Diverse Farms and Urban Gardens Serve as Refuges for Native Specialist Pollinators

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ABSTRACT

Urbanization and agricultural intensification are threats to global biodiversity and insect pollinator decline. Increased agricultural inputs and conventional tillage threaten native pollinator communities at the landscape scale. There are opportunities to enhance bee communities through on-farm diversification in an agricultural landscape. However, little is known about the effects of farm management on specialist native pollinators and whether these effects are observed across a heterogenous landscape. I observed pollinators on small-scale farms and urban gardens with contrasting farm management practices (monocultures vs. polycultures/urban gardens) in California's San Joaquin Valley to investigate the effects of field-scale diversification and surrounding landscape on specialist native pollinators. I selected sites where farmers grew squash (*Cucurbita pepo*) because the presence of its associated specialist squash bee allowed me to compare both specialist and generalist bee populations. I hypothesized that polyculture farms and urban gardens with diverse floral resources would exhibit greater abundance and diversity of bee populations than monoculture farms. I found that on-farm diversification enhances the abundance of specialist native pollinators, but not of total bees and other bees. Additionally, I observed a positive but insignificant trend between the proportion of surrounding green space and total bees and native bees. There is a negative correlation between the proportion of surrounding agricultural landscape and honey bee populations, but other bee types and total bees were unaffected. Thus, on-farm diversification and gardens in urban landscapes may mitigate the effects of land use change on native pollinator communities, while the effects of landscape heterogeneity remain unclear.

KEYWORDS

urbanization, agricultural intensification, squash bees, green space, floral resources

INTRODUCTION

Insect pollinator communities are increasingly threatened by climate change, habitat alteration, and agricultural intensification to maximize yield (Singh 2017). Habitat loss and fragmentation caused by urbanization and large-scale homogenization of crops are identified as some of the driving factors of pollinator decline (Baldock 2020). As urbanization is a growing phenomenon with an estimated 70% of the world to live in urban areas by the year 2050, its effects are proposed to contribute to insect pollinator decline through several mechanisms including the disturbance of food and nesting sites and negatively affecting pollinator species richness (Frankie 2009). However, conflicting evidence shows that greater insect biodiversity can be maintained within urban gardens and there may be opportunities to mitigate the effects of habitat fragmentation in a rural to urban gradient.

Some negative effects of habitat fragmentation in urban areas include lower insect pollinator visitation rates to flowers, loss of rare species, and decreased genetic diversity of species (Baldock 2020). For pollinators, there are links between species trait diversity and ecosystem function, such that bee communities with diverse functional traits provide more pollinator resources (Cohen 2020). Research shows there is a relationship between a habitat's local resources, landscape composition, biodiversity, and its insect pollinators' foraging habits, with their movement patterns having directly impacting ecosystem service provisioning (Cohen 2020). Thus, the effects of habitat fragmentation caused by increasing distances between pollinator habitats cause rates of pollination to decline (Cohen 2020). Urban gardens ameliorate these declines on bee populations by increasing habitat connectivity, especially if the gardens contain pollinator friendly flowers (Pardee and Philpott 2014). However, there is a gap in research on the effects of habitat loss on populations of rarer, specialist native bees.

Conservation efforts to preserve communities of rarer wild bees may serve as an insurance policy against biodiversity loss as urbanization and agricultural intensification increases (Williams et al. 2007). *Apis mellifera* (honey bees) are widely used in agriculture though they are at risk of decline and are expensive (Winfree et al. 2007). Fortunately, there are over 1600 bee species native to California that are able to serve as alternative pollinator communities (Frankie et al. 2009). Wild bees have the potential to play a significant role in agricultural crop pollination and can be used to replace honey bee colonies that are at risk of decline (Klein et al. 2007). Squash bees in particular, namely *Peponapis* and *Xenoglossa* spp., are specialist wild bees that rely on specific crops for floral resources. It is shown that their populations may be supported in agricultural landscapes through on-farm diversification of flowering crops and surrounding floral diversity (Guzman et al. 2019). Enhancing and increasing reliance on native pollinator species offers an important way we can improve agricultural resilience in an ecologically sustainable way while reducing the expense of honey bee rentals (Kremen 2002). Elucidating these effects in both agriculturally dominated landscapes and urban gardens may further our understanding of the biological tools available to help agroecosystems develop resilience against the adverse impacts of climate change and habitat alteration.

Although much of agriculture is dominated by large-scale monoculture farms, it also contains many small-scale polycultures, monocultures, and small farms embedded within the rural landscape in urban residential neighborhoods (i.e. "urban gardens") (Hall et al. 2017). It has been shown that habitat restoration through diversification can enhance bee populations by providing diverse nesting and foraging resources, increasing the spatiotemporal diversity of floral resources that support more abundant and diverse pollinator communities (Jha et al. 2013; Guzman et al. 2019). Thus, diversified small-scale farms can serve as biodiversity hotspots in increasingly intensified landscapes. Diversifying practices include the planting of more than one cultivar at a time in a "polyculture" farm, as opposed to a "monoculture" that only plants one crop in a given season and rotating these crops over seasons (Baldock 2020; Guzman et al. 2019). As agriculture continues to intensify and urban areas expand, it is worth the investigation of using these on-farm diversification methods to specifically protect native specialist pollinator communities.

