URBAN HONEY BEES AND FORAGE: THE ECOLOGICAL DIMENSION OF DISINVESTED NEIGHBORHOODS IN PHILADELPHIA, USA

Austin Martin, Department of Geography and Urban Studies, Temple University

Graduate Research Award: Sustainability Program recipient 2020

ABSTRACT

With bee decline underway across taxa on a global scale, cities increasingly stand as a haven for bee conservation. Primary drivers of bee decline include habitat fragmentation and high-input agricultural and lawn management – both of which can make non-urban landscapes more hostile to bees than urban landscapes. In this analysis, I draw from urban ecological methods and political ecological framings to better understand the urban landscape as a bee socio-economic system. Using data from the unique honey bee foraging assay of Sponsler et al. (2020) which describes plant genera identified from pollen DNA samples from apiaries across the city, I offer a geospatial analysis to describe spatial patterns of bee floral resources. I ask the following: I) What spatial patterns exist in floral resources for bees across the landscape of the city of Philadelphia? II) Do these spatial patterns correlate with the socio-economic variables of income and racial composition? and II) To what extent can urban ecology and the critical social sciences inform one another in the context of this socio-ecological system? Although I find no strong correlation between plant richness and demographic variables, I examine the dominant plant genera in select Philadelphia neighborhoods, contributing to urban political ecological understandings of weedy ecologies, marginalization, and social control.

INTRODUCTION

Bee decline in the U.S. and globally

The ecological stakes of these questions are urgent. With mounting 21st century ecological crises, a dire loss of insect biodiversity threatens both global ecosystem function and food system resiliency. Sánchez-Bayo and Wychkuys (2019), in a review of dozens of historical reports, project that 40% of the world's insect species will face extinction in the coming decades. Hymenoptera is the order of insects that includes bees, wasps, and ants, and according to the projections of this eco-historical review it is expected to fare among the worst of the insect taxa.

Bees are essential pollinators accounting for large portions of crops produced globally: in the United States, insect pollination ensures that about $15 billion worth of crops will be produced each year (Calderone 2012). This scale of production, however, undercuts the well-being of insect pollinators and bees specifically. The numerous array of wild bee species and cultivated European honey bees (*Apis mellifera*) alike face a growing crisis with measurable declines in both abundance and richness on most continents in recent decades (Zattara and Aizen

2021). Because managed honey bee colony numbers are easily reportable we can see a clear and bleak trend there: hives numbers halved since World War II and declined even more sharply in the past decade with about 38% of beekeepers' colonies reported dead between October 2018 and April 2019. In 13 years of recorded losses, that recent year was the worst die-off against an average backdrop of 19% losses, signalling a worsening issue (Bee Informed Partnership 2018, Ellis 2019).

The economic importance of managed *Apis mellifera* puts them front-and-center in the public's imagination when it comes to bee issues, obscuring the greater ecological importance of the roughly 4,000 wild bee species native to the United States. Some of these native bee species even face the threat of extinction – while honey bee populations are suffering declines, their global presence is not as precarious. Ecological research shows a clear decline among wild bees: Koh et al.'s (2016) team modeled wild bee abundance across the continental United States, finding a 23% drop in abundance between 2008 and 2013. Importantly, wild bee decline coincides spatially with pollinator-dependent cultivated crops. In essence, areas with concentrated intensive agriculture like the Mississippi River Delta, the Midwestern states with heavy corn and soy production, and California's Central Valley are among the U.S. regions with the sharpest declines in bee abundance. Intensive agriculture depends on industrial-scale pollination while simultaneously undercutting the viability of pollinators to perform the task (Ellis et al. 2019).

The most important factors contributing to this drop in bee abundance include the spread of introduced species and pathogens such as the notorious virus-spreading *Varroa* mite, habitat fragmentation and loss to both intensive agriculture and urbanisation, increasing fertilizer and agrochemical use (among these are neonicotinoids, a pesticide with known sub-lethal and compounding effects on bees), and climate change (Sánchez-Bayo and Wyckhuys 2019). This puts processes of land use transformation front and center in our understanding of the driving forces of bee decline. In this report, I will focus on understanding the role of urbanisation and habitat fragmentation in its effect on bee communities. The United Nations Development Programme estimates that by 2030, over 66% of the global population will reside in cities – marking a 55% increase compared to 2018 (United Nations Development Programme 2020). With rapid global urbanisation underway it is imperative to understand its role among the top drivers of bee decline.

Urbanisation and bee conservation

Despite urbanisation's important role in contributing to bee decline, urban landscapes themselves can support bee species in abundance and diversity. It is important here to draw a distinction between urbanisation as a process and the physical composition of land use types in cities. Urbanisation as a process involves the outward sprawling and encroachment of suburban landscapes. Further from a city's urban center, property sizes tend to be larger and they tend to be covered in a greater proportion of turfgrass, which requires intensive management with pesticides, herbicides, and fertilizers (Robbins and Birkenholtz 2003). Closer to its urban center, however, the patchwork of different land use types might facilitate biodiversity.

