., 2020) while bumblebees may be less impeded by areas of low resource density in these habitats (Langellotto et al., 2018). Urban environments are characterized by smaller proportions of woodland and shrub cover (i.e. greater distances to vegetation in urban settings) (Pozzi and Small, 2005; Dewitz, 2016) than rural environments which are characterized by greater proportions of vegetative cover (Pozzi and Small, 2005). Therefore, by virtue of their intrinsic properties, rural areas tend to provide greater floral diversity, which has been associated with improved pollinator diversity (Geslin et al., 2013; Plascencia and Philpott, 2017) and could explain the shift in pollinator community composition observed here. Studies show that rare species are especially lower in abundance in urban environments, which tend to favor insects adapted for more open habitat types including *Bombus, hylaeus*, and *Lasioglossum* (Banaszak-Cibicka et al., 2018; Harrison et al., 2018).

While we did not test for specific effects of these characteristics in relation to habitat type, proportion of vegetative cover is a primary factor of land-use classification and could help explain this trend within these habitats (Dewitz, 2016). Highly urbanized land-use types present significant barriers to gene flow facilitated by pollinators, reflected in lower genetic diversity of pollinator dependent plant species in highly urbanized settings (Emel et al., 2021). These low-resource areas within a habitat ultimately reduce connectivity of foraging resources, which has been shown to impede colonization of restored habitat (Palmer et al., 1997) and reduce overall insect abundance at a site (Hennig and Ghazoul, 2011). Greater understanding of which insect groups are supported by inherent factors of the habitat type a garden is placed in allows conservation efforts to be better directed and gardens to ultimately be more successful. Our data also suggests that the urban environment does not function as a subset of the rural environment. Overall pollinator richness and abundance vary little between the two, but community composition varies significantly (Harrison et al., 2018). Rural areas support a rich and abundant pollinator community with a broad range of functional traits (Fig. 4b) adapted for the conditions of the rural land-use type. As habitat becomes more urban, rare and specialized species are replaced with other native species better suited to these conditions, balancing out diversity and abundance within the garden (Harrison et al., 2018).

So far, most studies on pollinator-gardens have focused on evaluating general trends in the overall pollinator community (Kephart, 1983; Matteson and Langelloto, 2011; Salisbury et al., 2015; Rollings and Goulson, 2019) or on a specific group of pollinators (Sih and Baltus, 1987; Hanley et al., 2014; Couvillon et al., 2015; Davis et al., 2017; Mach and Potter, 2018). However, it is well known that pollinator insects do not share a common set of habitat and foraging requirements and therefore it is unlikely they will respond similarly to pollinator garden

characteristics (Fenster et al., 2004; Quistberg et al., 2016; Harrison et al., 2018). This is supported in our study by the fact that we observed differential responses among insect pollinator groups. Specifically, distance to vegetation, plant species richness, and presence of native plants, were shown to influence the proportional representation of bumblebees and ‘other insects’ but none of the other insect groups (e.g., small bees, lepidopterans). Studies investigating community composition in urban and rural settings, at a species and functional level, have indicated that species composition is also affected differentially by land use type. Functional traits such as sociality, nesting habit, body size, tongue length, and flight season, have been shown to be important factors in what insect species were present in a habitat (Hennig and Ghazoul, 2011; Geslin et al., 2013; Theodorou et al., 2020). While further research into how specific characteristics of habitat type influence community composition is necessary to elucidate mechanisms behind the trends, it is important to note that habitat type appears to have significant influence over the pollinator species present in the habitat.

Finally, our results could have important applied implications for the management and conservation of insect populations. For instance, our research suggests that small-scale urban gardens would be more effective conservation tools for Bumblebees, Lepidopteran, and small bees than for “other insect” types not supported by other important habitat aspects (Table 1). Furthermore, larger scale urban projects may foster insect diversity in cities by preserving areas of undisturbed woody vegetation, increasing floral diversity, and native flora, all of which can improve pollinator richness (Fig. 1). Florally diverse native plantings within parks and natural areas that improve connectivity of resources and meet the functional needs of various insect groups can further improve pollinator diversity and promote a more balanced representation of insect functional groups within the community. (Fig. 3). Overall, the results of this study can

help improve current pollinator garden guidelines and lead to the establishment of pollinator gardens that attract a high density and diversity of bees and other pollinators, thus improving preservation of biodiversity and a critical ecosystem service such as pollination.