This study researches the effects of farm management and landscape diversity on native pollinator community composition across different matrix types in California's Central Valley. Herein, I examine the extent to which diversified farming systems and urban gardens serve as a refuge for native pollinators. I asked two questions: 1) How does native pollinator abundance and diversity differ between small-scale monoculture, polyculture, and urban farms? 2) Does the amount of landscape diversity in a farm's surrounding matrix significantly influence the site's pollinator community composition? I evaluate the following hypotheses: 1) Diversified farming systems host a greater abundance of squash bees and non-squash specialist pollinators than monoculture farms given spatiotemporal diversity of floral and nutritional resources and 2) farm sites with greater surrounding landscape diversity have more abundant and diverse pollinator communities than sites with less landscape diversity.

METHODS

Study site

My study sites were all located in Fresno County in the agriculturally dominated landscapes of California's San Joaquin Valley. The region experiences a Mediterranean climate with an average rainfall of 13 inches per year and hosts a large range of annual and perennial crops, growing hundreds of varieties. The Valley contains a range of agricultural landscapes including many small-scale farms, where my research is focused, embedded within a regional matrix of predominantly large-scale farms. These small-scale farms often grow a large variety of crops over space and time as polycultures. I considered a farm a "polyculture" if there was more than one cultivar growing at the time of data collection. The county also contains heavily urbanized areas with little green space, where some community gardens are located. An urban garden is often the only agricultural system within miles of an urban residency.

To determine the impact of farming practices on pollinators, I selected four small-scale farm sites of each of the following matrix types: monoculture, polyculture, and urban garden. Polycultures and urban gardens were selected as sites if they grew at least two rows of *Cucurbita pepo* var. *cylindrica*, a summer variety of squash. The monocultures exclusively grew squash. This squash species relies entirely on insect pollination including that of specialist pollinators called squash bees, *Peponapis* and *Xenoglossa* spp. The squash bees are solitary ground-nesting species that habituate in ground space near their preferred pollen source (Hurd et al. 1974). Although a generalist pollinator like *A. mellifera* is also an effective squash pollinator, the specialist *P. pruinose* females will synchronize their activity with the opening of the squash flower at dawn, effectively pollinating the flower (Hurd 1974). The presence of squash on all the sites allowed us to study the effect of on-farm diversification on specialist and generalist pollinator communities independently.

Sampling methods

To determine the abundance and diversity of bees at each farm, I sampled the 12 sites from May 14 to June 1 of 2019. At each site, I established three parallel 10 meter transects running adjacent to rows of squash, approximately 5 meters apart. Some polycultures and urban gardens only grew two rows of squash, thus at least one of the transects always ran along a squash row that may have been near the edge of the farm. In all other cases, the transects ran 5 meters from the edge to isolate edge effects. I sampled between 7:30 am and 9:30 am, during squash bloom and when squash bees are still active. I spent roughly ten to twenty minutes along each transect at each site using net sweeping techniques to collect each bee I observed that contacted the anthers and stigmas of squash flowers, or potential pollinators. I identified the bees to the genus by their morphology and categorized them as “wild bees” or “non-native bees” then, more specifically, “squash bees,” “(non-squash) native bees,” and “honey bees.”

Analysis

Farm type on bee abundance and diversity.

To compare bee abundance and diversity across sites with different farm management types, I used general linear mixed effects models with the ‘lme4’ function in R (Bates et al. 2015) since both pollinator indices met assumptions of normality. For each bee group (squash bees, wild bees excluding squash bees, honeybees, and total bees) I calculated the total number of bees observed. I used the total number of bees sampled at each site to estimate the average richness, evenness, and Shannon Diversity of each farm type (Magurran 1988).

*Landscape diversity on bee abundance and diversity***.**

To compare pollinator richness and abundance across the sites, I used ArcGIS-digitized site maps (Guzman et al. 2019) to compare proportions of surrounding bare ground, vegetation, water, and farm type within a 500-meter radius around each site of each matrix type (Appendix A).

RESULTS

We sampled a total of 245 bees across all sites. Squash bee abundance had a range from 0 to 26 on a site, while honeybees, other native bees, and bumble bees ranged from 0 to 26, 15, and 1, respectively. Honeybees comprised about 50% of total bee abundance, followed by squash bees comprising 38%, then native bees and bumble bees comprising 11% and 0.8%, respectively.

Farm management impacts on bee abundance. Total bee abundance was unaffected by farm type. Honeybees are more abundant on monoculture farms than polyculture and urban farms, but this effect is not significant (p = 0.248). And while we found more native bees, excluding squash bees, on urban gardens than polycultures and monocultures, this result was not significant (p = 0.251). We found more squash bees on polycultures and urban gardens than monocultures (p = 0.001).

