Landscape structure influences on insect diversity across urban and peri-urban farms

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Abstract

Urban agriculture presents a variety of environmental and social benefits, including the critical value of providing green space that can support biodiversity in the developed landscape. Insect communities are especially important to farm success by affecting plant productivity and providing important ecosystem services such as pest control, pollination, and decomposition. Therefore, further investigation into how urban farms can support insect biodiversity is needed. The primary objectives of this study were to identify (1) common insect families present on vegetable crops on urban and peri-urban farms; (2) influence of surrounding percentage of development on insect family diversity and insect abundance at varying buffer scales; (3) any variation in impact of urbanization in open field vs. high tunnel growing environments; and (4) impact of landscape on natural pest control comparing the ratio of beneficial to pest insect families on these farms. We surveyed insects on tomato (*Solanum lycopersicum*) and pepper plants (*Capsicum spp*.) from 20 farms in or near Kansas City, Kansas. The farms were located along a gradient of urbanization and were sampled during early, middle, and late summer. Insects were monitored using timed observations, netting, sticky traps, and pitfall traps and identified to family level. The amount of developed landscape within the radii of 500 m, 1 km, and 5 km did not have significant relationships with insect family diversity or abundance. Developed landscape within a 100 m radius exhibited a non-linear relationship with insect family diversity and abundance, peaking at intermediate levels of development ($P < 0.05$). However, the ratio of beneficial to pest insect families remained stable regardless of surrounding development. Open field sites had significantly higher family richness and abundance than high tunnels ($P < 0.05$) and open field richness and abundance mirrored the overall intermediate-urbanization peak ($P < 0.01$). In contrast, high tunnel richness had no significant relationship with urbanization,

whereas high tunnel abundance decreased linearly as 100 m development increased ($P < 0.01$). Our findings suggest that urban farms at all levels of development can sustain functional insect communities, and farmers can actively support biodiversity by managing localized microhabitats adjacent to growing areas.

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Introduction

As human populations continue to shift towards increasing urbanization, interest in urban agriculture is growing. The world population is projected to have nearly 70% of people in urban areas by 2050 (Kundu et al., 2020). Satellite data indicates the rapid global expansion of the built-up footprint of urban areas, increasing nearly twice as fast as the human population (Melchiorri et al., 2018; United Nations, 2025). In the United States, an estimated 80% of the population lives in urban areas (World Bank, 2024).

Urban agriculture has become increasingly popular with potential benefits to food security and social wellbeing (Mok et al., 2014). Urban agriculture not only provides a local food source, but can enhance resilience, sustainability, and multifunctionality in a community (Langemeyer et al., 2021; Teoh et al., 2024). Urban agriculture is also desirable for consumers. Consumers perceive urban farming positively as it relates to the three pillars of sustainability-economic, social, and environmental (Grebitus et al., 2017). Additionally, consumers have reported positive associations with urban farming such as fresh, local, and green (Grebitus et al., 2020).

Urban agriculture further contributes to city dynamics by providing green spaces which have the potential to shape flora and fauna biodiversity (Liborio-Cornet & de Verges, 2025). Urban agriculture can support higher biodiversity compared to conventional rural farms (Li et al., 2025). When integrated with other green infrastructure in cities such as parks, overall ecosystem functions can be enhanced (Li et al., 2025). For example, ecosystem services of biological control and maintenance of genetic diversity may be more common when green

infrastructure and urban farms act synergistically (Evans et al., 2022). These ecosystem services could determine the success of one of the most critical taxa for farmers, insects.

Insect Diversity and Farm Success

The insect biological community can have a considerable influence on the success of any farm, playing both detrimental and beneficial roles. Pest insects can cause plant damage and disease, leading to significant yield losses. For example, Savary et al. (2019) found that a range of 17 to 30% of global crop losses for five major crops were caused by pests and pathogens. In response to these threats, global insecticide use has risen an estimated 49% since the 1990s with the highest use in the Americas (FAO, 2026). Many farmers continue to rely on chemical pesticides to control insects despite damage to wildlife and human health to maintain high yields (Wilson and Tisdell, 2001).

Focusing on reducing pest damage alone neglects the positive contributions that other insects provide to agricultural productivity. Insects can provide valuable economic benefits because of ecosystem services such as pest control and pollination (Barragán-Fonseca et al., 2025; Clinton et al., 2018; Losey and Vaughan, 2006). The effectiveness of ecosystem services is directly linked to species richness (Dainese et al., 2019), which is the number of different species represented in a region. As we gain understanding of the impacts of urbanization on insects, farm management practices that more effectively manage pest control and pollination simultaneously are needed (Lundin et al., 2021).

Impacts of Urbanization on Insects

Insect diversity and abundance are changing on a global scale. Mounting evidence suggests a widespread, concerning trend of population decline connected to increasing human impact on the environment. Van Klink et al. (2020) reviewed 166 long-term case studies of insect assemblages, finding overall declines in terrestrial insect abundance. Major drivers of insect decline include habitat loss, pollutants, invasive species, and climate change (Sánchez-Bayo and Wyckhuys, 2019; Wagner et al., 2021). A multitude of these risks intersect in urban environments. In a meta-study of urbanization effects, Sanllorente et al. (2025) found an overall strong negative impact of urban environments on arthropod diversity. Habitat loss, increasing along a gradient towards city centers, is a leading cause of extinction and population decline of native species (Hald-Mortensen, 2023; McKinney, 2002). If not eliminated, natural habitats are often split into small, disconnected fragments with reduced habitat quality (Fahrig, 2003; Hu, 2026). Disconnected populations have lower genetic diversity which reduces adaptability to change, increasing extinction risks (Templeton, et al., 1990; Vandergast et al., 2007). Genetic viability of fragmented populations can be further harmed by random mutation causing loss of beneficial mutations or accumulation of harmful mutations (Hanski, 2011). However, urban areas may have pockets of high plant richness compared to rural farmland which could create refuge for pollinators (Baldock et al., 2015). Urban forests may have increased densities of arthropods compared to natural forests (Dreistadt et al., 1990; McIntyre, 2000).

The heat island effect, common in city environments, can alter insect ecology and evolution. Urban areas tend to have warmer climates than rural areas due to non-reflective impervious surfaces, pollutants, anthropogenic heat generation, and lack of evapotranspiration from vegetation (Taha, 1997; Zeleňáková et al. 2015). Urban warming may alter reproductive

timing in insects, as demonstrated in a study of acorn-dwelling ants (Chick et al., 2019). Urban heat islands have also been shown to influence the survival and development of some butterflies (Kaiser et al., 2016). Climate can alter insect phenology and distribution which ultimately influences interactions with other species (Menéndez, 2007). In a review of 31 plant eating pests, Lehmann et al. (2020) found more increases in pest damage (41% of species) than reduced effects (4% of species) because of climate warming. However, it is important to note that insect species have variable responses to warming of the climate (Lehmann et al., 2020).

Urbanization can influence ecological interactions such as predation, mutualism, and parasitism in urban environments. For example, Rocha and Fellows (2020) found specialized predators on aphids declined with increasing urbanization, but mutualistic ants increased in urban areas. Urban influences on parasitism are impacted by factors such as local plant patch size and isolation (Fenoglio et al., 2013). Changes in avian predators may be among the most significant impacts on urban biological communities. Urbanization can decrease bird species richness but increase abundance (Marzluff, 2001; Faeth et al., 2011). Increased bird predator densities can act as a primary control of arthropod populations (Faeth et al., 2005; Kozlov, 2017).

Insect Landscape Ecology Research

Spatial scale is a key consideration in landscape research with insect populations. The broad landscape can support or reduce resources across different land use types and impact connectivity of populations, which are essential to the survival of species that disperse over large distances. Previous studies have identified variation in insect richness and abundance between urban and rural landscapes by analyzing spatial indicators such as pavement and buildings,

vegetation type, road density, and human population density (Blair, 1996; McKinney, 2002; Pickett et al., 2001). Some landscape studies have found a negative relationship between insect species richness and urbanization (e.g. Bates et al., 2011; Merckx et al., 2019). In a study focused on pollinators, Ellis et al. (2025) found a reduction in species richness with increasing impervious surfaces across three cities. However, not all insect taxa are negatively impacted. For example, urbanization may have a limited impact or positive effect on bee richness (Banaszak-Cibicka and Żmihorski, 2012). Due to variation in each insect species response, urbanization is causing increased homogenization (McKinney, 2006). Many native species are disappearing, and establishment of adaptable non-native species is becoming common in urban landscapes (McKinney, 2006). The surrounding landscape can also alter the relationships between pests and beneficials, influencing natural pest control. In a review of 132 studies across a variety of pests and landscapes, Karp et al. (2018) found that enemy abundance and activity, pest abundance and activity, and crop yields all tended to have associations with surrounding landscape.

Relying solely on broader landscape trends may fail to capture critical local scale needs such as floral diversity, crop diversity, and nesting sites. Variations in farm insect populations in urban agriculture have a complex relationship with the local habitat. The makeup of a farm's habitat including presence of natural vegetation and plant heterogeneity influences the species richness (Habel et al., 2025; Lucatero et al., 2024). Additionally, on-farm practices such as use of diverse crops, organic methods, or ground cover impact the invertebrate communities and may interact with the landscape influence (Habel et al., 2025; Ploessl et al., 2023). Local management practices such as the utilization of high tunnels to grow crops may also alter the insect community response to urban landscapes. High tunnels, which are typically unheated clear polyethylene-covered structures, are becoming more popular for use in season extension across

the United States (Carey et al., 2009). The barrier and microhabitat created by high tunnels may alter pest colonization from the surrounding landscape (Ingwell et al., 2017; Leach & Isaacs, 2018).

Examining both local and landscape changes due to urbanization simultaneously can strengthen our understanding of the influence of human development. Ecologists may be studying too limited spatial scales, which may not appropriately consider species traits such as body size and home range (Jackson and Fahrig, 2015). Adams et al. (2020) found that both local factors (such as plant communities) and broad landscape characteristics interact to influence insect biodiversity in Los Angeles County. The effects of scale vary across insect orders and functional groups (González-Césped et al., 2021).

