The Effects of Socio-economic Variables on Urban Bee Community Composition in Metropolitan Detroit

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Abstract

In light of pollinator decline, green areas within cities can provide habitat for insect pollinators. As cities sprawl outward, lawns and lawn care chemicals expand in tandem with ecological repercussions, so the role cities play in pollinator conservation becomes increasingly important. Socio-economic factors like income and race may affect patterns of lawn care and cultivated plant diversity, which could affect pollinator communities in ways urban ecologists are only beginning to understand. Here we present a study of bees in 24 residential lawns in the city area and suburbs of Detroit along a socioeconomic gradient. We analyze relationships between census data, floral richness, and native bee abundance, diversity and composition. Through GIS analysis and selection of linear mixed models, we address the following questions, 1) Do temperature and floral species richness affect native bee abundance and genus richness in lawns? and 2) Do the socio-economic factors of income and race affect native bee abundance and richness across Metropolitan Detroit? Results show that both income and race have significant negative relationships with bee abundance while floral richness has a significant positive relationship with bee abundance. Likewise, income has a significant negative relationship with genus richness, but only when suburban sampling sites with high floral richness are removed from the model. Floral richness has a significant positive relationship with genus richness. This highlights the importance of local-level bee-friendly lawn landscape characteristics while also pointing to the detrimental landscape-level impact of lawn chemical inputs. These findings have potential relevant policy implications for lawn management, urban development and sprawl, and support policy initiatives on the municipal level to regulate the use of lawn chemicals.

Introduction

General global insect decline has been a cause for alarm among scientists and the general public (Hallman et al. 2017). In particular, key insect pollinator groups, essential for ecological functioning and plant reproduction (Klein 2007, Ollerton et al. 2011), are declining due to a range of human activities and related impacts including habitat loss, agricultural intensification, pesticides, and pathogens (González-Varo et al. 2013, Vanbergen et al. 2013). Habitat loss in particular is driven by human land-use change, comprised in part by urban development and sprawl. Urban land continues to expand globally: the proportion of the human population living in urban areas reached 50% in 2008 (UNFPA 2007), indicating the importance of understanding urban pollinator ecology. Researchers are finding diverse assemblages of bees in cities throughout the world, and in some cases, bee diversity and abundance is demonstrated to be greater in cities than in the rural areas surrounding them (Glaum et al. 2017, Sirohi et al. 2015, Matteson et al. 2008). Baldock et al. (2015), for instance, demonstrate higher levels of bee species richness in urban areas as compared to farmland. Further, demographic trends across cities have been shown to affect weed coverage, which in turn affects bee abundance (Iuliano et al. 2017). Glaum et al. 2017 suggest that a “shrinking cities” phenomenon, as seen in post-industrial cities like Detroit, can support native bee conservation. In these cases, declining human populations make way for greater open land and forage availability within urban centers.

Humans within growing urbanized areas affect the quality of potential native bee habitat with their behavior. Cultural norms, municipal codes, lawncare, and aesthetic preferences, which influence pesticide usage and the diversity of plants, change with a range of socioeconomic trends. In urban contexts, a primary driver of pollinator health is the presence and availability of flowers (Iuliano et al. 2017, Sirohi et al. 2015). The presence of more flowers in urban residential lawns can have a positive effect on bee communities. Furthermore, an urban heat island effect has been found in many cities and temperature has been shown to affect bee species composition by expanding the range of the more thermophilic species. Therefore, cities may affect bee communities through the heat island effect.

In terms of the way human demographics impact urban ecology, those with more valuable homes tend to use more bee-harming pesticides (Robbins et al. 2001), and pesticide use is demonstrably connected to native bee decline (Gill et al. 2012, Potts et al. 2010). Lawn sizes and the proportion of turfgrass on lawns are increasing with urban sprawl, requiring higher inputs of herbicides, pesticides, and synthetic fertilizers—serious sources of urban nonpoint pollution. Estimates put nationwide lawn coverage between 9 and 16 million hectares, surpassing the coverage of some export crops such as barley, cotton, and rice. As seen in intensive farming systems, lawn inputs lead to a "chemical treadmill", and must be applied in greater quantities over time to sustain the same results. The ecological impact of lawns, therefore, rivals that of agriculture (Robbins and Sharp 2003).