Urban ecological studies paint a spotty and case-by-case account of the capacity for cities to be a haven for bees: in some cases, urbanized landscapes are associated with less favorable conditions for bees than cropland, grassland, and forest (Sponsler and Johnson 2015). In other cases, however, urban landscapes are associated with greater levels of bee abundance and diversity than other landscapes, including cropland and nature reserves (Baldock 2015, Hall et al. 2016). Cities can provide complex and ecologically favorable landscapes for bees, supporting their diverse nesting and foraging needs and acting as a haven of conservation, in contrast to the sometimes ecologically hostile, agrochemical-laden suburban and agricultural land surrounding cities. As opposed to *Apis mellifera*, which live in large colonies numbering in the tens of thousands of individuals, a majority of wild bee species live solitary lifestyles. Depending on the species, their nesting requirements range from open hard-packed soil to soft soil to the dry, hollow stems of perennial plants. For this reason the heterogeneous landscapes of diverse urban land use types can make an ideal context for wild bee foraging and nesting (Baldock et al. 2019).

Just as diverse urban land use types might play a role in bee conservation, they can also allow for favorable conditions for managed *Apis mellifera* hives. Beekeeping is a viable and celebrated practice in some of the world's most dense and populous cities. I myself have kept honey bees across a spectrum of land-use settings and have found that my beehives accumulated more resources and survived winter seasons most often in a dense South Philadelphia neighborhood, and I share this experience with many others. Urban beekeeping remained relatively rare throughout the 20th century because of livestock ordinances and restrictions in cities, but this changed in the 2000s with a rise of hobbyists keeping bees in urban spaces ranging from rooftops to alleys. "Colony collapse disorder" (CCD) was in capturing media attention at the time, likely playing a role in urban beekeeping's uptick by motivating people to take up the hobby as a way to help the bee population (vanEngelsdorp et al. 2009). Throughout the 2010s, major cities started lifting beekeeping-related livestock ordinances in efforts to bolster their sustainability rhetoric and imagery, and urban beekeepers now enjoy a new level of civic endorsement (Sponsler and Bratman 2020).

This rise in urban beekeeping has led to Sponsler et al. (2020) conducting a unique honey bee foraging assay to describe floral resources in the urban landscape. Using pollen DNA samples from urban honey bee colonies, Sponsler's team described the temporal variation in floral resources across distinct seasons in Philadelphia, USA. This research acts as a useful guide for beekeepers to understand what is blooming and when as seasons change, but the spatial aspect of this data is yet to be described. To this end, I draw from quantitative urban ecological and geospatial methods and urban political ecological framings to ask the following research questions:

a) What spatial patterns exist in floral resources for bees across the landscape of the city of Philadelphia?

i) Do these spatial patterns correlate with the socio-economic variables of income and racial composition?
ii) To what extent can urban ecology and the critical social sciences inform one another in the context of this socio-ecological system?

METHODS

Apiaries and pollen samples

This study draws from data collected and prepared by Sponsler et al. (2020). Their fieldwork took place in 2017 and 2018 and involved 13 apiaries owned by the Philadelphia Bee Company in the city of Philadelphia, Pennsylvania, USA. Each research apiary varied in number of colonies but contained three that were designated for sampling purposes. This made for a total of 36 research colonies across the 13 apiaries. The colonies were established from April to May of the two study years and were housed in 10-frame Langstroth hives that were initially installed from smaller 4- or 5-frame starter nucleus colonies. Apiary placements ranged in character from rooftop to ground-level. During the months of data collection, the research colonies were equipped with Sundance I bottom-mounted pollen traps, which collected pellets of pollen from the legs of forager honey bees returning to the hive.

Sponsler's team collected pollen samples at 4 intervals in 2017 and 6 intervals in 2018. The samples were then processed for pollen DNA identification using polymerase chain reaction (PCR) at the Genomics Core Facility of Pennsylvania State University. Output data was archived on NCBI Sequence Read Archive under Bioproject PRJNA548320 and reference sequences from NCBI GenBank were used to identify DNA sequences to the plant's genus level (Sponsler et al. 2020). This dataset provides the proportional abundance of each plant genus per apiary at each sampling interval. Sponsler's team was fundamentally interested in describing the temporal variation in urban floral resources for bees. In contrast, my primary aim is to describe this data with a spatial analysis, so I pooled the proportional plant abundance data across all years and sampling intervals, taking the average for each research apiary location. In the summer of 2020 I traveled to the general location of each apiary (within roughly 500-1,000 meters) and made ground-truthing observations to confirm the most dominant plants identified in Sponsler et al.'s assay.