Research in landscape planning and local habitat modification to regulate the presence of beneficial insects is ongoing. Many insects travel between agricultural fields and nearby natural habitat daily (e.g. Duelli et al., 1990), indicating that farmers could potentially enhance these natural habitats to support insect diversity. The amount of non-crop habitat has been shown to influence pests, but further manipulative experiments altering landscape configuration are needed to better understand pest suppression (Haan et al., 2020). Native conservation plantings can support biological control agents and pollinators, but we have more to learn about the ideal size and distribution of plantings (Isaacs et al., 2009; Landis et al., 2000; McIntyre, 2000; Ranalli et al., 2025).

Additional research is needed to understand the overall variation in insect diversity and abundance across rural and urban landscapes at multiple spatial scales. Invertebrate taxa remain underrepresented in urban biodiversity research, and further study is needed to understand how different species respond to urbanization (Knapp, 2021). Urbanization impacts on farms using

organic practices could be particularly useful, as they create unique local habitats. Organic farms are often smaller, have more crop diversity, and are less likely to have regular pesticide use than conventional farms (Meehan et al., 2011; Nicholson and Williams, 2021; Orsini et al., 2013). In a comparison of organic and conventional tomato production in California, Letourneau and Goldstein (2001) found that organic farms had similar pest damage levels, but higher biodiversity. Insights on the impact of urbanization at multiple scales on organic farms could help to establish the value of local management for promoting insect conservation.

This study seeks to investigate insect diversity along a gradient of urbanization surrounding small-scale urban and peri-urban farms, which follow organic pest management practices. To evaluate the impacts of urbanization, this study will analyze (1) common insect families present on tomato and pepper crops on urban and peri-urban farms; (2) influence of surrounding percentage of development on insect family diversity and insect abundance at varying buffer scales; (3) any variation in impact of urbanization in open field vs. high tunnel growing environments; and (4) impact of landscape on the ratio of beneficial to pest insect families on these farms. We hypothesized that (1) insect families on pepper and tomato crops would be similar and dominated by pests, (2) higher intensity development in the surrounding landscape would decrease insect family diversity and different spatial scales would have varied impacts related to the mobility of the insects present on the farms, (3) high tunnels would have lower diversity than open field, and (4) the proportion of beneficial families compared to pest families would decrease with increasing urbanization. Altogether, the results of this study could determine how local and landscape factors impact insects and inform both our understanding of the benefits of farms in urban landscapes and potential management to support insect communities.

Methods

Insect family richness and abundance were surveyed on 20 farms along an urban-rural gradient during the 2023 (N = 10) and 2024 (N = 10) growing seasons (May – August). Study sites included commercial market farms, educational farms, and community gardens representative of the local farming network in the region. The sites represented a gradient of urbanization from high density, urban centers to rural landscapes within a 60 km radius of Kansas City, KS (Figure 1). All farms were characterized by high crop diversity and organic pest control practices (not necessarily certified organic). The median and mean farm size were 3.75 and 10 acres, respectively (Table 1). This study accounted for variation in management practices sampling both farms growing in open fields and in high tunnels. Insect sampling was conducted on pepper (*Capsicum spp.*) and tomato (*Solanum lycopersicum*), which were selected as representative specialty crops due to their economic importance and widespread cultivation in the region. Both crops are in the family Solanaceae and share many common pests. For each crop, insects were sampled using visual observation, netting, sticky traps, and pitfall traps.

Sampling Frequency and Protocol

Each site was sampled three times during the summer growing season. Across both years, sampling intervals were categorized as early summer (20 May-16 June), mid-summer (17 June-12 July), and late summer (15 July-9 Aug). While tomato were present on all farms during all three sampling periods, three farms had not yet planted peppers during the initial visit. Consequently, only mid- and late-summer samples were included from pepper for those locations.

Surveys were conducted between 08:00 and 13:00 on days with no active precipitation. Temperature, high wind speed, and average wind speed were recorded using a Kestrel 2000 weather meter (Nielsen-Kellerman, Boothwyn, PA). For each survey, timed observations, netting, sticky traps, and pitfall traps were used for monitoring insect populations. Sticky traps and pitfall traps were set for a period of 7 days (+/- 1 day in the event of inclement weather).

Insect Monitoring Techniques

We wanted to capture a broad range of arthropods, so we used multiple monitoring techniques to survey flying, foliage-dwelling, and ground-dwelling taxa. For each crop, three individual plants were sampled per farm. Distance between plants varied based on the spatial distribution at each site. Emphasis was placed on maximizing the distance between subjects to ensure that samples were representative of the entire farm for each crop. Four techniques were used to monitor and/or collect insects that were present. First, timed observations were performed for 10 minutes for each of the three individual plants per crops. All insects observed were recorded and photographed when possible with a digital mirrorless camera equipped with a 45mm f/2.8 macro lens (Leica DG Macro-Elmar, Panasonic). Second, a modified sweep netting method was used to sample each plant. To minimize plant damage, an upward sweep of the net was done on both sides of the plant with gentle agitation of the leaves to dislodge insects. Third, Trécé Pherocon AM No-Bait sticky traps (Trécé Inc., Adair, OK) were attached to stakes to collect insects at each plant. Sampling height was set with the bottom edge of the trap approximately level with the maximum plant height at the time of sampling. Finally, pitfall traps were set near each plant (within 0.5 m), which consisted of a plastic cup (473 ml/16 oz) placed in the ground flush with the surface (Figure 3a). Each cup was filled approximately three-quarters

full with propylene glycol. The top was covered with hardware cloth (1.3 cm/ 0.5 in) to exclude vertebrates and anchored with metal 25-cm landscape staples. A black plastic fence post cap held in place with steel tent stakes was placed approximately 5 cm above each trap to reduce incoming water from rain or overhead irrigation (Figure 3b).

Identification and Categorization of Insects

Insects were identified to the family level whenever possible using taxonomic keys in Borror and DeLong's Introduction to the Study of Insects (Triplehorn & Johnson, 2005) and Insects: Their Natural History and Diversity (Marshall, 2017). Family level identification was selected for the highest ecologically meaningful resolution while maximizing the farm sample size. Insect families were classified into functional groups of "beneficial" (primarily providers of ecosystem services such as biological control and pollination), "pests" (primarily with detrimental impacts), and "neutral or mixed" (families with negligible impact or proportionally balanced with pest and beneficial species). Insects that could be considered pests for stored grain products (e.g. Silvanidae) were classified as "neutral or mixed" in the context of this study, as the scope was limited to farms that focus on vegetable and fruit production.

Landscape Analysis

Urbanization of the surrounding landscape was quantified using the National Land Cover Database (NLCD) (U.S. Geological Survey, 2024) in ArcGIS Pro (Esri, Redlands, CA) at a series of buffer scales (100 m, 500 m, 1 km, and 5 km radii) for 2023 and 2024, corresponding with the year insects were sampled for each farm. Percentage of the NLCD categories of high

intensity development, medium intensity development, low intensity development, and developed open space were analyzed.

Using raw values for each category individually, data points were clustered at high and low urbanization. To better capture the gradient of urbanization, categories were combined and weighted to create an overall score for each radius using the following formula:

$$\text{Weighted Urbanization} = (\%\ \text{High} \times 4) + (\%\ \text{Medium} \times 3) + (\%\ \text{Low} \times 2) + (\%\ \text{Open} \times 1)$$

Farm characteristics by site including weighted urbanization scores across various radii are detailed in Table 1. Figure 2 illustrates the weighted urbanization scores at the 100 m radius.

Statistical Analysis

Prior to analysis, insect collection data from all sampling methods (observation, sweep netting, pitfall traps, and sticky traps) were pooled to calculate a total insect family richness and abundance for each unique combination of site visit and plant type. All statistical analyses were performed in R (version 4.6.1) (R Core Team, 2025). We fitted linear mixed-effects models (LMMs) and generalized linear mixed-effects models (GLMMs) for both linear and quadratic polynomial effects of weighted urbanization. For all models, year (2023 vs.2024), growing environment (open field vs. high tunnel), and plant type (tomato vs. pepper) were specified as fixed effects, while farm was included as a random intercept. Models with the best fit were determined using Akaike's Information Criterion (AIC). LMMs were compared using Maximum Likelihood (ML), while final AIC are reported from Restricted Maximum Likelihood (REML) fits.

Insect family richness was modeled with a negative binomial GLMM. Insect abundance data was $\log_{10}$ transformed where appropriate to meet the assumption of normality and analyzed with an LMM. Subsets of the data were evaluated using these same models to compare family richness and abundance between open field and high tunnel environments. The total number of beneficial families was divided by the total number of pest families to quantify the ratio of beneficial-to-pest families. Similarly, the beneficial abundance was divided by pest abundance to quantify beneficial-to-pest abundance. These beneficial-to-pest ratios for family and abundance were each analyzed with LMMs.

Results

Across all farms and samples, a total of 137 distinct families were identified. Families present on all 20 farms were: Aphididae (aphids), Carabidae (ground beetles), Chrysomelidae (leaf beetles), Cicadellidae (leaf hoppers), Coccinellidae (lady beetles), Dolichopodidae (long-legged flies), Elateridae (click beetles), Formicidae (ants), Gryllidae (crickets), Lampyridae (fireflies), Miridae (plant bugs), Sciaridae (dark-winged fungus gnats), and Staphylinidae (rove beetles). Family richness was similar between tomato (119 families) and pepper (110 families) (Table 2). Seven families accounted for 85% of the total abundance (Figure 4). Total insect abundance identified to family level was also similar between crop types, with 45,871 specimens recorded for pepper plants and 48,825 for tomato plants.

Modeling Influence of Weighted Urbanization Scores at Different Buffer Scales

The relationships between weighted urbanization score and insect family richness were tested for 100 m, 500 m, 1 km, and 5 km radii, but was only significant for the 100 m radius using a polynomial model (P <0.05, Table 3). In this model, insect richness peaks at intermediate levels of urbanization with a decline at low or high urbanization (Figure 5A). Across all other spatial scales, linear relationships were consistently negative, but there were no significant relationships for either linear or polynomial models (Table 3).