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Author contributions

Travis Watson designed and carried out the experiment and wrote the manuscript with the assistance Dr. Gerardo Arceo-Gómez. T.W. and G.A. designed the analysis model and T.W. performed the analysis. T.W. and G.A. interpreted the data and developed the conclusions.

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APPENDICES

Appendix A: Comprehensive List of Measured Variables

Comprehensive List of Measured Variables	
Floral Abundance	Average number of Total Blooms divided by number of data collection visits
Floral Species Richness	Total number of plant species recorded to be blooming at the site during the field season
Size	Size of the site in square meters based on physical measurements converted from standard to metric or ArcGIG Pro Measure Tool
Habitat Type	Categorical classification of habitat area surrounding site based on US Land Cover Data within 5 km radius
Distance to Vegetation	Distance in linear meters to nearest undeveloped wooded area based on Google Earth Distance Tool measurements
Floral Species Density	Total number of plant species in flower divided by Size in meters square
Flower Density	Average number of open blooms divided by Size in meters square
Pollinator Species Richness	Number of pollinator morphospecies observed at site
Pollinator Abundance	Total number of pollinator visits observed at the site divided by the number of data collection visits
Visitation Rate	Average number of pollinator visits divided by the average number of flowers
Native Proportion	Average proportional value of native plants to non-native plants observed to be blooming at the site
Radial Proportion	Average ratio value of radially symmetrical plant species to bilaterally symmetrical plant species blooming at site
Solitary Bee Abundance	Total number of recorded visits by bees other than <i>Apis</i> or <i>Bombus</i> divided by total number of data collection visits
Proportion of Solitary Bees	Average number of visits by solitary bee species divided by the total average number of insect visits
Social Bee Abundance	Total number of recorded visits by bees that are <i>Apis</i> or <i>Bombus</i> divided by the number of data collection visits
Proportion of Social Bees	Average number of social bee visits divided by total average number of insect visits
Honeybee Abundance	Total number of recorded visits by <i>Apis</i> species divided by number of data collection visits
Proportion of Honeybees	Average number of <i>Apis</i> species visits divided by total average number of insect visits
Bumblebee Abundance	Total number of recorded visits by <i>Bombus</i> species divided by number of data collection visits
Proportion of Bumblebees	Average number of <i>Bombus</i> species visits divided by total average number of insect visits

<i>Lepidopteran</i> Abundance	Total number of recorded visits by <i>Lepidopteran</i> species divided by number of data collection visits
Proportion of <i>Lepidopteran</i>	Average number of moths or butterflies visits divided by total average number of insect visits
Other Abundance	Total number of recorded visits by species not included in another group divided by number of data collection visits
Proportion of Others	Average number of visits by species not included in another group divided by total average number of insect visits