Here we present a study of bee community structure in residential lawns in Metropolitan Detroit, Michigan. A lawn in this study is considered to be the entirety of a given residential property excluding any structures. This includes various ground coverages such as turfgrass, flowerbeds, and gardens. We investigate relationships between the dependent variables of bee abundance and genus richness and the independent variables of socio-economic demographics (income and race), lawn floral species abundance, and temperature. Given the positive correlation between home value and pesticide use (Robbins et al. 2001), it bears investigating the links between bee community structure and socio-economic variables. Increased forage availability has been shown to be positively correlated with bee abundance (Iuliano et al. 2017), so floral species could prove to be a relevant factor in native bee community structure in lawns. The urban heat island effect has also been shown to negatively affect urban native bee populations (Hamblin et al. 2018), so temperature is another ecologically relevant variable to consider in this study. Specifically, I ask the following questions:

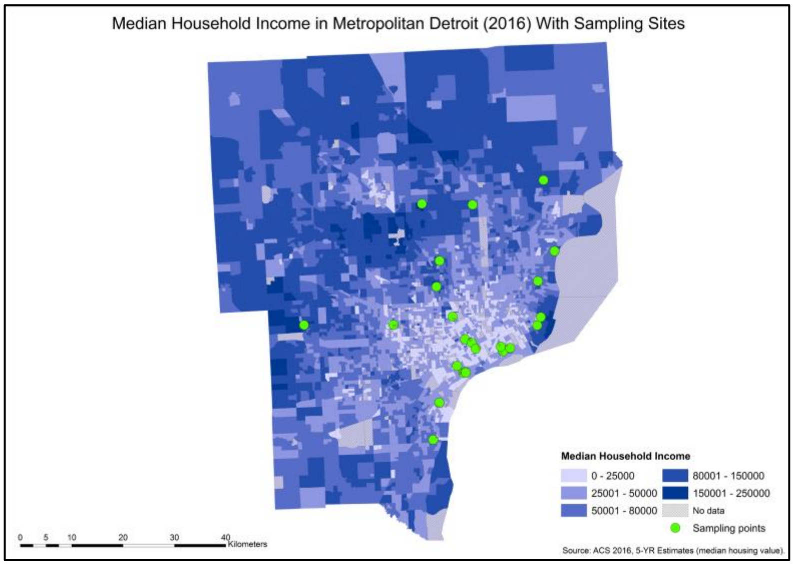
1. Do temperature and floral species richness affect native bee abundance and richness in lawns?
2. Do the socio-economic factors of income and race affect native bee abundance and richness across Metropolitan Detroit, Michigan?

Methods

Study Sites

This study encompasses 24 urban and suburban residential lawns throughout Metropolitan Detroit, Michigan. These sampling sites were selected based on availability through a network of personal contacts and acquaintances. Specifically, homeowners within Metropolitan Detroit willing to offer their lawns for sampling were sought out through word of mouth. Their geographic spread encompasses a wide range of household income levels and racial compositions of neighborhoods, and each residential lawn contained varying levels of turfgrass and flowerbed cover. Conducting this study on lawns in particular is important for addressing the research questions of the study: while existing research uses urban farms and gardens as sampling sites, no existing research uses lawns as the unit of analysis for understanding urban bee communities. Sites encompass a large, heterogeneous range of human demographic characteristics within this single geographic area, limiting effects from confounding divergent variables that come with distant geographic locations.

With permission from each of the homeowners, sampling of bee communities took place at each of these 24 residential lawns throughout the summer of 2016. These lawns were located in the Michigan townships of Northville, Wyandotte, Pleasant Ridge, Royal Oak, Troy, Sterling Heights, Macomb, St. Clair Shores, Grosse Pointe Farms, Grosse Pointe, and in the Detroit neighborhoods of Riverdale, Boynton, Mexicantown-Southwest Detroit, Hubbard, Richard, West Village, Indian Village, East Village, and Palmer Park. These sites span Wayne, Macomb, and Oakland Counties, and these counties encompass the entirety of the Detroit Tri-County Area, falling entirely within the Detroit Metropolitan Statistical Area (Fig. 1).



Source: ACS 2016, 5-YR Estimates (median housing value).

Figure 1: Twenty-four sampling sites across a gradient of median household income (2016) by block level in Metropolitan Detroit.