Similarly, the only significant relationship between weighted urbanization score and insect abundance was with the 100 m radius polynomial model ($P < 0.05$, Table 4). Insect abundance also peaks at intermediate levels of urbanization in this model and declines at the extremes (Figure 5B). The best fit models for all other radii had a consistently positive relationship between weighed urbanization and abundance, but none were significant (Table 4).

Crop type and sample year did not significantly affect insect family counts or insect abundance. When analyzed separately, pepper and tomato exhibited the same trends as the combined data, with peaks in intermediate weighted urbanization values for family richness for the 100 m radius (quadratic polynomial model, pepper $P < 0.05$; tomato $P < 0.05$). Log-transformed abundance for each crop followed a similar non-significant trend relative to weighted urbanization scores (quadratic polynomial model, pepper, $P = 0.08$; tomato $P = 0.06$).Given that the 100 m radius polynomial models showed the only significant relationship between urbanization and insect richness and abundance, all subsequent analyses of the data were conducted exclusively at the 100 m scale.

Impacts of Weighted Urbanization: Open Field vs. High Tunnel

To complement the combined dataset models, we examined impacts of the production system as well. The average wind speed recorded at the beginning of insect sampling was higher in open fields (0.62 m/s) than in high tunnels (0.27 m/s). Average temperature was 27.9 ºC in high tunnels and 26.8 ºC in open fields. However, during the mid-summer site visits the differences between high tunnel and open field systems were greater, averaging 29.4 ºC and 26.8 ºC respectively. We observed a higher family richness ($P < 0.05$) and abundance ($P < 0.05$) in the open field compared to the high tunnels. The dominant families were largely consistent between the growing systems. Formicidae (ants), Aphididae (aphids), and Cicadellidae (leafhoppers) were the most abundant for both. These three families accounted for approximately 70% of open field insect abundance, but only 55% of the individuals found in the high tunnels. Staphylinidae (rove beetles) had higher representation in the open field (6%) than in the high tunnels (3%). High tunnels had a greater representation of Sciaridae (7.9% vs. 4%),

Dolichopodidae (4.1% vs. 2%), and Lampyridae (6.3% vs. 0.4%). Because high tunnels create a physical barrier and protected microclimate that can modify landscape-level effects, open field and high tunnel samples were evaluated independently for influence of weighted urbanization scores at 100 m.

The best fit model for both open field family richness and $\log_{10}$(abundance) was a polynomial model with a peak at intermediate urbanization, similar to the overall dataset (family richness, $P < 0.01$, $\log_{10}$(abundance) $P < 0.05$, Figure 6A,C). In contrast, the high tunnel subset had a lower representation of intermediate-urbanization farms. While there was a slight negative trend, neither a linear model nor a polynomial model (Figure 6B) was significant for weighted urbanization and high tunnel family richness. Because the high tunnel abundance data displayed a bimodal distribution, a log transformation was deemed inappropriate. Interestingly, there were significantly fewer insects in urban high tunnels compared to rural high tunnels ($P < 0.01$, Figure 6D).

Landscape and the Beneficial-to-Pest Ratio

Because urbanization can impact insect species differently, we tested for relationships between weighted urbanization scores (at the 100 m radius) and functional groups of beneficial and pest insects. Total families identified for each farm by functional category and beneficial-to-pest ratios are shown in Table 5. When analyzed independently, both beneficial and pest measures of family richness and $\log_{10}$(abundance) mirrored the overall trend of the data, peaking at intermediate urbanization levels (Figure 7). However, neither beneficial nor pest family richness/abundance was significantly related to weighted urbanization. Given that both beneficial and pest groups responded with similar trends, the ratio of beneficial-to-pest insect families as

well as beneficial-to-pest abundance was not significantly impacted by weighted urbanization scores for 100 m (Figure 8). Furthermore, the plant type (tomato vs. pepper) and growing environment (open field vs. high tunnel) did not have a significant effect.

Discussion

The overall objective of this study was to explore how urbanization, crop type, and production system influence insect communities on small-scale farms that are using organic practices. Our findings demonstrate that the effects of higher intensity development immediately surrounding the farm (100 m) outweigh the broader surrounding landscape. Also, farms with intermediate levels of urbanization had the highest diversity and abundance of insects. Altogether, these results suggest that farms can support a diversity of insects even with high levels of urbanization in the surrounding landscape through local land management.

Overview of Families Identified

Across all 20 farms, tomato and pepper sampling yielded an average insect family richness of 48 per farm. Most of the total insect abundance was attributed to seven families (Formicidae, Aphididae, Cicadellidae, Staphylinidae, Sciaridae, Chrysomelidae, and Dolichopodidae) of the 137 that we identified. In a recent study of urban farms and prairies in the same geographic region, Schieuer (2026) found similar high abundances within these groups (e.g. Formicidae represented ~86% of the ground predators and Aphididae represented ~26% of foliar pests). However, some of the groups that were most abundant in Schieuer (2026) were not as well represented in this study, such as Thysanoptera/Aleyrodidae and wasps.

There were substantial overlaps in the crop insect communities, with most families identified occurring on both tomato and pepper. Both Aphididae (aphids) and Chrysomelidae (leaf beetles), which were among the most abundant families, include pest species that can cause significant economic losses in tomato and pepper crops (Diaz et al., 2026; Hoffmann et al., 1999; Lange & Bronson, 1981). Other common insect families we identified, Sciaridae (dark winged

fungus gnats) and Cicadellidae (leafhoppers), are minor pests to Solanaceous crops but can act as disease vectors (Cloyd, 2015; Lange & Bronson, 1981). The farms we sampled averaged 19.6 pest insect families and had nearly as many beneficial families (16). The high proportion of beneficial families that we observed may be related to the organic practices of the farms sampled. Letourneau and Goldstein (2001) found organic farms had a higher natural enemy abundance than conventional farms. While direct comparisons of total diversity between these farms and different urban green spaces such as public parks, vacant lots, or residential years remain challenging due to the wide variation in sampling protocols, urban agroecosystems are increasingly recognized as critical habitat refuges (Jha et al., 2023).

Impacts of Urbanization in the Surrounding Landscape

Our results indicate that the amount of urbanization in the broader surrounding landscape may not be a good predictor of insect abundance or diversity as the three largest spatial scales (500 m, 1 km, and 5 km) were not significant. Instead, development of the land directly on the farm or within very close proximity (100 m) was the most important spatial scale affecting insect communities. This supports other studies that have found local factors to be better predictors of insect communities. For example, Quistberg et al. (2016) found bee diversity and abundance were predicted better with local factors like floral diversity than the amount of developed land within 2 km in urban gardens. Similarly, Philpott et al. (2014) found that local factors including ground cover, rock cover, and forb cover were much stronger drivers of urban arthropod community composition than landscape factors in forest fragments, vacant lots, and community gardens. Philpott et al. (2014) identified vegetation as an especially important local factor driving presence of poor dispersers. The families identified in our study with the highest abundance

including Formicidae (ants), Aphididae (aphids), Cicadellidae (leaf hoppers), and Staphylinidae (rove beetles) are unlikely to be dispersing over long distances. Smaller body size, shorter wings, and shorter legs characteristic of these insect families are traits associated with limited dispersal (Renault, 2020), making immediate habitat changes more influential than the broader landscape.

Development intensity in the smallest radius we studied, 100 m, was a significant predictor of insect diversity and abundance, with both peaking at intermediate levels of urbanization (weighted urbanization scores of approximately 0.5-2). The peak that we observed at intermediate urbanization has been seen in other taxa, such as in plant, avian, and mammal diversity (e.g. Blair, 1996; Godefroid & Koedam, 2003; Racey & Euler, 1982). Among the insects, similar trends with a diversity peak at intermediate levels of disturbance have been noted in some studies of Odonata (damselflies and dragonflies), bees, and butterflies (Blair, 1997; Jere et al., 2020; Liow et al., 2001). However, arthropod responses to urbanization do not follow a single, common pattern and impacts are likely species-specific. In a review of research on urbanization impacts, McKinney (2008) found only 30% of invertebrate studies indicated peaks in species richness at intermediate levels. Therefore, while our research illustrates higher diversity at intermediate levels of development, more investigation into the species-specific responses contributing to this trend is warranted.

A few hypotheses have been proposed to explain the phenomenon of higher diversity at intermediate levels of development. One such hypothesis is the intermediate disturbance hypothesis (IDH), which states peak species diversity will be present at moderate levels of disturbance intensity due to disturbance altering competitive interactions preventing any one species from excluding the others (Connell, 1978). At low disturbance, the environment is stable for long periods, allowing dominant competitors to drive weaker species to extinction. In very

high disturbance, ecosystems must continually reset so they have a more limited number of rapid colonizers. While our results fit the predictions of this model, the IDH is not universal. While most publications that discuss IDH present evidence in favor of the hypothesis, many recent publications demonstrate less support for the IDH, especially in aquatic ecosystems (Moi et al., 2020).

Urban tolerance models may contribute to our understanding of increased arthropod diversity in farms with intermediate development in close proximity. Urban tolerance models suggest species can be classified as urban avoiders, urban adapters, and urban exploiters (Blair, 1996). Urban tolerance models have been used to predict species-specific responses to urbanization. For example, the impact of urbanization on butterflies can be driven by life history strategies such as broader thermal tolerance and food sources (Callaghan et al., 2021). Mixed impervious surfaces with pockets of habitat found near suburban farms in our study may support both urban adapters and urban exploiters, creating zones of higher biodiversity in arthropods.

An additional explanation may be the habitat heterogeneity hypothesis, which suggests an increasing number of habitat types in an area leads to an increased species diversity because there are more niches available (MacArthur and MacArthur, 1961; MacArthur and MacArthur, 1967). Arthropod species richness in urban areas has a positive relationship with habitat heterogeneity, suggesting that urban planners can support biodiversity by integrating a variety of habitats (Sattler et al., 2010). Báldi (2008) found for several arthropod taxa the habitat heterogeneity was more important than the habitat area to predict species richness. Urban farms in our study may have had too much impervious surface limiting the variety of habitats available or limiting dispersal ability of insects. Some of the rural farms in our study could have had habitat limitations due to nearby conventional farming or manicured landscapes dominated by

non-native species reducing host plant diversity. The suburban areas in our study may have provided more heterogeneity of habitats with possible mixed microhabitats of floral, nesting, and overwintering sites nearby. Urban farms and surrounding greenspaces may also provide varied habitats to support different life stages of the insects.