Data analysis

I rely on GIS mapping to geospatially analyze Sponsler et al.'s dataset. Using ArcGIS Desktop version 10.5.1, I drew 1 km buffers around each of the 13 research apiaries using the software's Buffer tool (Figure 1). This buffer represents the foraging range diameter within which honey bees will routinely survey the landscape for patches of floral resources. Although honey bees are known to extend their surveys up to several kilometers from the hive, the 1 kilometer buffer was chosen to avoid excessive overlap of buffers, which might wash out any meaningful patterns and characteristics in the statistical analysis. Prior studies demonstrate a honey bee foraging radius ranging from only a few hundred meters to an average of 1.7 kilometers (Free 1970, Michener 1974, Visscher and Seeley 1982), so a 1 kilometer radius appears to be the most appropriate when balancing the range of empirical honey bee studies with analytical acuity. With a land use raster of Philadelphia from the United States Geological Survey National Land Cover Database (NLCD), I used the Reclassify Spatial Analyst tool in ArcGIS to reassign the 21 land use categories into a more simplified 4-part categorization of ecological relevance to urban bees and floral resources: Developed, Open soil and lawn, Forest fragments, and Shrubs. With the spatial positions of Sponsler et al.'s research apiaries and their 1 kilometer buffers overlaid on these land use types it becomes possible to visually assess potential influences from these land use types.

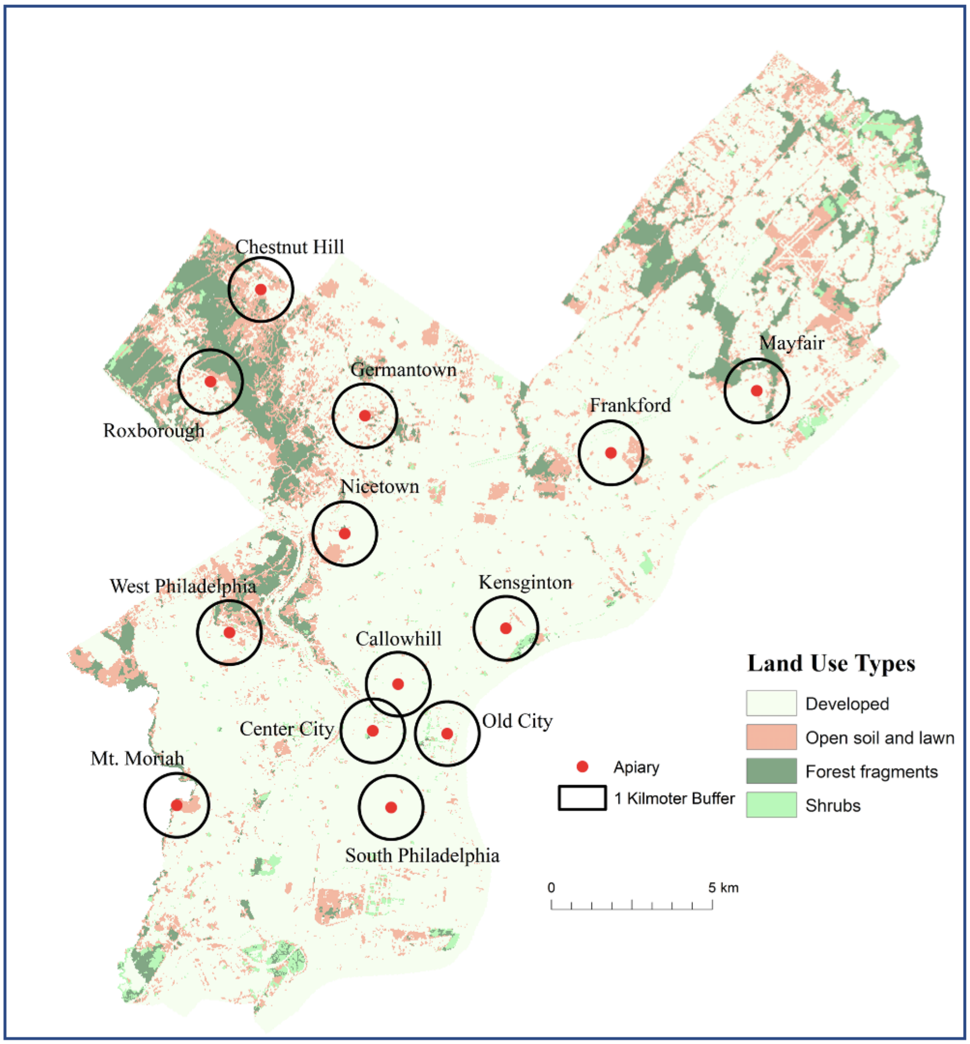

Figure 1. The 13 research apiaries with 1 kilometer buffers representing bee foraging areas. Four major urban land use types are represented within the city proper of Philadelphia, USA. Sources: Sponsler et al. (2020) and the United States Geological Survey National Land Cover Database.

