TITLE: **An Insect Community Study of the Morris Arboretum Green Roof**

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ABSTRACT:

Green roofs are becoming increasingly popular in cities around the globe because of their numerous benefits to humans. Green roofs can also benefit wildlife, particularly insects, through the creation of habitat. The goal of this study was to evaluate the biodiversity of the insect community on the Morris Arboretum intensive green roof and to identify management strategies to promote more diversity. We vacuum sampled the green roof three times in August and September 2017. Insects in the orders Lepidoptera, Coleoptera, Hemiptera, Hymenoptera, Neuroptera, and Mantodea were sorted, preserved, and identified to the lowest possible taxonomic rank. Overall, 891 insects were collected and identified. Two groups, ants and aphids, accounted for 566 of those insects. There was low diversity and abundance of Coleoptera and Lepidoptera, which could be attributed to the lack of fall-flowering plants, larval host plants, and overwintering sites. Additionally, there was low diversity of pollinator species, which may also be attributed to the lack of fall-flowering plants. In order to promote these groups, I suggest adding plants that provide high-quality pollen and nectar resources in the late summer and fall, as well as adding woody debris to provide habitat and overwintering sites. I also suggest maintaining open areas to provide habitat for ground-nesting insects. If these management suggestions are implemented, the increased diversity of habitat and resources will foster more diversity in the insect community.

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INTRODUCTION

As urbanization rates increase to accommodate the growing human population, green roofs are becoming more popular in cities across the globe because of their benefits to humans and wildlife. In addition to adding aesthetic value to urban areas, green roofs can extend the life of roof membranes, reduce stormwater runoff, reduce energy costs through more efficient insulation, improve air quality, and reduce the urban heat island effect (Getter and Rowe 2006). While these are often the primary justification for green roof installation, the creation of wildlife habitat is an important additional benefit. Urbanization and habitat loss are among the most serious threats to wildlife, and although the evidence of green roofs playing a major role in biodiversity conservation is still unclear, they can certainly act as refugia for wildlife populations in highly urbanized areas (Williams et al. 2014). Insects are likely to reap the greatest reward from the green roof movement considering their small size, relatively low resource consumption, and high mobility. With this in mind, motivated organizations can manage their green roofs for maximum wildlife value, especially relating to insects and other arthropods. Horticulturists at the Morris Arboretum are very interested in achieving this goal. In this study, our objective was to evaluate the insect community supported by the Morris Arboretum intensive green roof in order to establish baseline values and make management suggestions to improve the diversity of the insect community.

MATERIALS AND METHODS

Study Site

The Morris Arboretum intensive green roof was installed in 2010 in concurrence with the construction of the Horticulture Center on Bloomfield Farm. The green roof sits on top of a 6-bay, non-insulated equipment garage and measures 3,750 ft^2 with a 2/12 roof pitch. The site was originally planted in spring 2010, and plants have been continuously added as original plants die or are removed. As of August 2017, there were 141 taxa representing 71 genera and 30 families. Of those taxa, 66 are native to the United States and represent 58 unique species. Thirty taxa are native to Pennsylvania and represent 24 unique species.

Sampling

Arthropod samples were collected on August 9, August 23, and September 8 in 2017. Collections were conducted at least two weeks apart to maximize sampling without exhausting insect populations or double-sampling within a plant’s flowering window. Using a reversed leaf blower fitted with a paint strainer bag at the end of the vacuum tube, 90-100% of individual plants were vacuumed during each collection. Samples were placed in the freezer until sorting. Arthropods in each sample were separated, preserved, and sorted to taxonomic order. Insects in Lepidoptera (butterflies and moths), Coleoptera (beetles), Hymenoptera (bees, wasps, and ants), Hemiptera (true bugs), Neuroptera (lacewings), and Mantodea (mantids) were sorted to the lowest taxonomic rank possible. Insects were also identified by adult feeding guild. These groups were chosen based on diversity, importance to ecosystems, and ease of identification.