Appendix B: Comprehensive List of Flowering Plant Species

Comprehensive list of flowering plant species				
Botanical Name	Common Name	Symmetry	Native Status	Family
<i>Erysimum capitatum</i>	Western Wallflower	Radial	Native	Brassicaceae
<i>Eupatorium perfoliatum</i>	Early Boneset	Radial	Native	Asteraceae
<i>Galium triflorum</i>	Fragrant Bedstraw	Radial	Native	Rubiaceae
<i>Geranium maculatum</i>	Wild Geranium	Radial	Native	Geraniaceae
<i>Helianthus Spp. 7</i>	Small Sunflower	Radial	Native	Asteraceae
<i>Iberis sempervirens</i>	Candytuft	Bilateral	Introduced	Brassicaceae
<i>Lamium Spp. 3</i>	Mint Species	Bilateral	.	Lamiaceae
<i>Lantana Cultivar</i>	Lantana	Radial	Introduced	Verbenaceae
<i>Nepeta x faassenii</i>	Catmint	Bilateral	Introduced	Nepetoideae
<i>Plantago lanceolata</i>	Plantain	Radial	Introduced	Plantaginaceae
<i>Ranunculus bulbosus</i>	Buttercup	Radial	Introduced	Ranunculaceae
<i>Sherardia arvensis</i>	Field Madder	Radial	Introduced	Rubiaceae
<i>Solidago juncea</i>	Solidago	Radial	Native	Asteraceae
<i>Taraxocum officinale</i>	Dandelion	Radial	Introduced	Asteraceae
<i>Trifolium campestre</i>	Hop Clover	Bilateral	Introduced	Fabaceae
<i>Trifolium pratens</i>	Red Clover	Bilateral	Introduced	Fabaceae
<i>Trifolium repens</i>	White Clover	Bilateral	Introduced	Fabaceae
<i>Viola tricolor</i>	Wild pansy	Bilateral	Introduced	Violaceae
<i>Agastache foeniculum</i>	Anise Hyssop	Bilateral	Introduced	Lamiaceae
<i>Asclepias syriaca</i>	Common Milkweed	Radial	Native	Asclepiadaceae
<i>Canna coccinea</i>	Canna yellow	Bilateral	Introduced	Cannaceae
<i>Celosia cristata</i>	Cristate Red Flower	Cristate	Introduced	Amaranthaceae
<i>Daucus carota Spp</i>	Carrot Species	Radial	Introduced	Apiaceae
<i>Delphinium elatum</i>	Blue Delphinium	Radial	Introduced	Ranunculaceae
<i>Echinacea purpurea</i>	Purple Coneflower	Radial	Native	Asteraceae
<i>Helianthus Spp. 10</i>	Sunflower	Radial	Native	Asteraceae
<i>Helianthus Spp. 8</i>	Tall Sunflower	Radial	Native	Asteraceae
<i>Hemerocalis Spp.</i>	Peach Daylily	Radial	Introduced	Asphodelaceae
<i>Hypericum perforatum</i>	St. John's Wort	Radial	Native	Hypericaceae
<i>Monarda citriodora</i>	Purple Monarda	Bilateral	Native	Lamiaceae
<i>Oreganum vulgare</i>	Oregano	Bilateral	Introduced	Lamiaceae
<i>Passiflora incarnata</i>	Passionflower	Radial	Native	Passifloraceae
<i>Rudbeckia fulgida</i>	Rudbeckia small	Radial	Native	Asteraceae
<i>Rudbeckia hirta</i>	Black-eyed Susan	Radial	Native	Asteraceae
<i>Symphotrichum laeve</i>	Smooth Blue Aster	Radial	Native	Asteraceae
<i>Tropaeolum majus</i>	Orange Troika Nasturtium	Radial	Introduced	Tropaeolaceae