With ongoing global declines in insects, these ecological mechanisms offer valuable insights for both agricultural management and urban planning. For growers seeking to promote insect ecosystem services, our results indicate that urban density in the broader landscape does not significantly limit biodiversity on the farms. Consequently, farmers can successfully cultivate robust insect communities regardless of whether their operations are located in rural, suburban, or urban settings, provided they prioritize local habitat management. For city planners, these findings highlight the value of incorporating small scale urban farms across the urban gradient. Because local land management directly on or near farms exerts the strongest influence on insect populations, strategically placed organic agriculture spaces throughout cities can provide crucial habitat refuges.

Variation in Open Field and High Tunnel Growing Environments

Our study suggests that insect communities in high tunnels may have a unique response to urbanization. Our open field trends for family richness and abundance mirrored the overall data, but the high tunnels differed. We observed lower species richness and abundance in high tunnels compared to open field environments. While the physical barrier created by the polyethylene cover may have the potential to restrict insect movement, previous studies of introduced beneficial insects indicate that dispersal rate is high (Ingwell et al., 2018). The reduction in species richness may be related to alterations in abiotic and biotic factors within the

high tunnel. High tunnel environments may experience elevated air and soil temperatures during the day compared to open field environments (O'Connell et al., 2012; Wien, 2009). The high tunnel sites in our study had higher average temperatures than the open field, particularly in the mid-summer samples. Solar radiation and wind are often lower within high tunnels (Heckler, 2017; Lee et al., 2021). Blocking ultraviolet light has been shown to alter flight behavior of insect pests such as aphids and whiteflies (Dáder et al., 2015). The reduction in rainfall within covered high tunnels may reduce fungal disease in tomato (O'Connell et al., 2012), which is notable because crops infected with fungal diseases can be more susceptible to pests. For example, Qasim et al. (2022) found that non-vector whitefly pests increased feeding on tomatoes infected with powdery mildew. Due to the limited size of high tunnels compared to open fields, total diversity of host plants may be lower. These microclimate changes within high tunnels may favor some insect species and restrict presence of others. The finding of overall decreased insect abundance in high tunnels was unexpected and contradicts recent studies indicating that pest pressure is stronger in high tunnels (Ingwell et al., 2017; Leach & Isaacs, 2018). It is important to note, however, that this comparison was not the primary goal of the study and further research with a balanced design is necessary to support these findings.

The family richness of insects in high tunnels in our study did not have a significant relationship with the surrounding urbanization. The enclosed space and altered microclimate may act as a filter that overrides the influence of urbanization. Interestingly, the abundance of insects in high tunnels had a negative correlation with urbanization. A possible explanation is that there were fewer individuals tolerant of high tunnel conditions in the surrounding urban landscape available to colonize compared to rural habitats. In our study, we observed shifts in relative abundance of families that may be reflective of this varied high tunnel tolerance among the

insects present in urban zones. Sciaridae (dark-winged fungus gnats) and Lampyridae (fireflies) made up a higher proportion of the high tunnel insects compared to the open field. This may be an indication of the adaptability of these families to establish through two barriers, the urban landscape and the high tunnel microclimate. In contrast, soil-dwelling Staphylinidae (rove beetles) had a higher relative abundance in open fields than high tunnels indicating lower tolerance to the high tunnel conditions.

Ratios of Beneficial and Pest Families and Urbanization

When separated by categories of pest or beneficial, trends in insect family richness and abundance remained a concave shape with the highest values at intermediate urbanization for both groups. However, neither independently had a significant relationship with weighted urbanization. It is important to consider the ratio, because it can be an indication of how predators and prey interact, and could indicate shifts in their relationships. The similarities in the trends may have occurred because some of the pest and beneficial species have similar habitat needs. Pest and beneficial population dynamics are often directly linked (e.g. Greco et al., 1999; Rahman et al., 2010; Winder et al., 2001). The availability of prey/host insects is likely to be correlated with their predators/parasites. Similarly, there was no correlation in the ratio of beneficial families to pest families with the weighted urbanization. Some studies of non-agricultural sites indicate that insect pollinators and predators are reduced with urbanization (Bates et al., 2011; Merckx et al., 2019). In a study of allotment sites for household fruit and vegetable production, Ellis et al. (2025) found a reduction in pollinator species richness along an urbanization gradient. Dynamics may be more complex on urban farms. For example, Philpott et al. (2020) found natural enemy-to-pest ratios decreased with increasing urbanization, but only on

farms with agricultural land cover within 2 km. By contrast, urban cover was not a predictor for these rations in sites lacking nearby agricultural land (Philpott et al., 2020). Consistent with this result, we found that urban cover alone is not a universal driver. Our results indicate that farmers do not necessarily face a disproportionately large number of pests or beneficials within highly urban environments.

Future Research

The findings of this study highlight several promising directions for future research. (1) Our analysis successfully demonstrates family level relationships between insect communities and local surrounding development. Different patterns may emerge when examining species-level variation within insect families. More species-level research would be beneficial to look at the relationships between pest and predator species that are directly tied to one another. (2) Our findings indicate that development in the broader landscape is not as important as the local environment in determining insect communities. It would be beneficial to explore which local factors have the most influence along the urbanization gradient, especially ones that farmers control such as floral diversity/abundance and available habitat on the farm. (3) This study identified variation in how insect communities respond to urbanization within high tunnels, providing a foundation for future targeted research of combined effects of these protected environments across a complete gradient of urbanization. In our study, the farms which had high tunnels in this study were grouped as either high or low in weighted urbanization, with a gap in intermediate level urbanization. It is possible that there is a similar insect peak in intermediate development associated with high tunnels, but further research is needed to see if intermediate urbanization impacts high tunnels differently than open field environments.

Conclusion

Understanding how urbanized landscapes can influence biodiversity is critical. The goal of this project was to evaluate insect diversity and abundance across urban and peri-urban small-scale vegetable farms along a gradient of development. We identified a significant non-linear relationship at the local scale. Insect diversity and abundance peaked at intermediate levels of development within a 100 m radius. In contrast, urbanization levels at 500 m, 1 km, and 5 km showed no observable effect. This study offers a unique contribution to agroecology by examining a continuous urbanization gradient specifically with farms utilizing organic practices. Our findings demonstrate that while the level of urbanization has the potential to alter insect populations on a farm, the immediate surrounding habitat plays a more decisive role in shaping these communities than the broader landscape. These results provide insights for urban land management as well as urban agriculture. For city planners, integrating farming across urban zones and not just the rural peripheries can effectively support biodiversity. Additionally, our research suggests farmers growing amongst all levels of development can utilize hyperlocal management practices to provide habitat for insect communities. As land-use decisions are made in urban and rural areas, localized land-use decisions can preserve vital insect biodiversity and abundance.

Tables and Figures

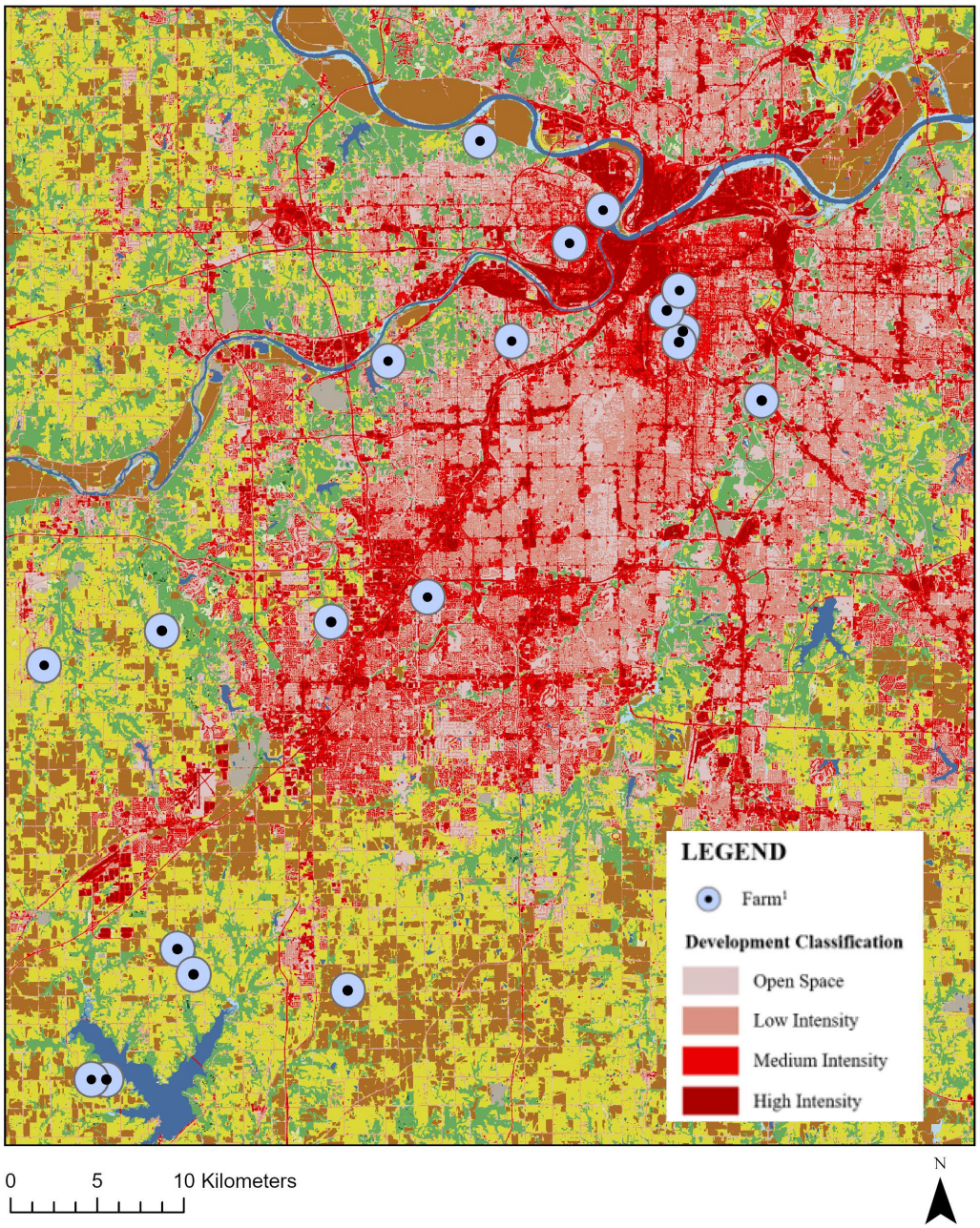


Figure 1. Spatial distribution of the study farms (N = 20).