Field Sampling

Each of the 24 sites were visited 3 or more times throughout the summer of 2016 (with the exception of 3 sites visited twice due to permission and weather constraints). Two collection methods were employed during each visit. First, an insect net was used for capturing bees that landed on observed flowers. As per LeBuhn's et al. (2003) suggestion for standardized bee monitoring methods, each netting session took place for one hour in the morning (9 am-12 pm) and one hour in the afternoon (12 pm-3 pm) for a 1-hectare bee inventory plot. However, each of the yards in this study were only a fraction of a hectare in area, so the netting time (both morning and afternoon) for each site visit was reduced proportionally to the lawn-to-standard bee inventory plot size ratio. Lawn area was measured using Google Earth satellite imagery. Second, bee bowls were deployed: 3-oz pan traps painted with UV-reflective coating and filled with a solution of water and dish detergent (LeBuhn et al. 2003). Bowls were methodically placed throughout the lawn (including turfgrass, gardens, or flowerbeds)10 meters apart from each other with 3 different colors in random order (blue, white, and yellow). Bowls were placed prior to 9 am and collected between 3 and 5 pm. Floral species richness was recorded for each lawn sampled and local temperature data was recorded using an anemometer. Bees were then identified to genus using Wilson and Carril (2015).

GIS Data

Socio-economic/demographic indicators related to race and household income were obtained from the US Census Bureau's 2016 American Community Survey. Specifically, these included median household income within the year leading up to 2016 and numbers of individuals broken down by race. Data from the latter indicator was used to calculate the black-to-white ratio. Both indicators were measured at the census block group level, the smallest geographical unit for which the bureau publishes sample data.

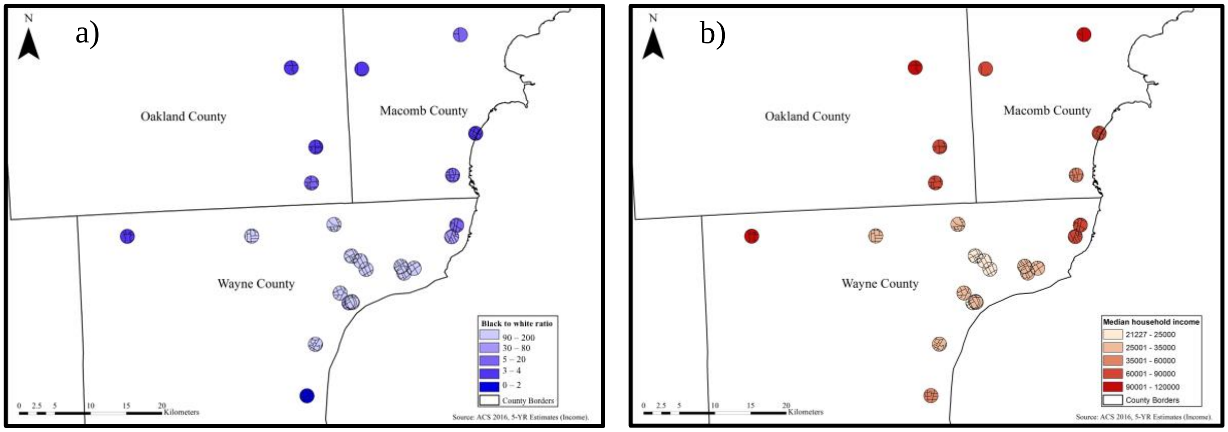
Geographic Information Systems (GIS) programs were used to create a profile for each sampling site. ArcGIS software was used to draw a 1-kilometer buffer zone around each of the 24 residential yards and overlay these buffers with American Community Survey data at the block group level for both median income and race variables. A 1-kilomoter buffer zone was used because this corresponds with the limited maximum foraging distance of native bees (Gathmann and Tscharntke 2002, Zurbuchen et al 2010). The area proportion of each census block within each buffer was determined and then multiplied by the variables corresponding with the same census blocks. These numbers were then summed to determine the neighborhood socio-economic values associated with each residential lawn.

Statistics

To assess relationships between dependent variables (bee abundance and genus richness) and independent variables (income, race, floral richness, and temperature), linear mixed models were used. Aikake information criterion (AIC) values were used to compare and select linear mixed models with the highest relative quality for each dependent variable. For bee abundance, income, race, and floral species richness were used as fixed effects and sampling day was used as a random effect. The linear mixed model for genus richness was the same: income, race, and floral species richness were used as fixed effects and sampling day was used as a random effect. Because the income data is on a much larger scale than the other explanatory variables, the scale command was used in RStudio to make comparing effect sizes more feasible. The variance inflation factor (VIF) was used in R to check each predictive factor, ensuring the models did not exhibit multicollinearity. A number of the sites with the highest income levels in the suburbs belong to homeowners with knowledge of and concern for bee conservation who employed pollinator-friendly lawncare practices. To avoid possible bias in the model, the 5 suburban sampling sites (all containing low black-to-white ratios) with the highest levels of floral species richness were eliminated from the analysis and the same linear mixed models were applied and compared to the linear mixed models without the eliminated sampling points (after using AIC values to determine the best fit models). All data were analyzed in RStudio version 1.1.456.