<i>Verbascum thapsus</i>	Mullein	Radial	Introduced	Scrophulariaceae
<i>Agastache scrophulariifolia</i>	Purple Giant Hissop	Bilateral	Native	Lamiaceae
<i>Aster prenanthoides</i>	Crooked-Stem Aster	Radial	Native	Asteraceae
<i>Conoclinium coelestinum</i>	Blue Mistflower	Radial	Native	Asteraceae
<i>Euthamia graminifolia</i>	Grass Leaved Goldenrod	Radial	Native	Asteraceae
<i>Foeniculum vulgare</i>	Fennel	Radial	Introduced	Apiaceae
<i>Helianthus grosseserratus</i>	Sawtooth Sunflower	Radial	Native	Asteraceae
<i>Lonicera sempervirens</i>	Coral Honeysuckle	Radial	Native	Caprifoliaceae
<i>Pycnanthemum muticum</i>	Clustered Mountain Mint	Bilateral	Native	Lamiaceae
<i>Rudbeckia laciniata</i>	Cutleaf Coneflower	Radial	Native	Asteraceae
<i>Rudbeckia subtomentosa</i>	Sweet Black Eye Susan	Radial	Native	Asteraceae
<i>Scrophularia marilandica</i>	Late Figwort	Bilateral	Native	Scrophulariaceae
<i>Silphium trifoliatum</i>	Cumberland Rosinweed	Radial	Native	Asteraceae
<i>Symphotrichum cordifolium</i>	Heart leafed aster	Radial	Native	Asteraceae
<i>Tithonia rotundifolia</i>	Mexican Sunflower	Radial	Introduced	Asteraceae
<i>Verbena bonariensis</i>	Tall Verbena	Radial	Introduced	Verbenaceae
<i>Vernonia noveboracensis</i>	New York Ironweed	Radial	Native	Asteraceae
<i>Cephalanthus occidentalis</i>	Buttonbush	Radial	Native	Rubiaceae
<i>Erigeron annuus</i>	Daisy Fleabane	Radial	Native	Asteraceae
<i>Liatriis spicata</i>	Gayfeather	Radial	Native	Asteraceae
<i>Lobelia cardinalis</i>	Red Cardinalflower	Bilateral	Native	Campanulaceae
<i>Ornithogalum umbellatum</i>	Star of Bethlehem	Radial	Introduced	Asparagaceae
<i>Phlox paniculata</i>	Tall Garden Phlox	Radial	Native	Polemoniaceae
<i>Verbesina alternifolia</i>	Wingstem	Radial	Native	Asteraceae
<i>Veronica spicata</i>	Spike Speedwell	Radial	Introduced	Plantaginaceae
<i>Viburnum rhytidophyllum</i>	Leatherleaf Viburnum	Radial	Introduced	Adoxaceae
<i>Helianthus 'Autumn'</i>	Autumn Sunflower	Radial	Native	Asteraceae
<i>Helianthus 'Lemon Queen'</i>	Lemon Queen Sunflower	Radial	Native	Asteraceae
<i>Helianthus Spp. 3</i>	Suflower Species	Radial	Native	Asteraceae
<i>Asclepias curassavica</i>	Mexican Butterfly Weed	Radial	Introduced	Apocynaceae
<i>Hydrangea arborescens</i>	Wild Hydrangea	Radial	Native	Hydrangeaceae
<i>Hydrangea quercifolia</i>	Oakleaf Hydrangea	Radial	Native	Hydrangeaceae
<i>Lavandula x intermedia 'Phenominal'</i>	Lavender	Radial	Introduced	Lamiaceae
<i>Perovskia atriplicifolia</i>	Russian Sage	Bilateral	Introduced	Lamiaceae
<i>Salvia nemerosa</i>	Blue Salvia	Bilateral	Introduced	Lamiaceae