Representative background land cover is derived from the National Land Cover Database 2024 layer (U.S. Geological Survey, 2024). Relevant development classification colors are shown.

[1]Farms of varying levels of urbanization in the Kansas City region were sampled for insect family diversity and abundance on tomato and pepper crops. Analyses utilized temporally aligned NLCD layers corresponding to individual farm sampling years (2023 or 2024).

Table 1. Site characteristics of 20 farms across an urbanization gradient in the Kansas City region (2023–2024).

Insect family diversity and abundance were surveyed at each location on tomato and pepper crops; Farms 1–10 were sampled in 2023 and Farms 11–20 in 2024.

[1]Based on the National Land Cover Database (NLCD) categories; Weighted urbanization score = (% high intensity development × 4) + (% medium intensity development × 3) + (% low intensity development × 2) + (% developed open space × 1)]

Farm #	Farm Name	Location (County, State)	Category	Approx. Farm Size (acres)	Sample in High Tunnel (HT) or Open Field (OF)	Weighted Urbanization Score[1]			
						100 m	500 m	1 km	5 km
1	K-State Olathe Horticulture Research and Extension Center	Johnson, KS	Research and Education	51.5	OF	0.162	0.104	0.287	0.231
2	Stu Shafer Open Petal Farm	Johnson, KS	Education	3	OF	1.412	2.325	2.420	2.383
3	The Garden at Dogwood Forest	Wyandotte, KS	Commercial	4.5	HT	0.000	0.382	0.634	0.911
4	Cultivate KC Juniper Training Farm	Wyandotte, KS	Education	9	OF	2.794	2.808	2.693	2.649
5	Groundspeak Farm	Miami, KS	Commercial	3	OF	0.714	0.096	0.105	0.091
6	KC Farm School at Gibbs Road	Wyandotte, KS	Education	14.5	OF	1.559	1.620	1.797	1.985
7	KC Healthy Kids Splitlog Farm	Wyandotte, KS	Community Garden	0.25	OF	2.722	2.756	2.846	2.636
8	Two Birds Farm	Wyandotte, KS	Commercial	20	OF	0.222	0.376	0.817	1.143
9	Hedgewood Farms	Miami, KS	Commercial	40	OF	0.000	0.000	0.051	0.233
10	Ophelia's Blue Vine Farm	Jackson, MO	Commercial	0.25	HT	2.857	2.580	2.824	2.753
11	Pat and Rachel's Garden	Johnson, KS	Commercial	13	HT (Tomato)/ OF (Pepper)	0.054	0.162	0.153	0.348
12	Moonlight Prairie Farm	Johnson, KS	Commercial	10	HT	0.171	0.180	0.152	0.256
13	Herdsman House Farm	Miami, KS	Commercial	2	OF	0.459	0.107	0.066	0.098
14	Woodland City KC	Jackson, MO	Commercial	0.5	HT	2.457	2.685	2.726	2.620
15	Moose Paw	Miami, KS	Commercial	3	HT (Tomato)/ OF (Pepper)	0.432	0.114	0.132	0.146
16	Sunset Garden	Johnson, KS	Community Garden	0.25	OF	2.559	2.219	1.852	2.028
17	Young Family Farm	Jackson, MO	Commercial	0.75	OF	2.657	2.628	2.620	2.565
18	Longfellow Community Garden	Jackson, MO	Community Garden	1	OF	2.714	2.983	2.924	2.758
19	Pickings and Pumpkins	Miami, KS	Commercial	10	OF	0.343	0.113	0.062	0.305
20	Urbavore Urban Farm	Jackson, MO	Commercial	13.5	OF	1.114	1.045	1.178	1.815

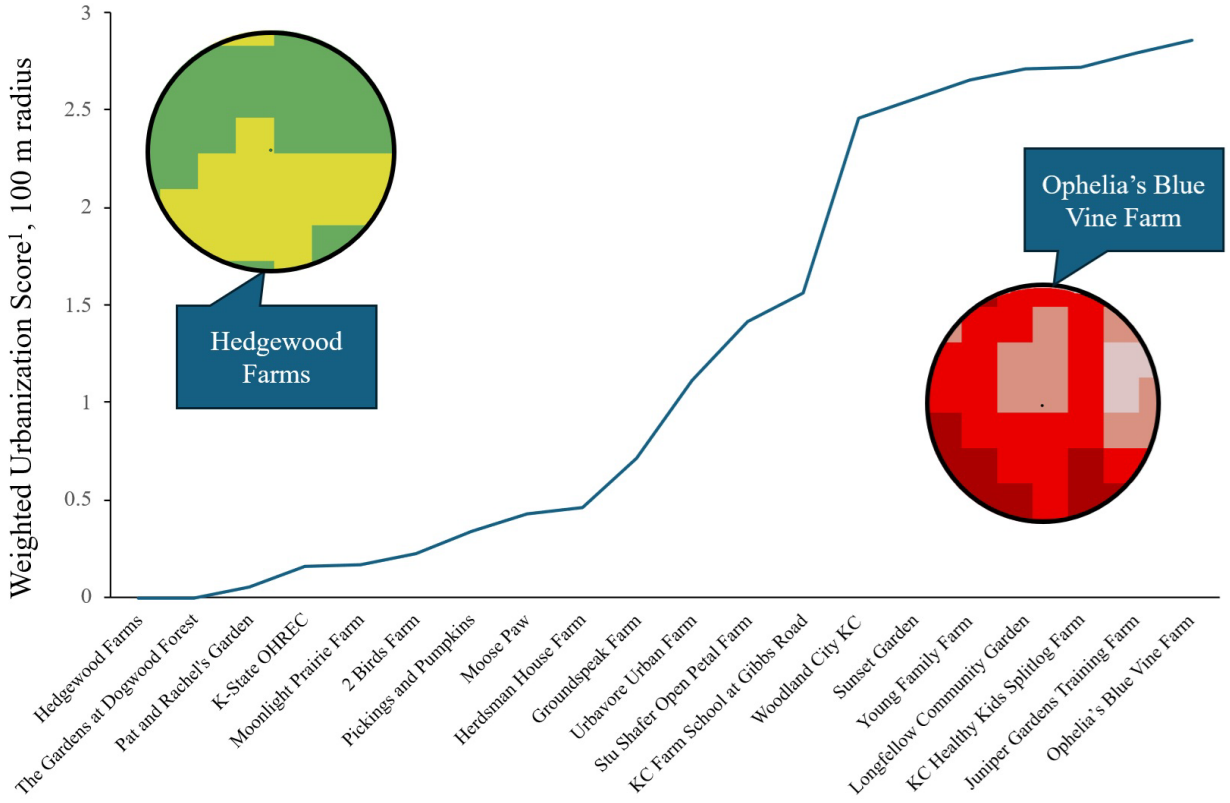


Figure 2. Weighted urbanization scores within a 100 m buffer by farm.

Farms of varying levels of urbanization in the Kansas City region were sampled for insect family diversity and abundance on tomato and pepper crops. Circular callouts show the 2023 NLCD land cover layer (U.S. Geological Survey, 2024) for Hedgewood Farms (no reds/no developed landcover) and Ophelia's Blue Vine Farm (darker red hues indicating higher development intensity).

[1]Based on the National Land Cover Database (NLCD) categories; Weighted urbanization score = (% high intensity development × 4) + (% medium intensity development × 3) + (% low intensity development × 2) + (% developed open space × 1)]

A B



Figure 3. Pitfall trap design for collection of insects.

(A) Configuration before cap installation showing the flush-buried cup covered with hardware cloth and (B) with fence post cap installed to prevent rainwater entry.

Farms of varying levels of urbanization following organic practices in the Kansas City region were sampled for insect family diversity and abundance on tomato and pepper crops.

Table 2. Functional category[1] for insect families identified sorted by host plant occurrence.

Abundance represents the total number of individuals collected across all farms[2] and sampling dates in 2023–2024.

[1]P = pest, B = beneficial, N = neutral/mixed

[2]Farms of varying levels of urbanization following organic practices in the Kansas City region were sampled for insect family diversity and abundance on tomato and pepper crops.