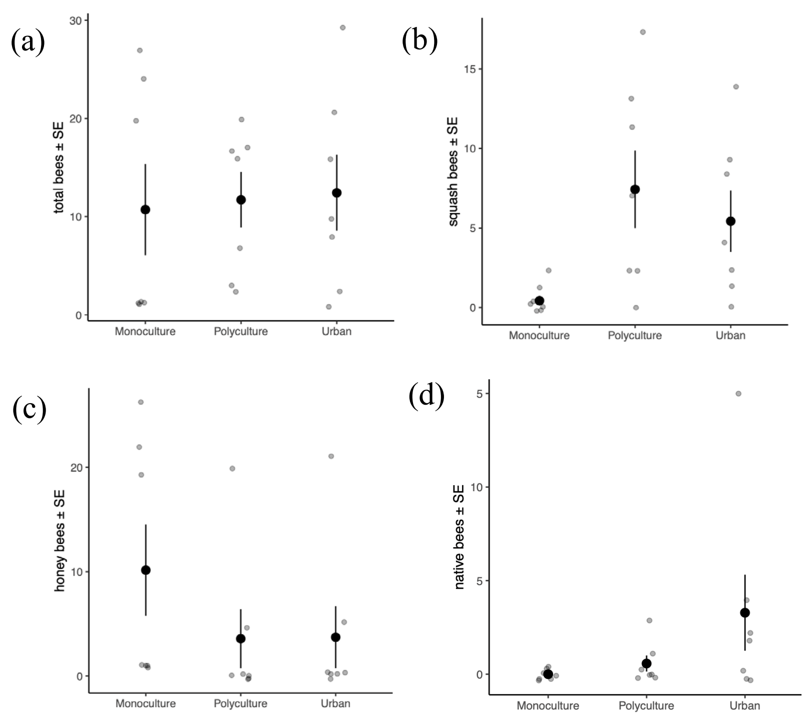

Figure 1. **Farm type and bee abundance.** The mean relative indices ± standard error of (a) total bees, (b) squash bees, (c) honey bees, and (d) native bees excluding squash bees across all farm types.

Landscape impacts on bee abundance. There is negative interaction between proportion of surrounding agricultural land and honey bee abundance and a trend for total bees driven by a single farm site. There is a positive trend between increasing agricultural landscape and squash bees. There is also a positive correlation between amount of green space and abundance of native bees, excluding squash bees.

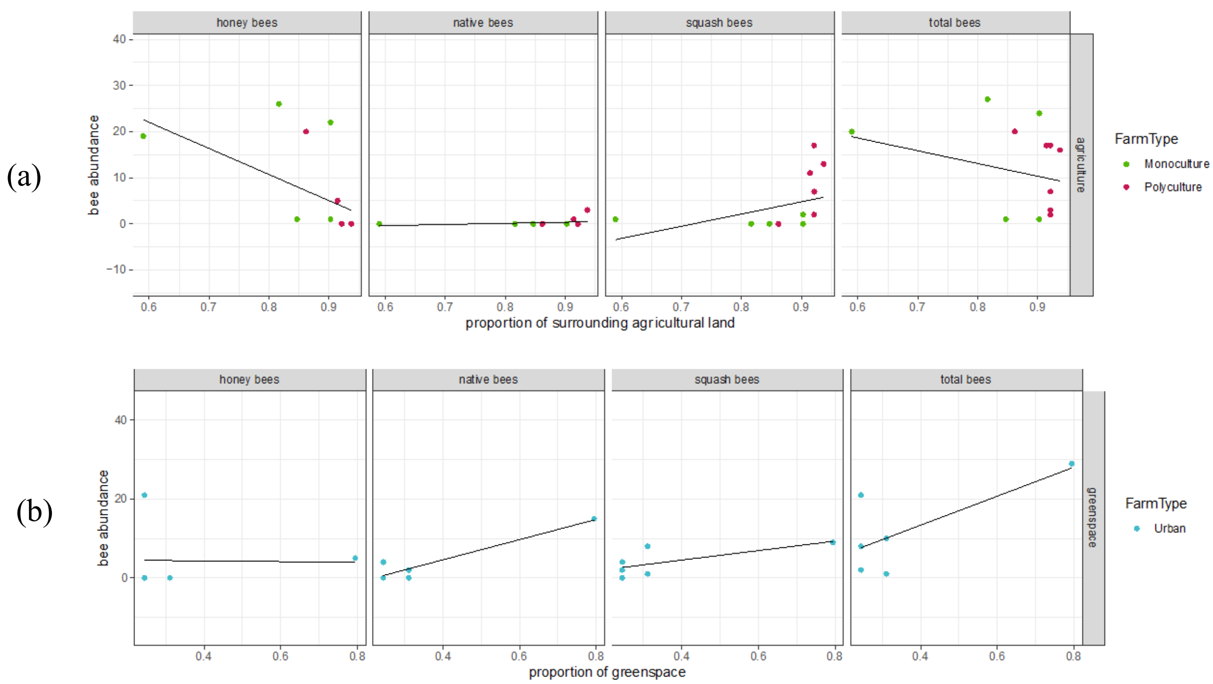

Figure 2. Agricultural land, green space, and bee abundance. The proportion of surrounding agricultural land and its effects on bee abundance in monocultures and polycultures (a) and the effects of surrounding green space on urban gardens (b).