I compiled data from the United States Census Bureau's 2015 American Community Survey data 5-year estimates (United States Census Bureau 2016) at the census tract level to measure demographic variables within the 1 kilometer buffers. Two variables were utilized in the analysis: median household income and percentage of non-white residents. To calculate these demographic variables meaningfully requires more than just summing each census tract's value because most census tracts do not fit cleanly into a given apiary buffer. To calculate the weighted average of the variables for each buffer, I used ArcGIS to calculate the percentage of the apiary buffer's area covered by each census tract and multiplied that value by each census tract's census figures. If a given census tract only covers a small portion on the edge of a given apiary buffer, for instance, its census value will not carry undue sway in the analysis.

RStudio Version 1.4.1103 was used to perform generalized linear models with the socio-economic variables and plant richness data.

RESULTS

With the proportional plant genus data pooled by apiary site and analyzed, a list in descending order of apiary sites with the greatest to lowest levels of plant richness shows the Callowhill location to represent the most richness in plant genera and the Mayfair location with the least (Table 1). Looking across the rows to associated median household income figures and non-white resident percentages shows no obvious pattern.

Apiary	Number of plant genera (richness)	Median household income ($)	Percent non-white residents
Callowhill	101	64007.61	57.4
Mt. Moriah	98	18998.96	96.2
Center City	91	78134.25	33.1
Old City	91	109377.7	28.4
Nicetown	87	37501.5	85.4
Germantown	84	26885.56	89.3
Kensington	84	59604.52	25.6
South Philadelphia	83	53249.52	46.5
Frankford	79	44907.19	83.1
West Philadelphia	77	42885.29	78.3
Chestnut Hill	74	103438.8	26.5
Roxborough	67	51369.74	17.8
Mayfair	51	54457.58	34.3

Table 1. Apiary sites listed with median household income and percent non-white resident figures in descending order from greatest to least plant richness.

A geovisualization of plant richness in apiary buffer sites allows one to observe urban land-use types relevant to each apiary buffer site (Figure 2). Visually, there is no obvious correlation between urban land use type and plant richness other than the cluster of high-richness apiary locations in and around Center City where the predominant land use type is developed.