Results

Across the 24 sample sites, 1,440 individual bee specimens were identified belonging to 6 families and 36 genera (Table 1). The 3 most well-represented families are Apidae, Halictidae, and Megachilidae, many genera of which exhibit solitary nesting behaviors in the ground or in wood. With the exception of the kleptoparasitic genus *Coelioxys* in the Megachilidae family, all of these genera feed on nectar and pollen from floral resources. Some of the genera belonging to the larger bee families (Apidae, Andrenidae, Halictidae, Megachilidae, and Colletidae) are ground nesters, excavating long tunnels in sunny bare soil with low flooding potential. Other Megachilid genera nest in already-existing holes such as in hollow stems or dead wood. *Xylocopa sp*., an Apid known colloquially as the carpenter bee, uses powerful mandibles to excavate their own tunnels in wood—this genus was represented in every county except Macomb.



Source: ACS 2016, 5-YR Estimates (Income).

Figure 2: Spatial representation of the two socio-economic independent variables in question: a) the ratio of white-to-black individuals and b) median household income numbers contained in census tracts contained within the 1-kilometer buffer zones of the 24 sampling sites distributed across Wayne, Oakland, and Macomb Counties.

Spatial representations of the explanatory variables show the geographical heterogeneity of these factors across Metropolitan Detroit. The black-to-white ratio shows higher proportions of black individuals in Wayne County, particularly the city of Detroit, and lower proportions in western and southern Wayne County and Oakland and Macomb Counties (Fig. 2a). The spatial representation of median household income reveals a similar distribution: median household income is lower within the buffer zones of sampling sites in the City of Detroit (Eastern Wayne County) than within the buffer zones of sampling sites in the surrounding metropolitan area (Fig. 2b).

Bee abundance

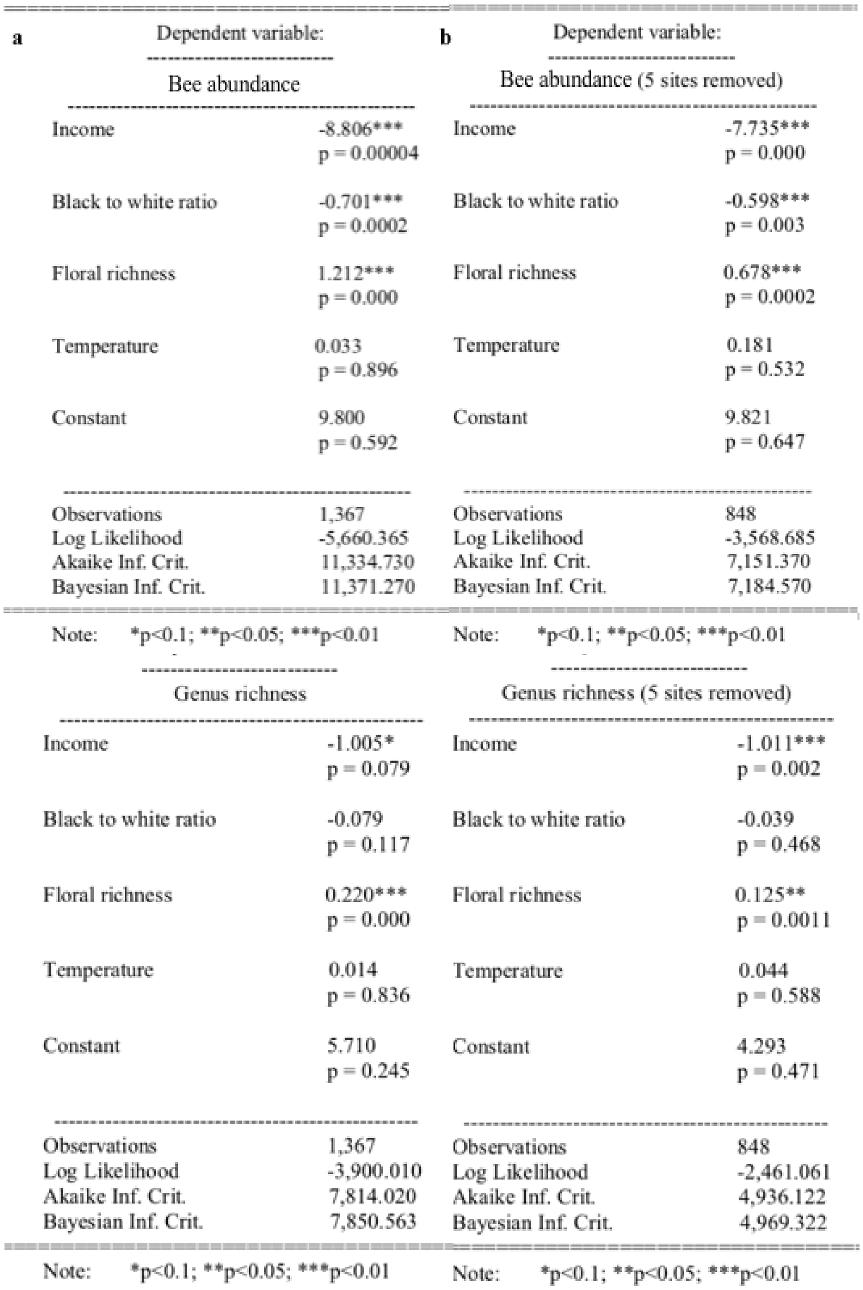
The linear mixed model used for bee abundance indicates that both median income and race are significant explanatory demographic variables (*p*=0.00004 and *p*=0.002 respectively) with a negative relationship between each