BOTH CROPS

Family	Category	Abundance
Formicidae (Ants)	N	19628
Aphididae (Aphids)	P	11332
Cicadellidae (Leafhoppers)	P	5616
Staphylinidae (Rove beetles)	B	3196
Sciaridae (Dark-winged fungus gnats)	P	2457
Chrysomelidae (Leaf beetles)	P	2251
Dolichopodidae (Long-legged flies)	B	1268
Gryllidae (True crickets)	N	798
Elateridae (Click beetles)	P	751
Tenebrionidae (Darkling beetles)	N	500
Carabidae (Ground beetles)	B	498
Lampyridae (Fireflies)	B	490
Membracidae (Treehoppers)	P	466
Laemophloeidae (Lined flat bark beetles)	N	430
Nitidulidae (Sap beetles)	N	356
Chironomidae (Non-biting midges)	N	337
Cydnidae (Burrower bugs)	N	242
Mordellidae (Tumbling flower beetles)	N	239
Coccinellidae (Lady beetles)	B	204
Scarabaeidae (Scarab beetles)	N	198
Chloropidae (Frit flies)	P	191
Berytidae (Stilt bugs)	P	146
Ulidiidae (Picture-winged flies)	P	131
Anthocoridae (Minute pirate bugs)	B	126
Miridae (Plant bugs)	N	101
Curculionidae (True weevils)	P	90
Syrphidae (Hoverflies)	B	87
Coreidae (Leaf-footed bugs)	P	83
Braconidae (Braconid wasps)	B	82
Pentatomidae (Stink bugs)	P	79
Aleyrodidae (Whiteflies)	P	67
Drosophilidae (Vinegar flies)	P	66
Halictidae (Sweat bees)	B	61
Muscidae (House flies and allies)	P	58
Calliphoridae (Blow flies)	P	56
Delphacidae (Delphacid planthoppers)	P	56
Culicidae (Mosquitoes)	P	55
Noctuidae (Cutworm moths)	P	55
Tingidae (Lace bugs)	P	54
Acrididae (Short-horned grasshoppers)	P	53
Anthicidae (Ant-like flower beetles)	B	50
Chrysopidae (Green lacewings)	B	40
Heleomyzidae (Heleomyzid flies)	N	37
Hesperiidae (Skippers)	B	35
Thripidae (Common thrips)	P	31
Latridiidae (Minute brown scavenger beetles)	N	26
Cecidomyiidae (Gall midges)	B	23
Geocoridae (Big-eyed bugs)	B	21
Erotylidae (Pleasing fungus beetles)	N	20
Ichneumonidae (Ichneumon wasps)	B	20
Silvanidae (Silvanid flat bark beetles)	N	20
Cantharidae (Soldier beetles)	B	17
Ectobiidae (Wild cockroaches)	N	15
Nabidae (Damsel bugs)	B	15
Pieridae (Whites, yellows, and sulphurs)	P	15
Rhyparochromidae (Dirt-colored seed bugs)	N	15
Apidae (Bees)	B	14
Reduviidae (Assassin bugs)	B	13
Histeridae (Clown beetles)	B	12
Bethylidae (Bethylid wasps)	B	11
Cerambycidae (Longhorn beetles)	P	11
Encyrtidae (Encyrtid wasps)	B	11
Platystomatidae (Signal flies)	N	11
Mycetophilidae (Fungus gnats)	N	10
Meloidae (Blister beetles)	B	9
Geotrupidae (Earth-boring dung beetles)	B	8
Issidae (Issid planthoppers)	N	8
Nymphalidae (Brush-footed butterflies)	B	8
Rhaphidophoridae (Cave crickets)	N	8
Lygaeidae (Seed bugs)	P	7
Tipulidae (Crane flies)	N	7
Crambidae (Crambid snout moths)	P	6
Erebidae (Erebid moths)	P	6

BOTH CROPS CONTINUED

Family	Category	Abundance
Mycetophagidae (Hairy fungus beetles)	N	6
Blattidae (Cockroaches)	P	5
Buprestidae (Metallic wood-boring beetles)	N	4
Derbidae (Derbid planthoppers)	N	4
Phlaeothripidae (Tube-tailed thrips)	B	4
Platygastridae (Platygastrid wasps)	B	4
Tachinidae (Tachinid flies)	B	4
Ceraphronidae (Ceraphronid wasps)	B	3
Thyreocoridae (Ebony bugs)	P	3
Asilidae (Robber flies)	B	2
Ceratopogonidae (Biting midges)	P	2
Hydrochidae (Water scavenger beetles)	N	2
Lauxaniidae (Lauxaniid flies)	N	2
Oecanthidae (Tree crickets)	B	2
Rhopalidae (Scentless plant bugs)	N	2
Scirtidae (Marsh beetles)	N	2
Sphecidae (Thread-waisted wasps)	B	2
Tephritidae (True fruit flies)	P	2
Vespidae (Vespid wasps)	B	2

TOMATO ONLY

Family	Category	Abundance
Ectopsocidae (Outer barklice)	N	6
Alydidae (Broad-headed bugs)	P	4
Byrrhidae (Pill beetles)	N	2
Cicindelidae (Tiger beetles)	B	2
Coniopterygidae (Dustywings)	B	2
Cynipidae (Gall wasps)	N	2
Diapriidae (Diapriid wasps)	B	2
Pyrochroidae (Fire-colored beetles)	N	2
Tiphiidae (Tiphiid wasps)	B	2
Crabronidae (Crabronid wasps)	B	1
Cryptophagidae (Silken fungus beetles)	N	1
Heteroceridae (Variegated mud-loving beetles)	N	1
Lycaenidae (Gossamer-winged butterflies)	B	1
Monotomidae (Root-eating beetles)	B	1
Mutillidae (Velvet ants)	N	1
Mymaridae (Fairyflies)	B	1
Papilionidae (Swallowtail butterflies)	N	1
Proctotrupidae (Proctotrupid wasps)	B	1
Psychodidae (Moth flies)	N	1
Pteromalidae (Pteromalid wasps)	B	1
Salpingidae (Narrow-waisted bark beetles)	B	1
Scoliidae (Scoliid wasps)	B	1
Sphingidae (Sphinx moths)	P	1
Spongiphoridae (Little earwigs)	N	1
Stenopsocidae (Narrow barklice)	N	1
Thynnidae (Thynnid wasps)	B	1
Trogidae (Hide beetles)	B	1

PEPPER ONLY

Family	Category	Abundance
Nogodinidae (Nogodinid planthoppers)	N	2
Sarcophagidae (Flesh flies)	N	2
Anthribidae (Fungus weevils)	N	1
Attevidae (Tropical ermine moths)	N	1
Caeciliusidae (Lizard barklice)	N	1
Cupedidae (Reticulated beetles)	N	1
Empididae (Dance flies)	B	1
Fanniidae (Little house flies)	P	1
Flatidae (Flatid planthoppers)	P	1
Forficulidae (Earwigs)	N	1
Pemphredonidae (Aphid wasps)	B	1
Phalacridae (Shining flower beetles)	B	1
Rhysodidae (Wrinkled bark beetles)	N	1
Sphaeroceridae (Lesser dung flies)	N	1
Stratiomyidae (Soldier flies)	B	1
Tenthredinidae (Common sawflies)	P	1
Tettigoniidae (Katydids)	N	1
Therevidae (Stiletto flies)	B	1

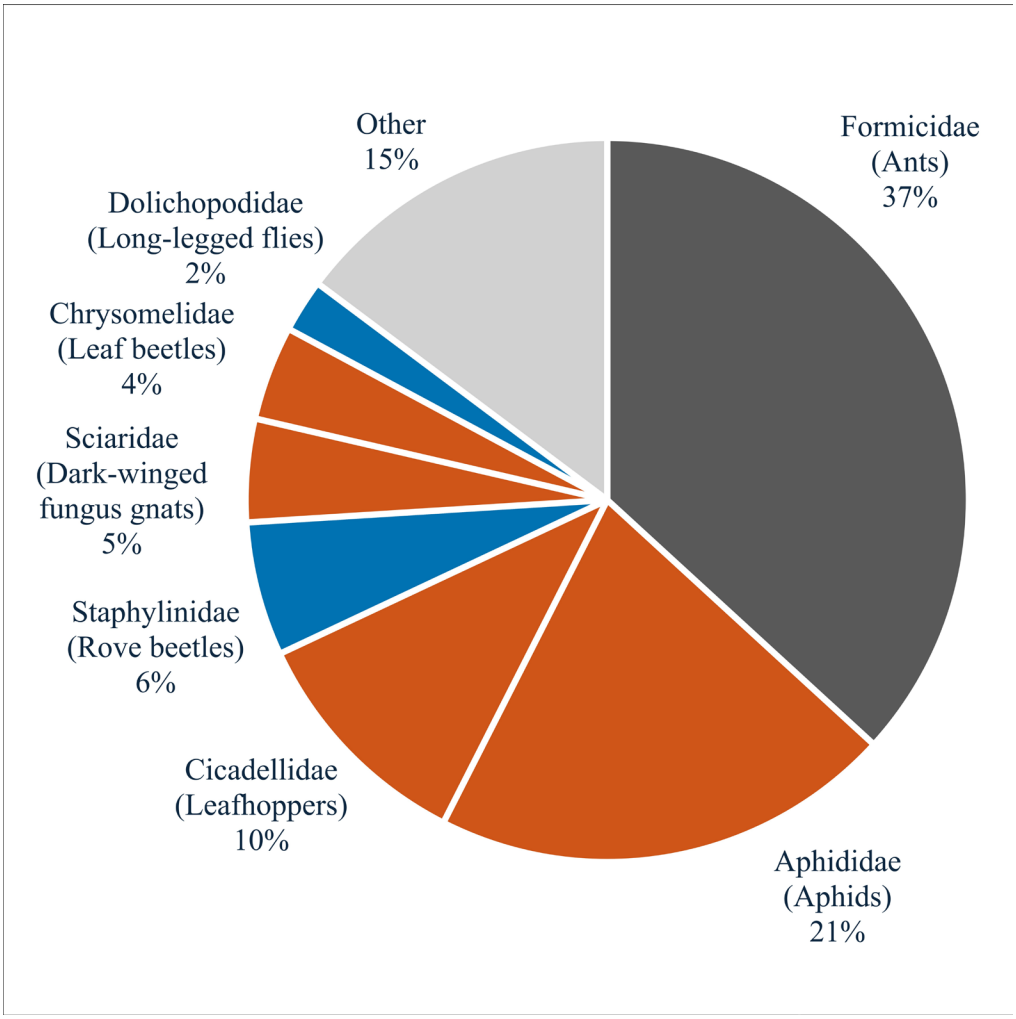


Figure 4. Relative abundance of insect families.

Data represents the total specimens that were identified to family level (N = 53,330) for all farms combined[1]. Families with an abundance less than 1% of the total are grouped under "Other." Colors denote functional categories: orange (pest), blue (beneficial), dark gray (neutral or mixed).

[1]Farms of varying levels of urbanization following organic practices in the Kansas City region were sampled for insect family diversity and abundance on tomato and pepper crops.

Table 3. Model selection statistics for linear versus polynomial effects of farm[1] weighted urbanization[2] on insect family richness across 100 m, 500 m, 1 km, and 5 km landscape buffers using GLMMs.

† indicates the top-ranked model at each spatial scale based on Akaike Information Criterion (AIC). Coefficient estimates (±SE) are provided alongside marginal (R^2_m) and conditional (R^2_C) variance explanations.