<i>Solanum carolinense</i>	Horse Nettle	Radial	Native	Solanaceae
<i>Tradescantia virginiana</i>	Spiderwort	Radial	Native	Commelinaceae
<i>Asclepias tuberosa</i>	Butterfly Weed	Radial	Native	Asclepiadaceae
<i>Calystegia sepium</i>	Hedge Bindweed	Radial	Native	Convolvulaceae
<i>Chamaecrista fasciculata</i>	Partridge Pea	Radial	Native	Fabaceae
<i>Cichorium intybus</i>	Chicory	Radial	Native	Asteraceae
<i>Geranium pratense</i>	Meadow Cranesbill	Radial	Native	Geraniaceae
<i>Monarda clinopodia</i>	White Bee Balm	Bilateral	Native	Lamiaceae
<i>Monarda didyma</i>	Red Bee Balm	Bilateral	Native	Lamiaceae
<i>Oenothera biennis</i>	Common Evening Primrose	Radial	Native	Onagraceae
<i>Rubus odoratus</i>	Purple Flowering Paspberry	Radial	Native	Rosaceae
<i>Silphium perfoliatum</i>	Cup Plant	Radial	Native	Asteraceae
<i>Symphyotrichum novae-angliae</i>	New England Aster	Radial	Native	Asteraceae
<i>Chrysanthemum Spp.</i>	Crysanthemum	Radial	Introduced	Asteraceae
<i>Cleome Spp. 1</i>	Spider Flower	Bilateral	Native	Capparaceae
<i>Cosmos Spp. 1</i>	Cosmos	Radial	Native	Asteraceae
<i>Delphinium Spp. 1</i>	Larkspur	Radial	Introduced	Ranunculaceae
<i>Dianthus Spp.</i>	Dianthus red	Radial	Introduced	Caryophyllaceae
<i>Echinacea purpurea 2</i>	White Coneflower	Radial	Native	Asteraceae
<i>Helianthus mollis</i>	Downy Sunflower	Radial	Native	Asteraceae
<i>Helianthus Spp. 5</i>	Sunflower	Radial	Native	Asteraceae
<i>Lantana camara</i>	Lantana	Radial	Introduced	Verbenaceae
<i>Salvia farinacea</i>	Blue Salvia	Bilateral	Introduced	Lamiaceae
<i>Tagetes Spp.</i>	Marigold	Radial	Introduced	Asteraceae
<i>Tropaeolum Spp.</i>	Nasturtium	Radial	Introduced	Trapolaceae
<i>Zinnia Spp.</i>	Zinnia fuschia	Radial	Introduced	Asteraceae
<i>Buddleia davidii</i>	Butterfly Bush	Radial	Introduced	Scrophulariaceae
<i>Coreopsis spp. 1</i>	Short Orange Tickseed	Radial	Native	Asteraceae
<i>Coreopsis spp. 2</i>	Tall Orange Tickseed	Radial	Native	Asteraceae
<i>Coreopsis spp. 3</i>	Tall Yellow Tickseed	Radial	Native	Asteraceae
<i>Coreopsis spp. 4</i>	Short Yellow Tickseed	Radial	Native	Asteraceae
<i>Coreopsis spp. 5</i>	Purple tickseed	Radial	Native	Asteraceae
<i>Coreopsis spp. 6</i>	Light purple/pink Tickseed	Radial	Native	Asteraceae
<i>Ipomoea purpurea</i>	Morning Glory	Radial	Introduced	Convolvulaceae
<i>Stokesia laeavis</i>	Stokes Aster	Radial	Introduced	Asteraceae
<i>Symphytum officinale</i>	Common Comfrey	Radial	Introduced	Boraginaceae
<i>Viola Spp.</i>	Viola species	Bilateral	Introduced	Violaceae