Farm management impacts on bee diversity. There was no consistent effect of the amount of landscape heterogeneity on bee diversity. The exception to this is trend found within a positive interaction between the proportion of green space surrounding urban gardens and higher values of species evenness that is statistically insignificant (Figure 3).

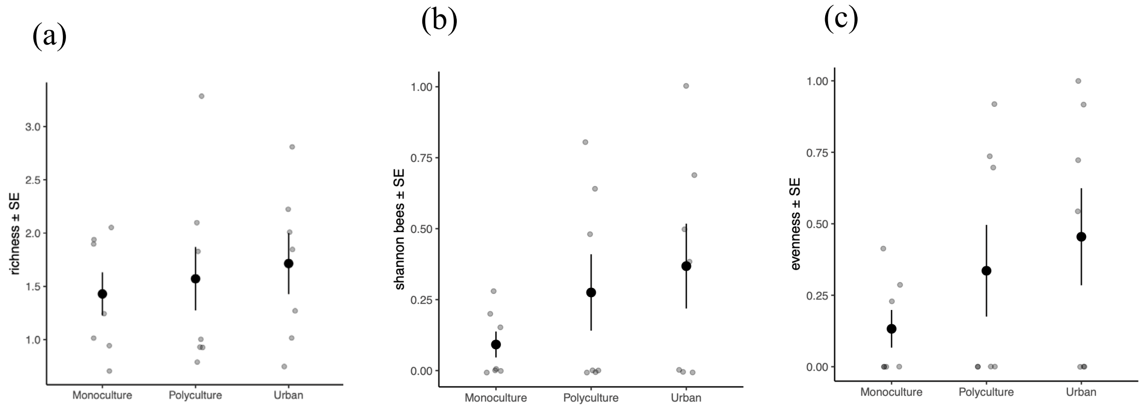

Figure 3. **Farm type and bee diversity.** The mean relative indices ± standard error of (a) richness, (b) evenness, and (c) Shannon diversity across farm types.

Landscape diversity impacts on bee abundance. There was no consistent effect of the level of surrounding landscape diversity on bee abundance. There is a slight positive interaction between landscape diversity and squash bee abundance on polycultures, but this effect is not observed for other bees nor in polycultures or urban gardens.

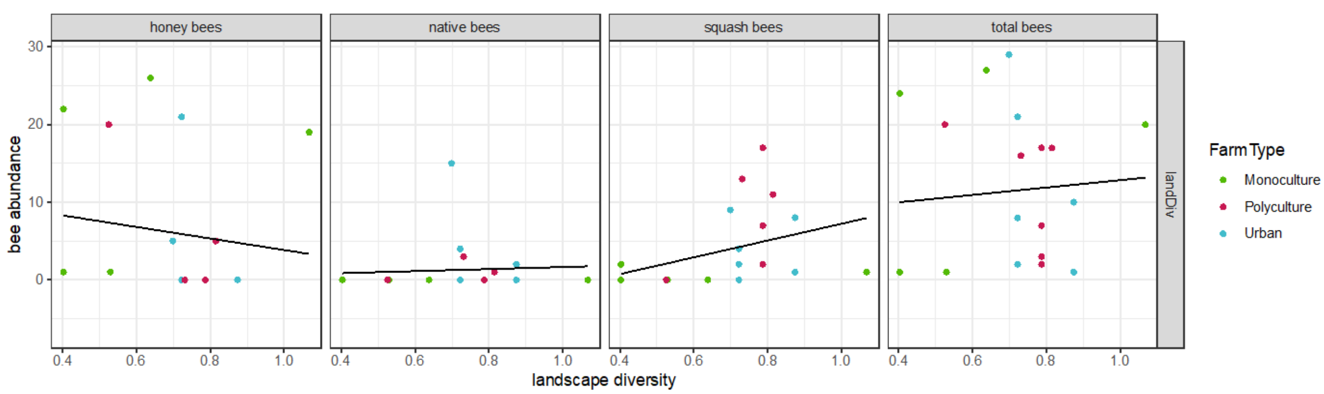

Figure 4. **Surrounding landscape diversity and bee abundance.** Surrounding landscape diversity and its effects on bee abundance in monocultures, polycultures, and urban gardens.

DISCUSSION

Urban gardens may serve as a refuge for native specialist pollinators and therein increase opportunities to utilize urban habitats as resources for conservation (Sivakoff et al. 2018). My study examined the effect of crop diversity and surrounding greenspace on specialist native pollinator communities in the San Joaquin Valley, where the landscape is affected by land use change and urbanization. My findings highlight an important interaction between crop diversity, habitat composition, and squash bee populations across landscape types. Contrary to my hypothesis, we found no significant difference in total bee population among farms. However, native squash bee populations were affected by local factors including habitat features on small-scale farms. I found more native bee individuals in polyculture and urban garden farms than monocultures. These results are congruent with at least one other study finding that across farm management types, diverse floral resources through space and time are beneficial for rarer, specialist bees in an agriculturally intense landscape (Guzman et al. 2019).