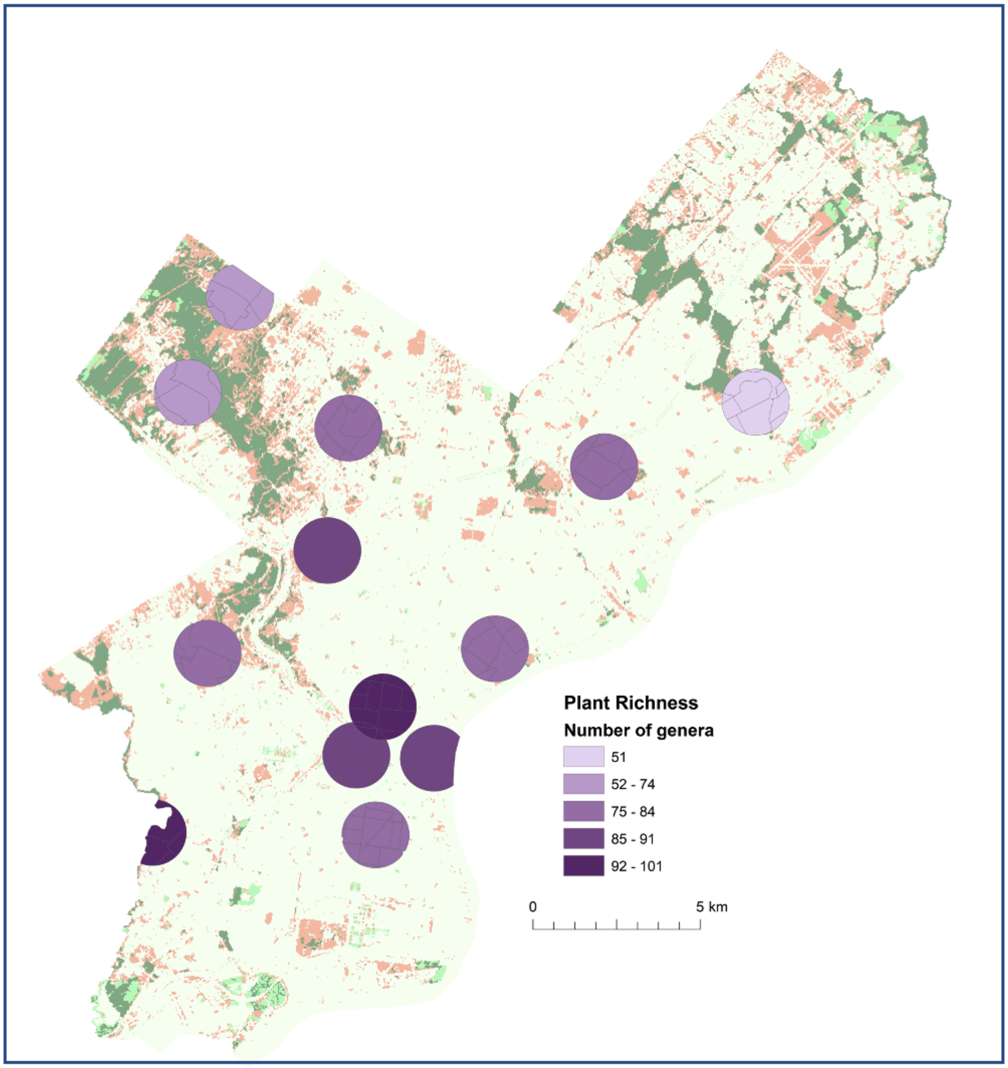

Figure 2. Plant richness. The darker the apiary buffer, the greater number of plant genera represented by pollen data from that apiary. Callowhill and Mt. Moriah feature the greatest plant richness and Mayfair features the lowest.

A geovisualization of median household income and percent non-white residents shows the distribution of these key socio-economic variables among the apiary sites (Figure 3).

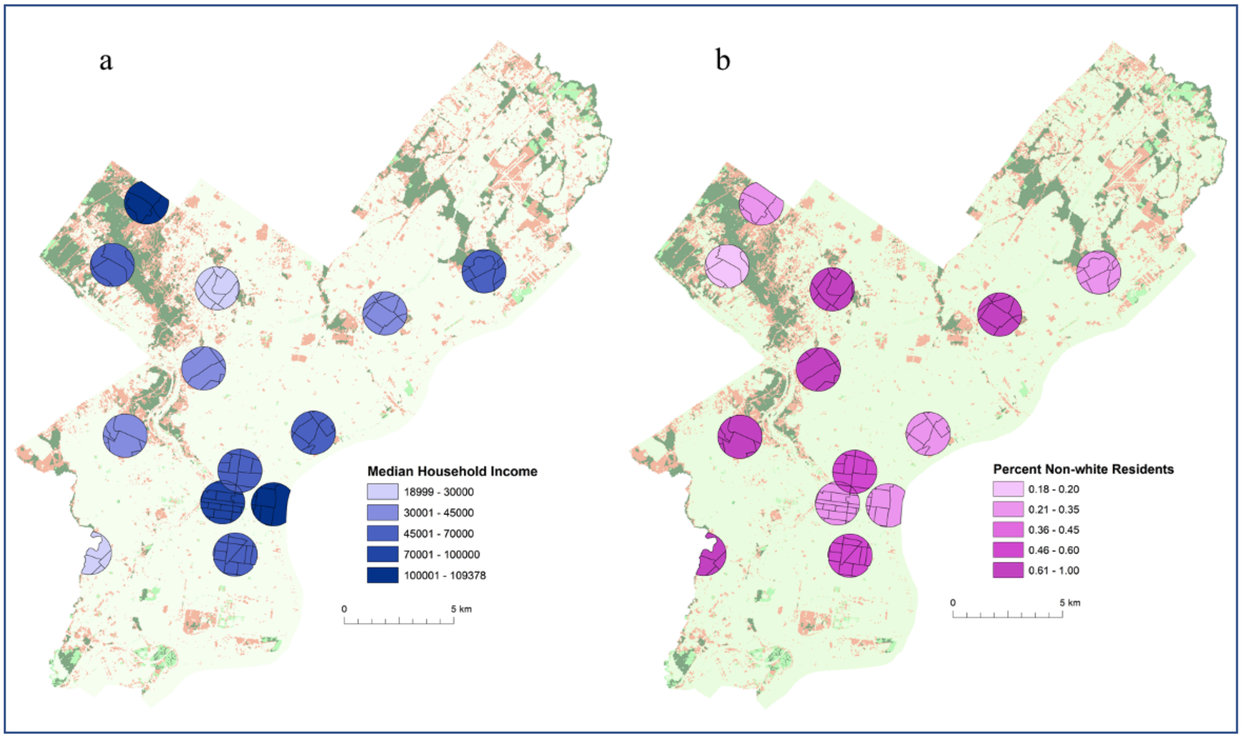

Figure 3. Socio-economic variables. For median household income (**a**), the darker the apiary buffer, the greater the median household income weighted and averaged across the apiary buffer area. For percent non-white residents (**b**), the darker the apiary buffer, the greater the percentage of non-white residents weighted and averaged across the apiary buffer area.
Source: US Census Bureau ACS 5-Year Estimates.

The generalized linear model results show a negative and non-significant relationship between median household income and plant genus richness and a positive and non-significant relationship between percent non-white residents and plant genus richness. These existent but weak relationships are apparent in scatterplots of the data points (Figure 4).