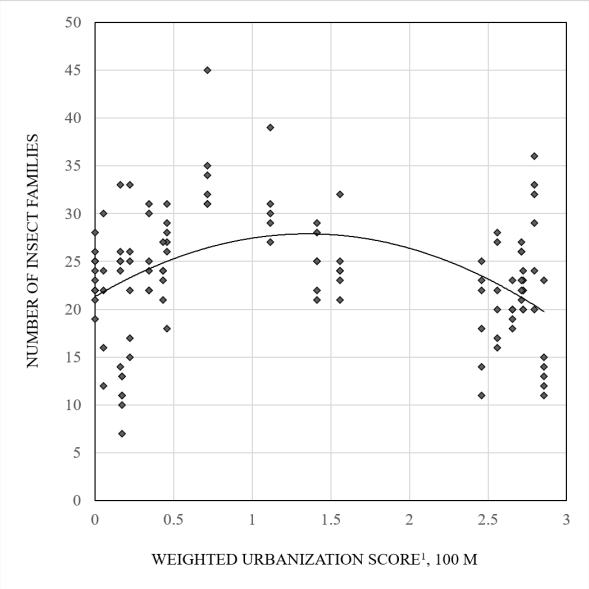
*$P < 0.05$.

[1]Farms of varying levels of urbanization following organic practices in the Kansas City region were sampled for insect family diversity and abundance on tomato and pepper crops.

[2]Based on the National Land Cover Database (NLCD) categories; Weighted urbanization score = (% high intensity development × 4) + (% medium intensity development × 3) + (% low intensity development × 2) + (% developed open space × 1)]

Radius	Model	AIC	Δ AIC	Coefficient Estimate β±SE	R_m^2	R_C^2	p-value
100 m	Linear	728.1	+1.8	-0.030 ± 0.036	0.164	0.467	0.397
	Polynomial†	**726.3**	**0**	**Linear: -0.355 ± 0.386**	**0.248**	**0.487**	**0.357**
				Quadratic: -0.831 ± 0.335			**0.013***
500 m	**Linear†**	**727.9**	**0**	**-0.034 ± 0.033**	**0.172**	**0.468**	**0.314**
	Polynomial	729.8	+1.9	Linear: -0.431 ± 0.331	0.174	0.467	0.194
				Quadratic: -0.139 ± 0.303			0.648
1 km	**Linear†**	**727.7**	**0**	**-0.037 ± 0.034**	**0.175**	**0.468**	**0.281**
	Polynomial	729.3	+1.6	Linear: -0.460 ± 0.253	0.187	0.472	0.069
				Quadratic: -0.297 ± 0.263			0.26
5 km	**Linear†**	**728.1**	**0**	**-0.033 ± 0.037**	**0.167**	**0.468**	**0.361**
	Polynomial	729.8	+1.7	Linear: -0.393 ± 0.264	0.174	0.47	0.136
				Quadratic: -0.229 ± 0.283			0.42

A. Family Richness*



B. Log_{10}(Abundance)*

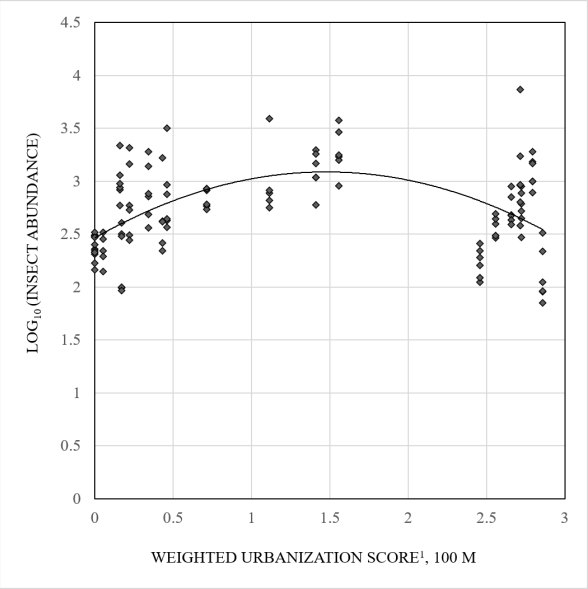


Figure 5 Relationship between farm weighted urbanization score for a 100 m radius for (A) number of insect families identified and (B) log_{10}(insect abundance) for all farms.

Farms of varying levels of urbanization following organic practices in the Kansas City region were sampled for insect family diversity and abundance on tomato and pepper crops.

Diamond points represent data for each plant and site visit (N = 117).

*$P < 0.05$.

[1]Based on the National Land Cover Database (NLCD) categories; Weighted urbanization score = (% high intensity development × 4) + (% medium intensity development × 3) + (% low intensity development × 2) + (% developed open space × 1)]

Table 4. Model selection statistics for linear versus polynomial effects of farm[1] weighted urbanization[2] on log_{10}(abundance) across 100 m, 500 m, 1 km, and 5 km landscape buffers using LMMs.

† indicates the top-ranked model at each spatial scale based on Akaike Information Criterion (AIC). Coefficient estimates (±SE) are provided alongside marginal (R^2_m) and conditional (R^2_C) variance explanations.

*$P < 0.05$.

[1]Farms of varying levels of urbanization following organic practices in the Kansas City region were sampled for insect family diversity and abundance on tomato and pepper crops.

[2]Based on the National Land Cover Database (NLCD) categories; Weighted urbanization score = (% high intensity development × 4) + (% medium intensity development × 3) + (% low intensity development × 2) + (% developed open space × 1)]

Radius	Model	AIC	Δ AIC	Coefficient Estimate β±SE	R_m^2	R_C^2	p-value
100 m	Linear	49.3	+6.6	0.013 ± 0.049	0.234	0.578	0.793
	Polynomial†	**42.7**	**0**	**Linear: 0.178 ± 0.514**	**0.393**	**0.611**	**0.735**
				Quadratic: -1.501 ± 0.534			**0.013***
500 m	**Linear†**	**49.0**	**0**	**0.024 ± 0.047**	**0.24**	**0.577**	**0.619**
	Polynomial	49.8	+0.7	Linear: 0.303 ± 0.596	0.253	0.587	0.62
				Quadratic: -0.587 ± 0.591			0.339
1 km	**Linear†**	**49.0**	**0**	**0.026 ± 0.047**	**0.241**	**0.577**	**0.588**
	Polynomial	49.3	+0.4	Linear: 0.337 ± 0.595	0.264	0.591	0.581
				Quadratic: -0.685 ± 0.596			0.271
5 km	**Linear†**	**48.9**	**0**	**0.031 ± 0.051**	**0.243**	**0.577**	**0.547**
	Polynomial	50.4	+1.5	Linear: 0.367 ± 0.608	0.24	0.588	0.556
				Quadratic: -0.392 ± 0.607			0.53

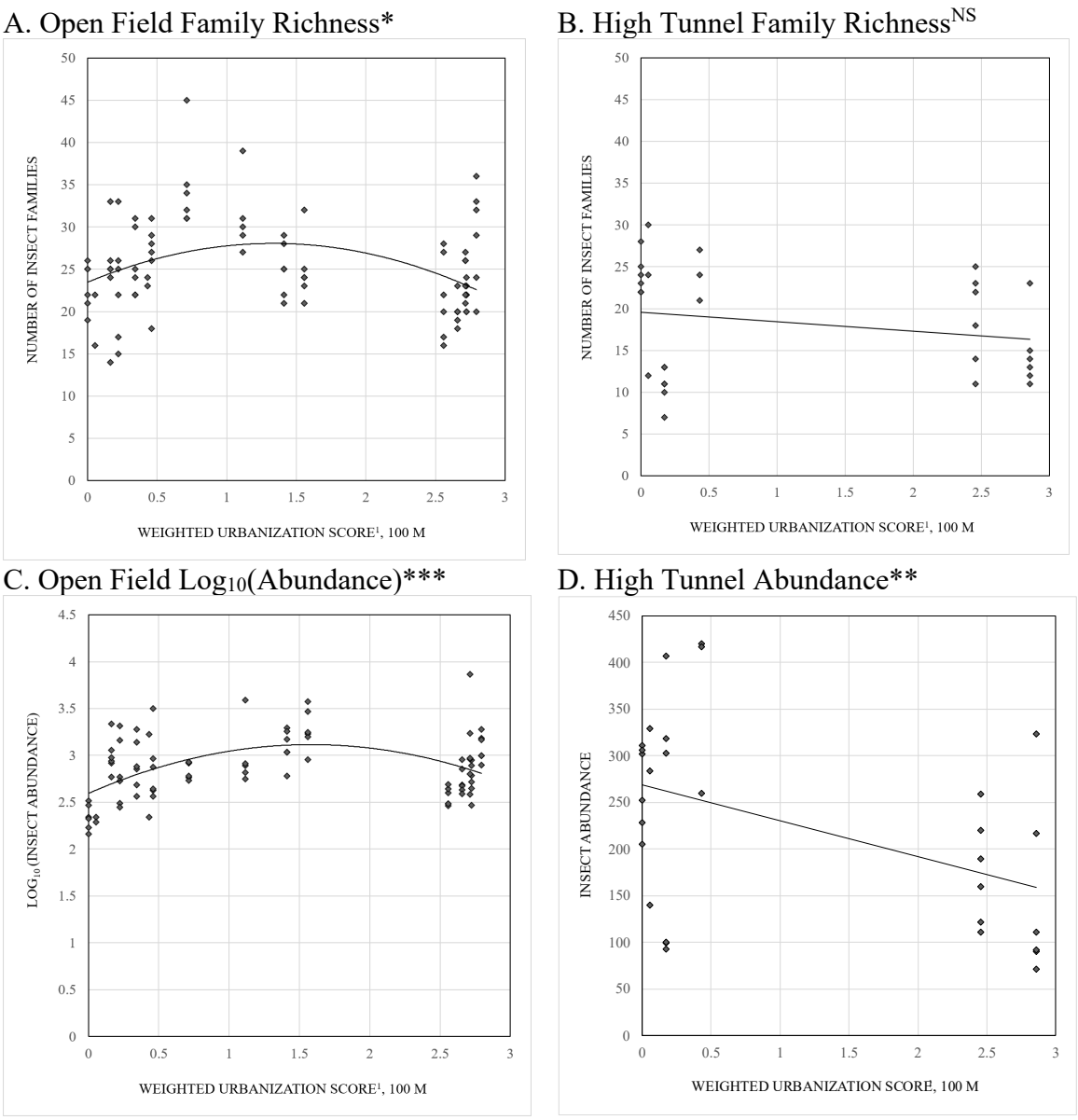


Figure 6 Relationship between the farm-weighted urbanization score[1] (100 m radius) and insect community metrics across growing environments

(A) family richness in open fields, (B) $\log_{10}$(abundance) in open fields, (C) family richness in high tunnels, and (D) untransformed abundance in high tunnels.