Although my sites were not chosen based on their surrounding landscape features due to a lack of landscape diversity in the study region, my models accounted for this variable and were measured as a covariable. My results suggest that surrounding green space has a positive effect on native bee populations in urban gardens, while this trend was not significant for polyculture and monoculture farms in an agricultural landscape.

Farm management impacts on bee abundance and diversity

Matrix types. The first research question aimed to address whether matrix types differ in native pollinator abundance and diversity. My results corroborate a study investigating the effects of on-farm diversification in an agriculturally intensive region, such that crop rotation provided continuous diversity of floral resources that support specialist bee populations (Kremen et al. 2018). Polycultures and urban farms exhibited greater numbers of squash bees relative to squash monocultures. Despite their associations to specific nectar resources, squash bees may benefit from non-squash flowering plants serving as back-up resources through time (Jha & Kremen 2013). As the squash flower closes throughout the morning, squash bees can rely on other on-site flowers for resources. One study found that honeybees are able to switch their foraging behavior when offered low-quality solutions (Arenas & Kohlmaier 2019). This may also be true for individual solitary bees on a diversified site, such that they do not have to travel to another farm for their protein and carbohydrate needs.

There may be other drivers such as no-tillage and organic management that explain enhanced native pollinator populations on small scale farms and in urban gardens. The urban gardens I sampled were diversified and pesticide-free, and the greater abundance of native bees and squash bees may be explained accordingly (Baldock et al. 2020). Additionally, urban sites are isolated from other farms and lack alternative options for pollinators, yielding range-limited effects on the site. Until there is more data around the foraging habits of solitary bees, these results should be carefully interpreted (Kremen et al. 2018) but our evidence suggests that urban gardens serve as refuge for wild pollinators.

Contrary to other studies, bee diversity was not predicted by on-farm habitat complexity (Cely-Santos & Philpott 2019; Guzman et al. 2019). My data shows insignificant increases of species richness, evenness, and Shannon Diversity on diversified sites. One study finds a positive interaction between species richness and flower number (Pardee & Philpott 2014). Since our diversified sites were smaller in size, containing 2 rows of squash compared to the hundreds of rows in monocultures, flower abundance may be a driver of native bee diversity. Foraging biology research has established "concentration" and "dilution" effects that connect the density of heterogenous floral populations with floral visitations (Cohen 2020). Foragers become concentrated when high local floral diversity and abundance mediate pollination through increased recruitment to a site and it exhibits higher pollinator abundance. Comparatively, high resource areas can also dilute per-plant visitation when a limited number of foragers are spread out in a high resource patch (Wenninger 2016). It is unclear whether this phenomenon is exhibited in my study as the number of study sites may be a limiting factor.

Surrounding landscape and bee community composition

Greenspace. There was no consistent effect on the proportion of green space across bee abundance, although there were positive interactions with native bees and total bees in urban gardens. Bees nest in various substrates in urban areas including soil and burrowed plant stems as well as preexisting cavities in human structures and fences (Frankie et al. 2009). Although I did not observe a correlation between green space and ground nesting solitary squash bees, the enhancement of total bee populations indicates that available nesting sites may be an important driver to overall bee community resilience. Opportunities and approaches for increasing bees' habitat value lie within the correlation between pollinator health and foraging. By increasing the amount of green space around an urban garden with foraging species such as flowers and hedgerows, studies show that there are similar beneficial effects for specialist and generalist pollinators (Hall et al. 2017). Garden management may play a particularly important driver in pollinator resilience since the studies indicate landscapes with greater amounts of both ornamental plants and sustenance-oriented food crops promote pollination patterns (O'Connel et al. 2021).

My observations of the effect of agricultural land (green space) around small-scale farms exhibit an interesting effect on squash bees on polyculture farms. One study investigating the scale-dependent effects of landscape context on pollinator guilds (Steffan-Deweenter et al. 2002) found that species richness and abundance of solitary wild bees exhibit a positive correlation with the percentage of seminatural surrounding habitat for scales up to 750 m, but these effects were not seen for bumble bees and honey bees. Since this study did not research questions supported by data in other empirical studies, it concludes that solitary wild bees are more greatly affected by local landscape destruction than social bees. This may be attributed to changing interactions between mutualistic plant-pollinator and competitive native bee vs. honey bee dynamics. There is need for more research to confirm these effects at different spatial scales and investigating differences in habitat size and isolation in agricultural systems (Thies and Tscharntke 1999) as well as for different bee species. However, it is understood that surrounding landscapes with increased floral diversity contributes to more pronounced functional diversity of pollinator communities on-site (Kremen et al. 2018).