Table 1. Sampled bee families (bold) and their representative genera organized by county. Wayne County is divided into the city of Detroit and its suburbs. Apidae, Halictidae, and Megachilidae are the most highly represented bee families in the study.

Macomb County	Oakland County	Wayne County (suburbs)	Waye County (Detroit)
Andrenidae	**Andrenidae**	**Andrenidae**	**Andrenidae**
Andrena	Andrena	Andrena	Andrena
Perdita	Calliopsis	Calliopsis	Calliopsis
Apidae	Perdita	Perdita	Perdita
Anthophora	Protandrena	Protandrena	Protandrena
Bombus	**Apidae**	Pseudopanurgus	Pseudopanurgus
Ceratina	Anthophora	**Apidae**	**Apidae**
Epeolus	Bombus	Bombus	Anthophora
Colletidae	Ceratina	Ceratina	Bombus
Colletes	Epeolus	Epeolus	Ceratina
Hylaeus	Eucera	Melissodes	Epeolus
Halictidae	Melissodes	Nomada	Eucera
Agapostemon	Nomada	Xeromelecta	Holcopasites
Agapostemon	Xeromelecta	Xylocopa	Melissodes
Augochlorella	Xylocopa	**Colletidae**	Nomada
Augochloropsis	**Colletidae**	Colletes	Peponapis
Dieunomia	Colletes	Hylaeus	Svastra
Halictus	Hylaeus	**Halictidae**	Triepeolus
Lasioglossum	**Halictidae**	Agapostemon	Xylocopa
Megachilidae	Agapostemon	Augochlora	**Colletidae**
Coelioxys	Augochlora	Augochlorella	Colletes
Hoplitis	Augochlorella	Augochloropsis	Hylaeus
Megachile	Augochlorini	Dieunomia	**Halictidae**
Osmia	Augochloropsis	Dufourea	Agapostemon
	Dieunomia	Halictus	Augochlora
	Dufourea	Lasioglossum	Augochlorella
	Halictus	Sphecodes	Augochlorini
	Lasioglossum	**Megachilidae**	Augochloropsis
	Sphecodes	Anthidium	Dieunomia
	Megachilidae	Chelostoma	Dufourea
	Anthidium	Coelioxys	Halictus
	Chelostoma	Dianthidium	Lasioglossum
	Coelioxys	Heriades	Sphecodes
	Heriades	Hoplitis	**Megachilidae**
	Hoplitis	Megachile	Anthidiini
	Megachile	Osmiini	Anthidium
	Osmiini	Osmia	Chelostoma
	Osmia	Trachusa	Coelioxys
	Paranthidium	**Mellitidae**	Heriades
	Stelis	Macropis	Hoplitis
	Mellitidae		Megachile
	Macropis		Osmiini
			Osmia
			Paranthidium
			Stelis
			Trachusa
			Mellitidae
			Hesperapis
			Macropis

socioeconomic variable (income and black-to-white ratio) and bee abundance. Floral richness had a positive relationship with bee abundance (*p*=0.000) (Table 2a). Sampling day, used as a random effect within the linear mixed model, accounts for 53.8% of the variation.