Dominant plant genera

While sites such as West Philadelphia and Kensington demonstrated evenness across proportions of plant genera present in the pollen samples, a few sites featured dominant plant genera found in disproportionately high abundance. Frankford and Mayfair for example, both Northeast Philadelphia neighborhoods with extensive lawn coverage as well as some park space, featured clover (*Trifolium spp.*). This is considered herbaceous flora associated with open landscapes and mid-successional forest edges and was most likely a feature of Pennypack Park's presence within the Mayfield buffer. Interestingly, Old City's leading pollen signature was also *Trifolium spp.,* suggesting the open lawn spaces of the neighborhood's famous Independence Historical National Park feature prominently in honey bee foraging.

Ailanthus altissima, an invasive and fast-growing tree known as the "tree of heaven," disproportionately dominated in the South Philadelphia and Nicetown neighborhood buffers.

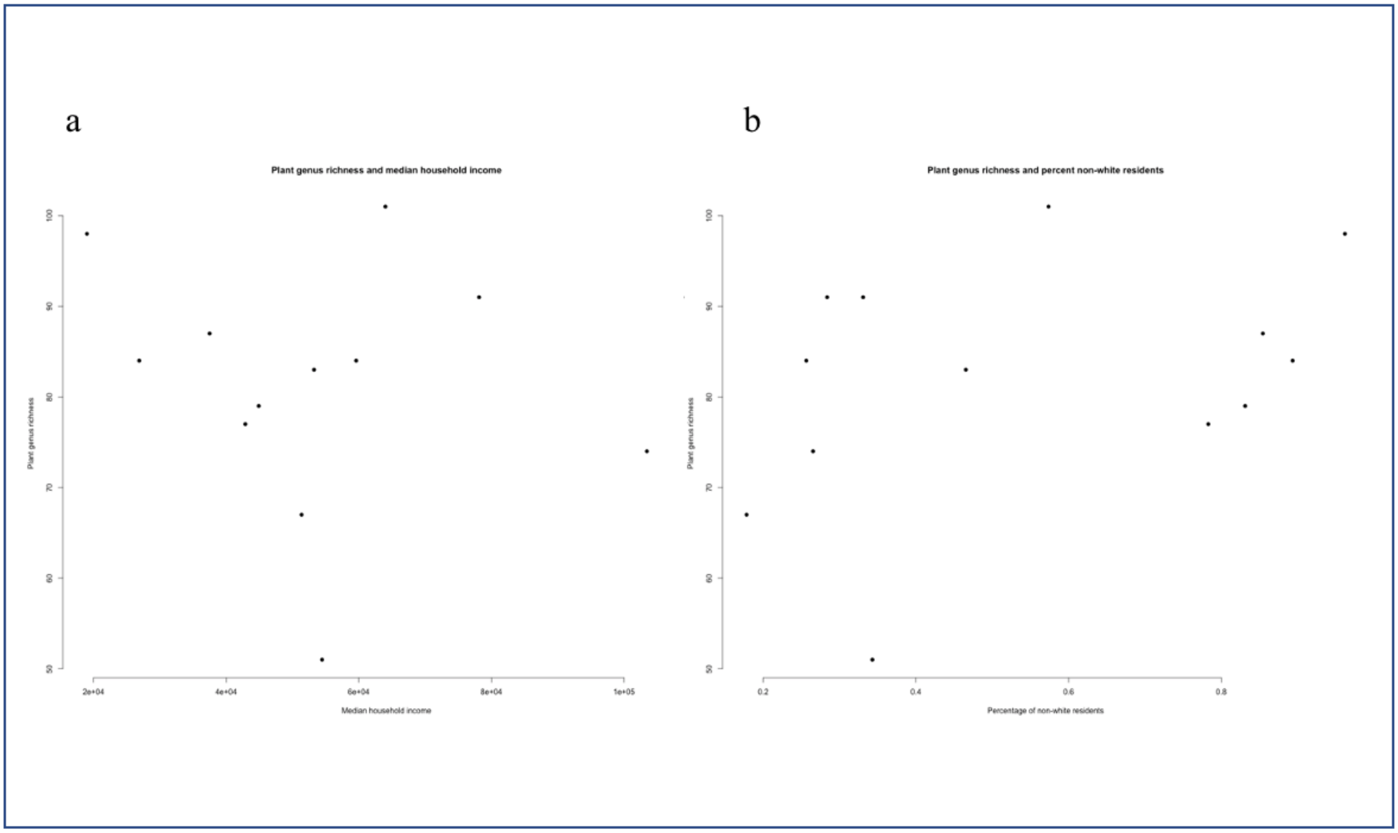

Figure 4. Scatterplots depicting (**a**) the effect of median household income on plant genus richness and (**b**) the effect of neighborhood racial proportions on plant genus richness. A generalized linear model shows a negative but non-significant relationship between median household income and plant richness (with a coefficient of -33.96 and a p-value of 0.956) and a positive but non-significant relationship between plant genus richness and percentage of non-white residents (with a coefficient of 0.0079 and a p-value of 0.224).