Landscape diversity. There was no consistent effect of the level of surrounding agricultural landscape or greenspace on pollinator abundance. I observed a negative correlation between increasing agricultural land and honey bee abundance, suggesting that generalist bees may be affected by landscape complexity in an agricultural region if limited in diversity of floral nectar resources (Kremen et al. 2018). The opposite trend was observed for squash bees and polyculture farms, such that increasing agricultural land around these sites increased their populations. If the surrounding fields also contained squash, this trend may be explained by the greater availability of squash flowers across sites. There is a need for more research to determine the drivers of these trends and their effects beyond the field scale. Because the amount of green space relative to other land use impacts total bee populations in urban gardens, there is growing support for the presence of diverse, floral resources in the surrounding landscape to enhance generalist bee populations.

Limitations and future directions

The positive interactions observed between native pollinators and surrounding green space are driven by a single data point, such that I must proceed with caution when extrapolating the implications of my findings. There are opportunities for more research with methodologies that compare more sites with models that account for levels of diversity on polyculture farms to conduct a robust in between and within farm-site analysis on pollinator foraging behavior in addition to community composition (O'Connell et al. 2020). This is especially true for better understanding these interactions in urban areas where the benefits of crop diversification for native pollinators can be explored within the context of shifting conservation practices (Hall et al. 2017). Advocacy for conservation techniques in urban areas such as restoration work and species monitoring can be supported through data that evaluate the functional ecology of bee populations on these smaller scales (Hall et al. 2017).

Broader implications

Urban gardens may be able to support bees by providing resources in environments that otherwise lack them (Pardee and Philpott 2014). This finding maintains the broader implication that diversified farming systems enhance resilience as agricultural intensification increases. Additionally, the effects of urbanization can be mitigated at the field-scale with the inclusion of florally diverse green spaces and gardens. These pattens may be similarly observed on larger scales in agriculturally intense regions. As habitats continue to fragment and agricultural intensification increases, it is important that farmers and stakeholders in urban design can enhance resilient green spaces for the health of their managed ecosystems and the abundance of endangered pollinator species.

ACKNOWLEDGEMENTS

Aidee Guzman, Patina Mendez, Leslie McGinnis, and Claire Kremen in the ESPM Department comprised my primary support group for this project and their guidance was essential for my involvement in research. I would like to thank Aidee for her continual dedication to her student mentees over the years and encouragement throughout my entire undergraduate experience. Her passion inspires me to pursue research and reach levels of academia I once never thought feasible. Professor Mendez and Leslie supported the composition of this project with unwavering enthusiasm and engaging teaching strategies, successfully facilitating my research amidst the challenges we faced during a public health crisis. Without them this work from home would not be possible. I am grateful for Dr. Kremen's feedback and expertise in refining my methods of data collection. I also extend huge thanks to Martin Bañuelos and Paula Yang for assisting in the collection and analysis of the pollinator and landscape data. My cohort of peers were instrumental in my ability to maintain a positive attitude and form lasting friendships throughout this experience. Lastly, I would like to thank my family including my parents, siblings, grandparents, aunts and uncles, and cousins for their excitement, sacrifice, and unconditional love and support for every endeavor on which I embark.

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APPENDIX A: Surrounding landscape