Zinnia Spp. 1	Red Zinnia Hybrid	Radial	Introduced	Asteraceae
Achillea millefolium	Yarrow	Radial	Hybridized	Asteraceae
Allium Spp. 1	Allium Species	Radial	Native	Liliaceae
Apocynum cannabinum	Indian Hemp	Radial	Native	Apocynaceae
Asclepias Spp.	Milkweed-like	Radial	Native	Asclepiadaceae
Centaurea cyanus	Pink Bachelor Buttons	Radial	Introduced	Asteraceae
Helianthus Spp. 2	Sunflower	Radial	Native	Asteraceae
Hydrangea paniculata 'Limelight'	Limelight Hydrangea	Radial	Introduced	Hydrangeaceae
Ipomoea lacunosa	White Morning Glory	Radial	Native	Convolvulaceae
Amsonia Spp	Small Blue Starflower	Radial	Native	Apocynaceae
Coriopsis Spp. 19	White frilly tickseed	Radial	Native	Asteraceae
Eupatorium purpureum	Joe Pye	Radial	Native	Asteraceae
Helianthus Spp. 6	Large Sunflower	Radial	Native	Asteraceae
Hosta cultivar	Hosta white	Radial	Introduced	Asparagaceae
Hydrangea panniculata	Pannicled Hydrangea	Radial	Introduced	Hydrangeaceae
Lily Spp.	Lilly	Radial	Introduced	Liliaceae
Melissa officinalis	Lemon Mint	Bilateral	Introduced	Lamiaceae
Carthamus tinctorius	Safflower	Radial	Introduced	Asteraceae
Coreopsis verticillata	Threadleaf Coreopsis	Radial	Native	Asteraceae
Eurybia divaricata	White Wood Aster	Radial	Native	Asteraceae
Gallium odoratum	Sweet Woodruff	Radial	Introduced	Rubiaceae
Leucanthemum vulgare	Oxeye Daisy	Radial	Introduced	Asteraceae
Mint Var.1	Blue mint variety	Bilateral	Native	Lamiaceae
Penstemon digitalis	White Beardstongue	Bilateral	Native	Scrophulariaceae
Physalis virginiana	Virginia Ground Cherry	Radial	Native	Solanaceae
Pycnanthemum pilosum	White Mint	Bilateral	Native	Lamiaceae
Sphagneticola trilobata	Small Yellow Groundcover	Radial	Introduced	Asteraceae
Baptisia Spp. 1	Baptisia	Bilateral	Native	Fabaceae
Campanula kemulariae	Bellflower	Radial	Introduced	Campanulaceae
Corydalis lutea	Fumewort	Bilateral	Introduced	Fumariaceae
Cynoglossum amabile	Chinese Forget-me- not	Radial	Introduced	Boraginaceae
Dianthus barbatus 1	Sweet William	Radial	Introduced	Caryophyllaceae
Erigeron philadelphicus	Daisy Fleabane	Radial	Native	Asteraceae
Euonymus atropurpureus	Burning Bush	Radial	Native	Celastraceae
Heuchera americana	Coral Bells	Radial	Native	Saxifragaceae
Impatiens hybrid	Sunpatiens	Bilateral	Introduced	Balsaminaceae
Iris sibirica	Siberian Iris	Bilateral	Introduced	Iridaceae
Itea virginica	Sweetspire	Radial	Native	Iteaceae

Lamium maculatum	Spotted Dead-nettle	Bilateral	Introduced	Lamiaceae
Lamprocapnos spectabilis	Asian Bleeding Heart	Bilateral	Introduced	Papaveraceae
Sisyrinchium angustifolium	Narrowleaf Blue-eyed grass	Radial	Native	Iridaceae
Stylophorum diphyllum	Wood Poppy	Radial	Native	Papaveraceae
Tiarella cordifolia	Foam Flower	Radial	Native	Saxifragaceae
Zizia aurea	Golden Alexander	Radial	Native	Apiaceae
Amphicarpaea bracteata	Hog Peanut	Bilateral	Native	Fabaceae
Aquilegia Spp. 1	Columbine	Radial	Native	Ranunculaceae
Crepis capillaris	Hawksbeard	Radial	Introduced	Asteraceae
Digitalis Spp.	FoxGlove	Bilateral	Introduced	Plantaginaceae
Galium aparine	Sticky bedstraw	Radial	Native	Rubiaceae
Iris germanica cv.	Iris	Bilateral	Introduced	Iridaceae
Oxalis stricta	Common Woodsorrel	Radial	Native	Oxalidaceae
Spirea japonica Spp.	Spyrea	Radial	Introduced	Rosaceae
Thymus vulgaris	Cooking Thyme	Bilateral	Introduced	Lamiaceae
Centaurea montana	Corn Flower	Radial	Introduced	Asteraceae
Clematis viticella	Clematis	Radial	Introduced	Ranunculaceae
Heleborus Spp.	Heleborous cv.	Radial	Introduced	Ranunculaceae
Hemerocallis lilioasphodelus	Daylily Spp.	Radial	Introduced	Asphodelaceae
Lonicera Spp.	HoneySuckle	Radial	Native	Caprifoliaceae
Pelargonium X hortorum	Geranium	Bilateral	Introduced	Geraniaceae
Peonia lactiflora cv.	Peony	Radial	Introduced	Paeoniaceae
Petunia Spp.	Petunia	Radial	Introduced	Solanaceae
Pulmonaria officinalis	Lung Wart	Radial	Introduced	Boraginaceae
Rose Spp.	Knockout Roses	Radial	Introduced	Rosaceae
Vinca minor	Periwinkle	Radial	Introduced	Apocynaceae

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