Table 2. Linear mixed model output with income, race, floral richness, and temperature as fixed effects, and sampling day as a random effect. **a** Bee abundance as the response variable. Income and black to white ratio have significant negative relationships with bee abundance; floral richness has a significant positive relationship with bee abundance. **b** Bee abundance with 5 sites removed as the response variable. Income and black to white ratio have significant negative relationships with bee abundance; floral richness has a significant positive relationship with bee abundance. **c** Genus richness as the response variable. Income has a non-significant negative relationship with genus richness; floral richness has a significant positive relationship with genus richness. **d** Genus richness with 5 sites removed as the response variable. Income has a significant negative relationship with genus richness; floral richness has a significant positive relationship with genus richness.



a	Dependent variable:	**b**	Dependent variable:
	Bee abundance		Bee abundance (5 sites removed)
Income	-8.806*** p = 0.00004	Income	-7.735*** p = 0.000
Black to white ratio	-0.701*** p = 0.0002	Black to white ratio	-0.598*** p = 0.003
Floral richness	1.212*** p = 0.000	Floral richness	0.678*** p = 0.0002
Temperature	0.033 p = 0.896	Temperature	0.181 p = 0.532
Constant	9.800 p = 0.592	Constant	9.821 p = 0.647
Observations	1,367	Observations	848
Log Likelihood	-5,660.365	Log Likelihood	-3,568.685
Akaike Inf. Crit.	11,334.730	Akaike Inf. Crit.	7,151.370
Bayesian Inf. Crit.	11,371.270	Bayesian Inf. Crit.	7,184.570
Note:	*p<0.1; **p<0.05; ***p<0.01	Note:	*p<0.1; **p<0.05; ***p<0.01

	Genus richness		Genus richness (5 sites removed)
Income	-1.005* p = 0.079	Income	-1.011*** p = 0.002
Black to white ratio	-0.079 p = 0.117	Black to white ratio	-0.039 p = 0.468
Floral richness	0.220*** p = 0.000	Floral richness	0.125** p = 0.0011
Temperature	0.014 p = 0.836	Temperature	0.044 p = 0.588
Constant	5.710 p = 0.245	Constant	4.293 p = 0.471
Observations	1,367	Observations	848
Log Likelihood	-3,900.010	Log Likelihood	-2,461.061
Akaike Inf. Crit.	7,814.020	Akaike Inf. Crit.	4,936.122
Bayesian Inf. Crit.	7,850.563	Bayesian Inf. Crit.	4,969.322
Note:	*p<0.1; **p<0.05; ***p<0.01	Note:	*p<0.1; **p<0.05; ***p<0.01

Genus richness

The linear mixed model used for bee genus richness reveals no significant relationship with median income or black-to-white ratio. However, floral richness has a significant positive relationship with genus richness (p=0.000) and a negative but non-significant with median income (p=0.079) (Table 2b). The random effect of sampling day accounts for 50.8% of variation within the linear mixed model.

Bee abundance and genus richness after data elimination

A number of the sites with the highest income levels in the suburbs belong to homeowners with knowledge of and concern for bee conservation who employed pollinator-friendly lawncare practices. To avoid possible bias in the model, the 5 suburban sampling sites (all containing low black-to-white ratios) with the highest levels of floral species richness were eliminated from the analysis and the same linear mixed models were applied. With the elimination of these points, income (p=0.000) and black-to-white ratio (p=0.003) remain significant negative explanatory variables for bee abundance and floral richness remains a significant positive explanatory variable (p=0.0002) (Table 2b). The random effect of sampling day accounts for 45% of the variation in the model.

For genus richness, income emerges a significant negative explanatory variable (p=0.002) and floral richness remains a significant positive explanatory variable (p=0.0011) (Table 2d). The random effect of sampling day accounts for 52.2% of the variation within the linear mixed model.