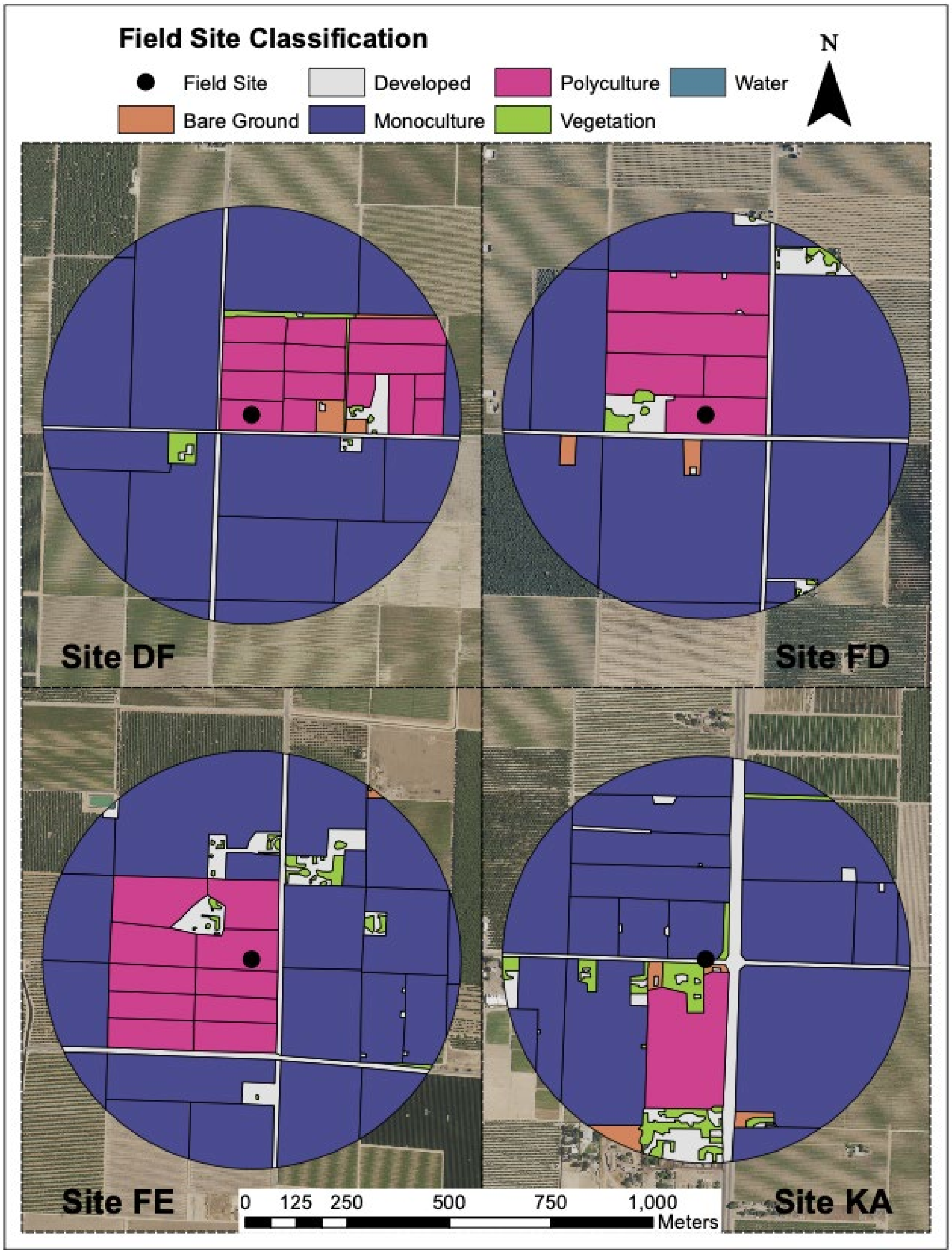

Figure A1. Polyculture farms. The surrounding landscape composition of my polyculture sites within a 500-meter radius.