RESULTS

A total of 891 insects were collected in orders Lepidoptera, Coleoptera, Hymenoptera, Hemiptera, Neuroptera, and Mantodea (Table 1). Of the insects for which adult feeding guilds were determined, 44.2% were sap suckers, 12.8% were parasitoids, 3.6% were pollinators, 1.8% were leaf chewers, 1.5% were nectar feeders, 1% were predators, and <1% were flowers chewers (Figure 1).

Table 1. Total individuals collected by taxonomic order.

Order	August 9	August 23	September 8	Total
Hymenoptera	294	85	70	449
Hemiptera	309	38	49	396
Coleoptera	18	4	6	28
Lepidoptera	6	4	2	12
Neuroptera	3	1	0	4
Mantodea	1	0	1	2
Total	631	132	128	891

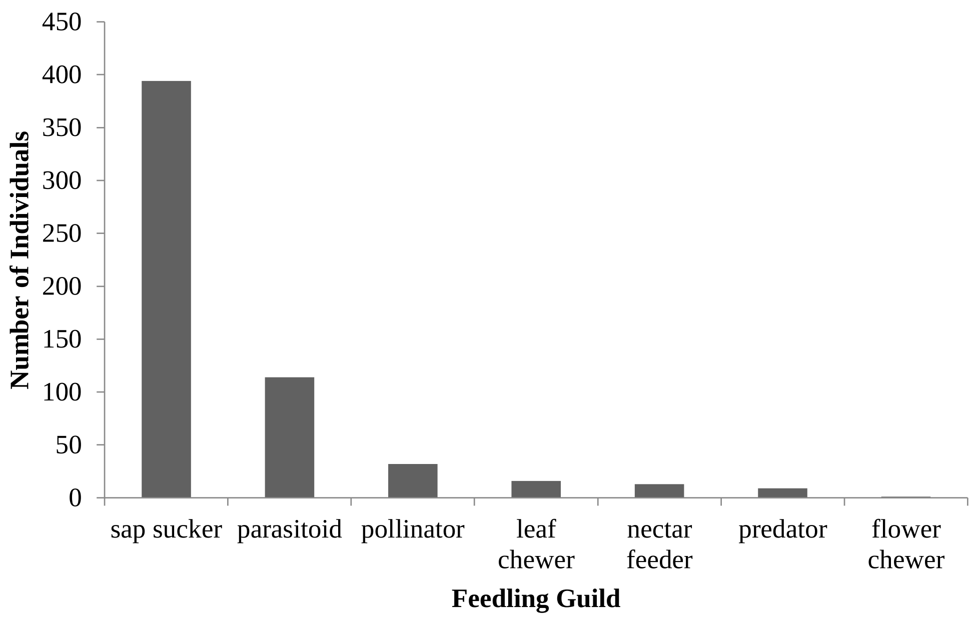

Figure 1. Number of individuals by adult feeding guild.

Hymenoptera was the most abundant order with 449 individuals representing 8 different families. The most abundant Hymenopteran family was Formicidae (ants), which consisted of 302 individuals (Appendix 1). Parasitica was the second most abundant group with 106 individuals. Parasitica is a non-taxonomic group composed of multiple families of parasitoid wasps, but these individuals were not identified to family due to their very small size and difficulty to key. Halictidae (sweat bees) was the third most abundant order with 29 individuals. All other families had fewer than 10 individuals. Overall, 21 individuals in Hymenoptera were identified only to genus and another 10 individuals were identified to species. I identified one sand wasp (*Hoplisoides* sp.), which is a solitary wasp that nests in sandy soils. While *Hoplisoides* adults feed only on nectar, they capture and paralyze prey in the suborder Homoptera to take to their burrows for their larvae to consume upon hatching (Bohart and Menke 1976). I also identified 20 sweat bees in the genus *Lasioglossum*. Most bees in this genus are generalist pollinators, though some can be oligolectic, meaning that they collect pollen from a limited selection of plants. There were three common eastern bumble bees (*Bombus impatiens*), which are generalist pollinators. In contrast to most bumble bee populations, common eastern bumble bees are experiencing steady or increasing population growth in most of the U.S. (Hatfield et al. 2014). I also identified seven confusing metallic furrowing bees (*Halictus confusus*). These sweat bees are generalist pollinators and are among the most common bees in North America. They nest in sandy soils and can be variably social depending on location and population (Richards et al. 2010). Overall, 25% of Hymenopteran individuals were parasitoids and 7% were pollinators.