Likewise, the invasive and exotic woody vine genus *Aralia spp.* (most likely the species *Aralia elata* or spikenard) featured prominently in the Roxborough and Chestnut Hill buffer sites.

DISCUSSION AND CONCLUSION

With the above results we can see with more granularity the dynamics and components of cities insofar as they can be a haven for bees. Intensively managed agricultural land and urbanizing sprawl with encroaching high-input lawn management are twin contributors to bee decline, leaving the heterogeneous and complex landscape of the city core as a potential bastion of bee conservation. Given the clear and omnipresent evidence of global bee decline across regions and taxa decades in the making (Zattara and Aizen 2021), it is more important than ever to elucidate the necessary conditions for cities to play this role. Necessary for this task is the transdisciplinary pairing of urban ecology and the critical social sciences and environmental humanities.

Understandings of trends and structures in the political economy, for instance, give urban theorists and urban political ecologists insight into the forces shaping uneven investment and disinvestment in the built environment (Harvey 1989, Harvey 1978). The positivist and ahistorical orientation of urban ecology's history positions it as less able to understand flows of capital or forces of governance and social control shaping the urban socio-ecological-system – this is precisely why urban ecology and the critical social sciences must operate in greater lock-step. Urban political ecology analyzes how social marginalizations and inequities are produced and reproduced. In his analysis of the history of Cobb's Creek Park, for instance, Alec Brownlow (2006) describes the palpable disconnection felt between the park and the surrounding residents of low-income and predominantly Black and brown neighborhoods. Woody vines predominate in parks that have experienced decades of consistent disinvestment – an aspect of a structurally racist urban governance mechanism – leading neighbors to fear the park: "among long-marginalized adjacent black communities, the decay of their local ecologies over the past several decades is widely perceived as indicative of a more widespread and historical crisis of social control, whereby histories of racism, isolation, poverty, and political neglect are implicated in uneven patterns of ecological blight and a pervasive fear of nature" (Brownlow 2006). Using Sponsler et al.'s honey bee foraging assay data, this analysis was able to make strong analytical inroads between urban ecology and the critical social sciences to describe Philadelphia's urban ecology in political ecological terms.

A side-effect of the social control and marginalization endemic to Philadelphia is the breakdown of community sovereignty and control over the direction of environmental change and conditions. This analysis describes "an emerging ecological structure that is the product of political neglect and ecological change" (Brownlow 2006). *Ailanthus altissima*, or "tree of heaven," featured most prominently in South Philadelphia and Nicetown, is one such indicator. Some of the characteristics shared by these two neighborhood buffers are their majority-Black and low-to-middle-income composition. Patrick (2014) notes that *A. altissima*'s predominance usually suggests urban blight and decay and stands as a signal for neighborhood redevelopment to begin. Part of what makes *A. altissima* so successful in disinvested urban landscapes is its quality of allelopathy – a variety of chemicals the plant produces to inhibit the growth of adjacent plants. Another component is the recent arrival of the spotted lanternfly (*Lycorma delicatula*), an insect that is indigenous to Southern China, Taiwan, and Vietnam. It feeds on the sap of a variety of trees and plants, but *A. altissima* is its preferred host. The spotted lanternfly's U.S. presence was first recorded in 2014 in Berks County, Pennsylvania, and has since spread to a number of nearby counties and states with the potential to inhabit a majority of the Eastern U.S. In conjunction with *A. altissima*, itself categorized as invasive and noxious, these invasive species positively interact with one another in line with what ecologists call the invasive meltdown theory (Simberloff and Von Holle 1999). This analysis highlights aspects of this loss of community control over environmental change: in Philadelphia, emergent weedy ecologies spatially coincide with the city's history of spatially uneven development, disinvestment, and social marginalization.

ACKNOWLEDGMENTS
I would like to greatly thank Rebecca Collins and Caroline Burkholder at Temple University's Office of Sustainability for their support in this research endeavor. I also give many thanks to Doug Sponsler for offering his team's data and urban ecological insight, as well as my advisor Hamil Pearsall for providing key insights to my thought process throughout this project.

REFERENCES

Baldock, Katherine C. R., Mark A. Goddard, Damien M. Hicks, William E. Kunin, Nadine Mitschunas, Lynne M. Osgathorpe, Simon G. Potts, et al. 2015. "Where Is the UK's Pollinator Biodiversity? The Importance of Urban Areas for Flower-Visiting Insects." *Proceedings of the Royal Society B* 282 (20142849). http://dx.doi.org/10.1098/rspb.2014.2849.

Baldock, Katherine C.R., Mark A. Goddard, Damien M. Hicks, William E. Kunin, Nadine Mitschunas, Helen Morse, Lynne M. Osgathorpe, et al. 2019. "A Systems Approach Reveals Urban Pollinator Hotspots and Conservation Opportunities." *Nature Ecology & Evolution* 3: 363–73. https://doi.org/10.1038/s41559-018-0769-y.