Discussion & Conclusions

Linear mixed models for bee abundance and genus richness were compared containing 1) the full set of 24 sampling sites and 2) a reduced set of 19 of the total sampling sites. The eliminated data points represent the sampling sites located in the Michigan townships of Northville, Grosse Pointe Farms, Sterling Heights, Troy, and Royal Oak, spanning all 3 counties in the study. Each of these points are located in the suburbs outside of the urban core of Detroit, and each of these points contains unusually high floral abundance—the homeowners at each of these sites intentionally cultivate their landscaping to benefit pollinator biodiversity. Their effort potentially harbors greater bee diversity in these 5 lawns than in lawns of homeowners in similar demographic categories.

Linear mixed model results show that income has a negative correlation with bee abundance when all sampling sites are included in the model (p=0.00004) (Table 2a) as well as when the 5 data points are eliminated (p=0.000) (Table 2b). Genus richness, however, shows a different pattern than bee abundance: income has a significant negative correlation with genus richness only when the 5 data points are removed (p=0.002) (Table 2d). In the case of genus richness, the intentionally pollinator-friendly landscaping of homeowners provides the forage needed to support higher numbers of bee genera, and removing these sampling sites from the model revealed their effect. Further, each of the four linear mixed models show a significant positive relationship between floral diversity and bee abundance and genus richness (p=0.000 and 0.0002 for each of the abundance models and p=0.000 and 0.0011 for each of the richness models) (Table 2). These results are congruent with those of Pardee and Philpott (2014), which demonstrate that urban gardens containing native plants positively affect bee abundance and the richness of cavity-nesting species. Without the 5 data points and their unusually high floral abundance, a clear pattern emerges showing higher levels bee abundance and genus richness in lower-income areas in Detroit’s core and lower levels of bee abundance and genus richness in affluent suburbs surrounding the urban core. Higher-income suburbs in Metropolitan Detroit harbor lower bee diversity: as those with higher values in homes use greater levels of bee-harming pesticides (Robbins et al. 2001), the lawn and its surrounding landscape become more hostile to bees, affecting their community composition.

Race shows a strong negative relationship with bee abundance but not with richness. The higher the black-to-white ratio, the lower the bee abundance in both the model with all 24 sampling sites (p=0.0002) (Table 2a) and the model with the 5 removed sites (p=0.003) (Table 2b). This suggests that lawns in neighborhoods with higher black-to-white ratios harbor fewer bee-friendly local characteristics, resulting in lower numbers of bees.

Sampling sites with higher black-to-white ratios harbored genus richness levels with no significant difference from sites with lower black-to-white ratios. This suggests the "shrinking cities" phenomenon, wherein postindustrial cities with histories of economic hardship develop high numbers of vacant lots and therefore more available forage and nesting for bees, bears important relevance to bee diversity (Glaum et al. 2017). This process only applies to postindustrial urban areas, however, and cannot be generalizable to all cities. The most represented families in this study (Apidae, Halictidae, and Megachilidae) contain solitary nesting genera that rely on readily-available wood and soil: materials made more available on the landscape level in a shrinking city like Detroit.

Just as well, processes in urban sprawl determine lawn characteristics relevant to insect pollinators. As cities have sprawled outward since the 20th century, the lawn-to-property size ratio has grown in conjunction with property size, meaning increasingly higher coverages of turfgrass over time in urban areas of the United States as one gets further form a given city's core. Estimates show about 2.3% of urban areas covered in turf, and this number is expected to continue expanding in the United States and Canada as urban areas continue growing. In addition to stunting forage availability, these large areas of turf require extensive inputs ranging from synthetic fertilizers to bee-harming pesticides (Robbins and Birkenholtz 2003; Robbins and Sharp 2003). For these reasons, it is crucial this study was conducted using the lawn as the unit of analysis. The socio-economic contours of urbanizing landscapes are a critical dimension in properly understanding urban bee community structures, and the findings of this study have implications for municipal-level lawn chemical application.

Understanding other aspects of bee community composition reflected in the data—bee abundance and genus richness—will require measurements of additional variables. To deepen the insights of this study, future research should involve more detailed landscape-level variables that can account for bee nesting and foraging availability. Obtaining qualitative data to demonstrate lawn inputs is another important line of inquiry for future related studies. The interdisciplinary methodology employed in this study offers a novel approach to urban ecological dynamics with the lawn as the unit of analysis. As global cities continue expanding, understanding pollinator declines in this context will become increasingly urgent.

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