Hemiptera was the second most abundant order with 396 individuals representing 12 different families. The most abundant Hemipteran family was Aphididae (aphids) with 264 individuals, followed by Cicadellidae (leafhoppers) with 50 individuals and Tingidae (lacebugs) with 35 individuals (Appendix 1). Overall, 68 individuals were identified to genus and 6 individuals were identified to species. I identified one stilt bug (*Jalysus* sp.), which is a predator of Lepidoptera eggs and can be an effective biological control agent against pest caterpillar species (Kester and Jackson 1996). There were 26 individuals in *Oecleus*, a genus of phytophagous planthoppers with host plants ranging from grasses to asters to yuccas, all of which are present on the green roof (Kramer 1977). I identified 35 lace bugs in the genus *Corythucha*, which consists of numerous species of phytophagous insects, many of which feed on woody plants. Further identification, though difficult, could lead to knowledge of specific host plant associations (Guidoti et al. 2015). There was one cixiid planthopper in the genus *Haplaxius*. These phytophagous insects have specific host plants, some of which are present on the green roof, such as yuccas, agaves, and grasses (Wilson 1994). There was also one derbid in the genus *Anotia*. These planthoppers feed on fungal hyphae as nymphs and are thought to feed on woody plants as adults, though information about host plants is limited (Wilson 1994). One big-eyed bug (*Geocoris* sp.) was identified, which is a tiny but important predator that prefers small, soft-bodied prey, such as thrips and mites. Of the four stink bugs identified, one was in the genus *Euschistus*, a group of generalist phytophagous stink bugs often called the "brown stink bug complex" (Esquivel et al. 2009). There were also two generalist phytophagous *Thyanta* stink bugs and one rice stink bug (*Oebalus pugnax*), which, despite its common name, also feeds on seed heads of wild grasses, such as crabgrass and barnyard grass (Awuni 2013). In Cicadellidae, there were two *Memnonia flavida*, which specialize on native grasses, such as *Andropogon* and *Bouteloua curtipendula*, both of which are present on the green roof or in the surrounding landscape (Paiero et al. 2010). I identified three long-necked seed bugs (*Myodocha serripes*). Although records indicate these insects feed on *Fragaria* and *Hypericum* seeds, which are not present on the green roof, there is a reliable record that demonstrates an association with *Euphorbia maculata*, which is one of the most prevalent weed species (Wheeler 1981). Overall, 99.5% of the Hemipterans collected were sap suckers.

Coleoptera was the third most abundant order with 28 individuals representing four families. The most abundant Coleopteran family was Chrysomelidae (leaf beetles) with 16 individuals. Each of the other families only had one individual (Appendix 1). Of the leaf beetles, 15 were in the genus *Glyptina*, which consists of leaf chewing species that usually specialize on Euphorbiaceae (Arnett et al. 2002). This may imply that these beetles associate with *Euphorbia maculata*, the only known member of Euphorbiaceae on the green roof. There was also one *Longitarsus* flea beetle. Species in this genus often specialize on a single family of plants, such as Asteraceae or Lamiaceae, both of which are well-represented in the green roof plant community (Kelley and Dobler 2011). There was also one dusky lady beetle (tribe Scymini), which feeds on small arthropods, such as mites and aphids, and one minute seed weevil (subfamily Ceutorhynchinae), which, if identified to species, may lead to knowledge of specific host plant associations. Overall, 84.2% of the Coleopterans collected were leaf chewers in their adult stages.

Lepidoptera was the fourth most abundant order with 12 individuals. However, due to the difficult nature of identifying caterpillars and micro-moths, only one individual could be identified further. This individual was an adult red-banded hairstreak (*Calycopis cercrops*) of the family Lycaenidae, which relies on nectar as an adult and feeds on dead leaves and detritus as a caterpillar (Opler and Malikul 1998).