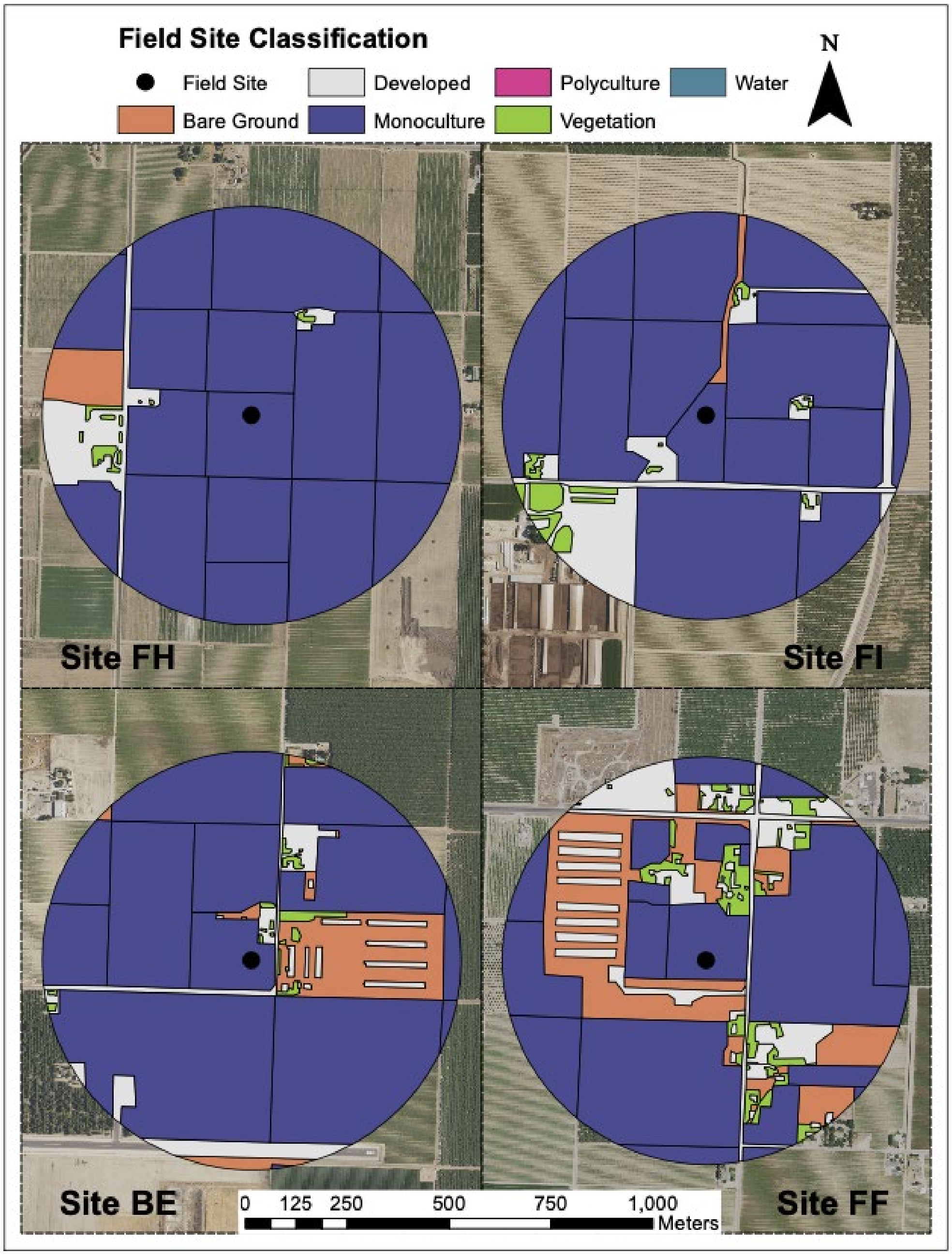

Figure A2. Monoculture farms. The surrounding landscape composition of my monoculture sites within a 500-meter radius.

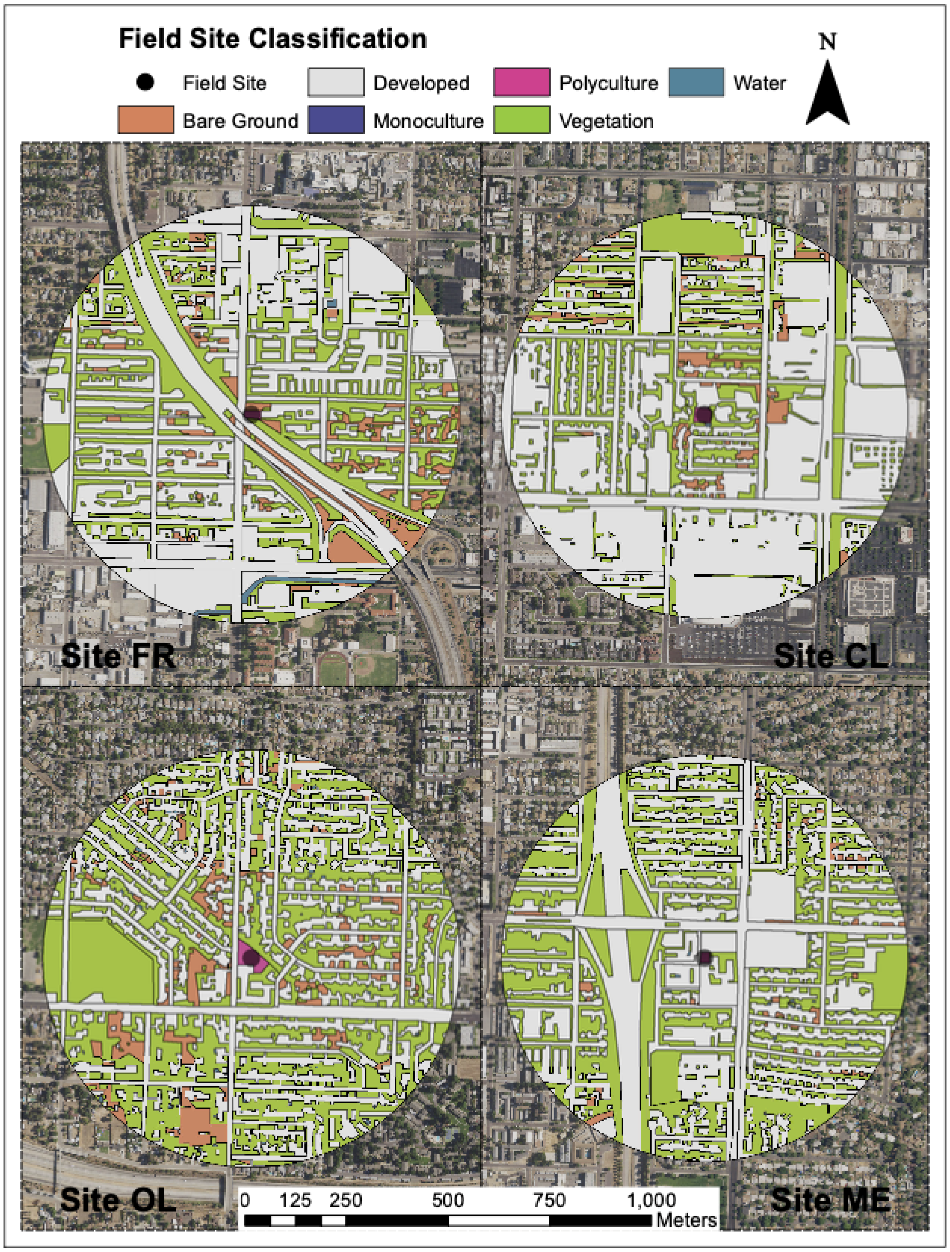

Figure A3. Urban gardens. The surrounding landscape composition of my urban garden sites within a 500-meter radius.