Farms of varying levels of urbanization following organic practices in the Kansas City region were sampled for insect family diversity and abundance on tomato and pepper crops.

Diamond points represent data for each plant and site visit (open field N = 87, high tunnel N = 30).

*P < 0.05, **P <0.01, ***P <0.001.

[1]Based on the National Land Cover Database (NLCD) categories; Weighted urbanization score = (% high intensity development × 4) + (% medium intensity development × 3) + (% low intensity development × 2) + (% developed open space × 1)]

Table 5. Total insect families identified for each farm by functional groups of beneficials, neutral/mixed, and pests.

Ratio of beneficial families to pest families is provided for each location.

[1]Farms of varying levels of urbanization following organic practices in the Kansas City region were sampled for insect family diversity and abundance on tomato and pepper crops.

Farm[1]	Families by Functional Category				Beneficial-to-Pest Ratio
	Beneficial	Neutral/ Mixed	Pest	Total	
Groundspeak Farm	23	17	23	63	1.000
Cultivate KC Juniper Training Farm	18	17	25	60	0.720
Urbavore Urban Farm	21	14	23	58	0.913
K-State OHREC	17	20	20	57	0.850
Stu Shafer Open Petal Farm	20	12	21	53	0.952
Two Birds Farm	19	14	20	53	0.950
The Garden at Dogwood Forest	17	15	20	52	0.850
Herdsman House Farm	18	13	21	52	0.857
Moose Paw	15	14	23	52	0.652
Hedgewood Farms	16	17	16	49	1.000
KC Farm School at Gibbs Road	15	12	19	46	0.789
Woodland City KC	13	10	22	45	0.591
Longfellow Community Garden	18	10	17	45	1.059
Pickings and Pumpkins	15	10	20	45	0.750
Pat and Rachel's Garden	13	10	21	44	0.619
KC Healthy Kids Splitlog Farm	14	9	20	43	0.700
Sunset Garden	16	10	17	43	0.941
Ophelia's Blue Vine	14	8	18	40	0.778
Young Family Farm	10	9	16	35	0.625
Moonlight Prairie Farm	9	8	11	28	0.818
Average	**16.05**	**12.45**	**19.65**	**48.15**	**0.821**

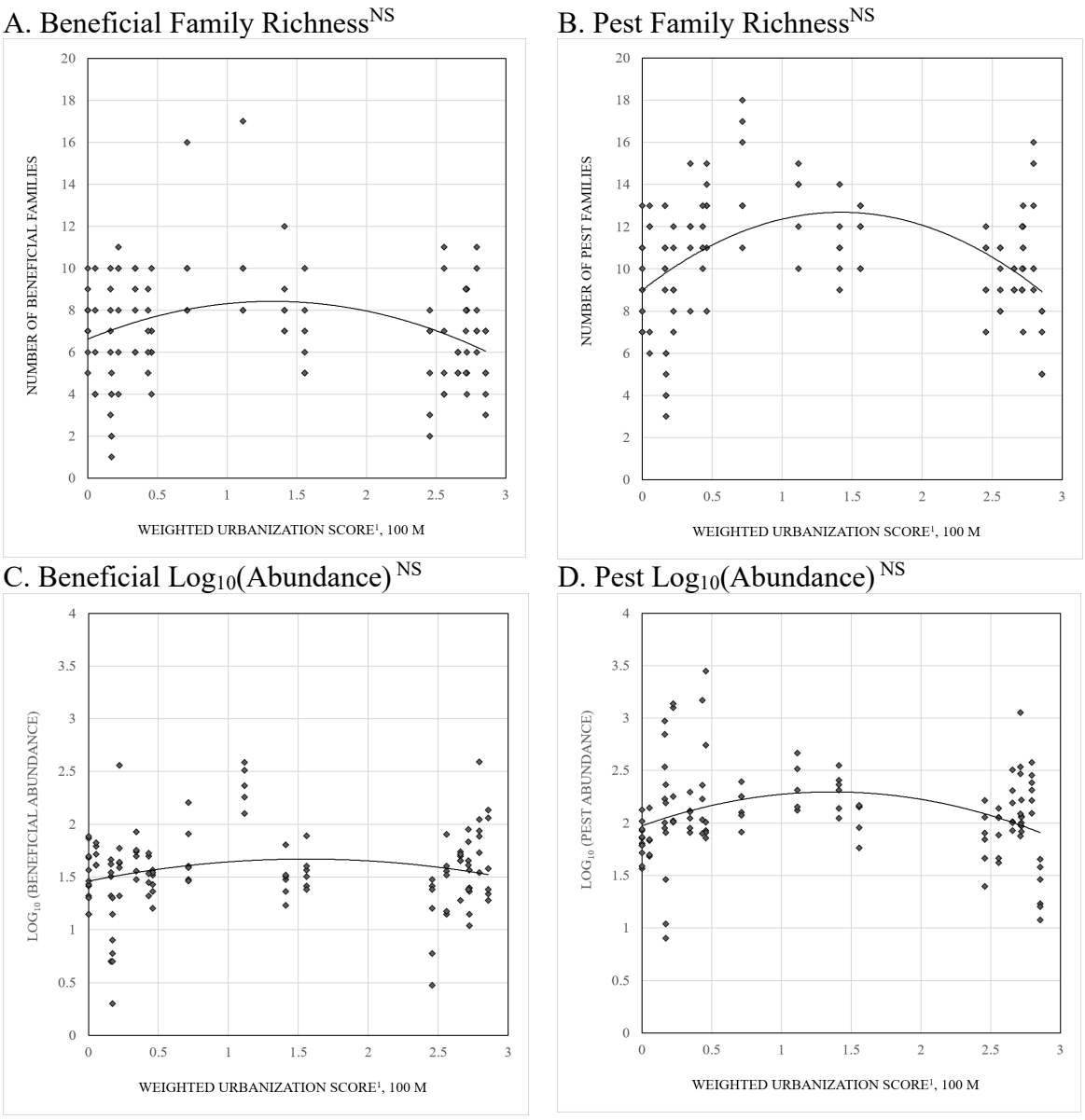


Figure 7. Relationship between the farm weighted urbanization score (100 m radius) and insect community metrics across functional categories.

(A) beneficial family richness, (B) pest family richness, (C) beneficial $\log_{10}$(abundance), and (D) pest $\log_{10}$(abundance).

Farms of varying levels of urbanization following organic practices in the Kansas City region were sampled for insect family diversity and abundance on tomato and pepper crops.

Diamond points represent data for each plant and site visit (N = 117).

NS = not significant

[1]Based on the National Land Cover Database (NLCD) categories; Weighted urbanization score = (% high intensity development × 4) + (% medium intensity development × 3) + (% low intensity development × 2) + (% developed open space × 1)]

A. Beneficial-to-Pest Family Richness[NS] B. Beneficial-to-Pest Log_{10}(Abundance)[NS]

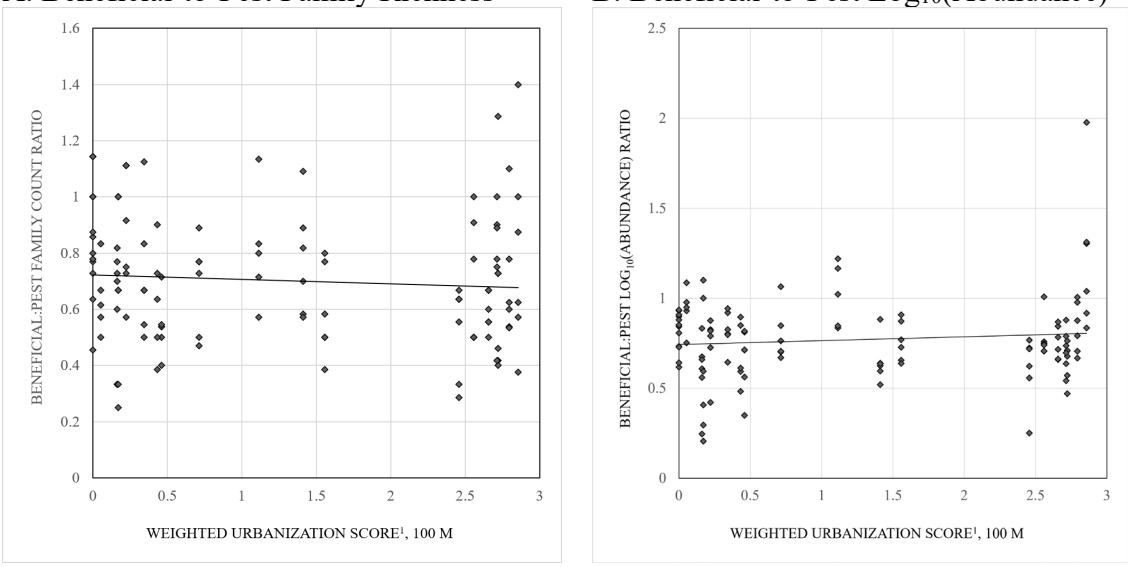


Figure 8. Relationship between farm weighted urbanization score (100 m radius) for (A) ratio of beneficial-to-pest insect families identified and (B) ratio of beneficial-to-pest log_{10}(abundance).

Farms of varying levels of urbanization following organic practices in the Kansas City region were sampled for insect family diversity and abundance on tomato and pepper crops.

Diamond points represent data for each plant and site visit (N = 117).

NS = not significant

[1]Based on the National Land Cover Database (NLCD) categories; Weighted urbanization score = (% high intensity development × 4) + (% medium intensity development × 3) + (% low intensity development × 2) + (% developed open space × 1)]

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