Brownlow, Alec. 2006a. "An Archaeology of Fear and Environmental Change in Philadelphia." *Geoforum* 37: 227–45. https://doi.org/doi:10.1016/j.geoforum.2005.02.009.

———. 2006b. "Inherited Fragmentations and Narratives of Environmental Control in Entrepreneurial Philadelphia." In *In the Nature of Cities: Urban Political Ecology and the Politics of Urban Metabolism*, 208–25. New York, NY: Routledge.

Calderone, Nicholas W. 2012. "Insect Pollinated Crops, Insect Pollinators and US Agriculture: Trend Analysis of Aggregate Data for the Period 1992-2009." *PLoS ONE* 7 (5): e37235. https://doi.org/doi:10.1371/journal.pone.0037235.

Ellis, Rebecca A., Tony Weis, Sainath Suryanarayanan, and Kata Beilin. 2020. "From a Free Gift of Nature to a Precarious Commodity: Bees, Pollination Services, and Industrial Agriculture." *Journal of Agricultural Change*, 1–23. https://doi.org/10.1111/joac.12360.

Free, J. B. 1970. *Insect Pollination of Crops*. London, England: Academic Press.

Hall, Damon M., Gerardo R. Camilo, Rebecca K. Tonietto, Jeff Ollerton, Karin Ahrné, Mike Arduser, John S. Ascher, et al. 2016. "The City as a Refuge for Insect Pollinators." *Conservation Biology* 31 (1): 24–29.

Harvey, David. 1978. "The Urban Process under Capitalism: A Framework for Analysis." *International Journal of Urban and Regional Research* 2 (1–3): 101–31. https://doi.org/10.1111/j.1468-2427.1978.tb00738.x.

———. 1989. “From Managerialism to Entrepreneurialism: The Transformation in Urban Governance in Late Capitalism.” *Swedish Society for Anthropology and Geography* 71 (1).

Michener, C. D. 1974. *The Social Behavior of Bees: A Comparative Study*. Cambridge, Massachusetts, USA: Harvard University Press.

Patrick, Darren J. 2014. “The Matter of Displacement: A Queer Urban Ecology of New York City’s High Line.” *Social & Cultural Geography* 15 (8): 920–41.

Robbins, Paul, and Trevor Birkenholtz. 2003. “Turfgrass Revolution: Measuring the Expansion of the American Lawn.” *Land Use Policy* 20 (2): 181–94. https://doi.org/10.1016/S0264-8377(03)00006-1.

Sánchez-Bayo, Francisco, and Kris A.G. Wyckhuys. 2019. “Worldwide Decline of the Entomofauna: A Review of Its Drivers.” *Biological Conservation* 232 (April): 8–27. https://doi.org/10.1016/j.biocon.2019.01.020.

Simberloff, Daniel, and Betsy Von Holle. 1999. “Positive Interactions of Nonindigenous Species: Invasional Meltdown?” *Biological Invasions* 1 (21–32).

Sponsler, DB, and RM Johnson. 2015. “Honey Bee Success Predicted by Landscape Composition in Ohio, USA.” *PeerJ* 3: e838. https://doi.org/DOI 10.7717/peerj.838.

Sponsler, Douglas B., and Eve Z. Bratman. 2020. “Beekeeping in, of or for the City? A Socioecological Perspective on Urban Apiculture.” *Https://Ecoevorxiv.Org/5whu8/?Fbclid=IwAR36FH599sNugHa9oBKjNa1sukOLwUN73bHiOxQ7_6BPXZ8Ik5Y-Rktp_gk*.

Sponsler, Douglas B., Don Shump, Rodney T. Richardson, and Christina M. Grozinger. 2020. “Characterizing the Floral Resources of a North American Metropolis Using a Honey Bee Foraging Assay.” *Ecosphere* 11 (4).

United Nations Development Programme. 2020. “Issues Brief: Urban Climate Resilience.”

United States Census Bureau. 2016. “American Community Survey.” http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml.

United States Geological Survey. 2016. “National Land Cover Database.” https://www.mrlc.gov/data?f%5B0%5D=category%3Aland%20cover&f%5B1%5D=year%3A2016.

vanEngelsdorp, Dennis, Jay D Evans, Claude Saegerman, Chris Mullin, Eric Haubruge, Bach Kim Nguyen, and Frazier Maryann. 2009. “Colony Collapse Disorder: A Descriptive Study.” *PLoS ONE* 4 (8): e6481.

Visscher, P. Kirk, and Thomas D. Seeley. 1982. “Foraging Strategy of Honeybee Colonies in a Temperate Deciduous Forest.” *Ecology* 63 (6): 1790–1801.

Zattara, Eduardo E., and Marcelo A. Aizen. 2021. "Worldwide Occurrence Records Suggest a Global Decline in Bee Species Richness." *OneEarth* 4: 114–23. https://doi.org/10.1016/j.oneear.2020.12.005.