Neuroptera was the fifth most abundant order with four individuals representing two families, Chrysopidae (green lacewings) and Hemerobiidae (brown lacewings; Appendix 1). None of these individuals were identified further than family. Most members of these two families are predators as adults and larvae.

Mantodea was the least abundant order with two individuals representing one family, Mantidae. I identified one Chinese mantis (*Tenodera sinensis*) and one European mantis (*Mantis religiosa*), both of which are non-native generalist predators.

DISCUSSION

Community Assessment

Overall, the insect community on the Morris Arboretum intensive green roof is fairly abundant and diverse. However, there are groups that are severely lacking in species richness and abundance. There is a notable lack of abundance and diversity of beetles. Beetles are the most diverse group of insects with more than 25,000 species from 130 families recorded in North America alone. They also represent a wide variety of feeding guilds, including leaf chewers, pollen feeders, decomposers, and predators. However, I only identified 19 individuals representing four families and three feeding guilds. One possible explanation for this lack of diversity is the absence of overwintering sites on the green roof. Many beetles rely on woody debris and leaf litter to provide shelter and warmth during the cold winter months. The green roof has only three deciduous woody plant species and one piece of dry woody debris. Another possible explanation is the lack of pollen and nectar resources during the sampling period. Of the 141 plant taxa on the green roof, very few flower in the late summer and early fall. Sampling for this study concurred with the flowering of *Achillea millifolium*, *Bigelowia nuttallii*, and *Allium cernuum*. Many beetle species rely on pollen and nectar as secondary sources of nutrients, especially later in the season, so the lack of resources during this time severely impacts the ability of the green roof to support these species.

There was also a distinct lack of diversity and abundance of butterflies, moths, and caterpillars. We found one butterfly, six micro-moths, and five larvae. One potential explanation is the low richness and abundance of larval host plants. Many caterpillars specialized on certain groups of plants so if those plants are absent, then the caterpillars and butterflies will be absent. Of the 141 plant taxa, 12 are known to support Pennsylvania butterfly species. However, even though those species are present, they may not be present in high enough numbers to support caterpillars. For instance, our green roof has butterfly weed (*Asclepias tuberosa*) but there are relatively few stems, which may not provide enough foliage for a caterpillar to successfully metamorphose. Another possible reason for the lack of butterflies is the lack of nectar resources. As mentioned previously, very few plant species were flowering during the sampling period, and considering that butterflies can only get nectar from certain types of flowers, there was likely a distinct lack of suitable nectar plants for adult butterflies and day-flying moths. Lastly, our sampling may have occurred too late to accurately sample most of the Lepidopteran community. By late August, most caterpillars have already metamorphosed to their adult stages, which are highly mobile and can travel miles in search of nectar resources.

Lastly, there were relatively few pollinators, with 32 individuals representing only three taxa, which is almost certainly due to the lack of late-season flowers on the green roof. Considering the strong economic and ecological concerns regarding pollinator populations, the promotion of this group on the green roof should be a priority in the future.

Management Suggestions

In order to improve the diversity of the insect community on the green roof, I propose six management solutions. A complete plant suggestion list can be found in Table 2.

1. Increase the number and diversity of late-season pollen resources

Using late-flowering plants with high-quality pollen, such as gray goldenrod (*Solidgao nemoralis*), will attract and sustain more beetle, bee, and wasp species. A diverse selection of plants that produce flowers with a variety of colors, shapes, sizes, and heights will attract the most diverse assemblage of insect species.

2. Increase the number and diversity of late-season nectar resources

Some flowers, like those of meadow blazing star (*Liatris ligulistylis*), are particularly attractive to butterflies. By planting a variety of high-quality nectar resources, the green roof will attract many more Lepidoptera and may even become an important stopover for migrating butterfly species, such as monarchs.

3. Increase the abundance of larval host plants already present

Some plants already present on the green roof are host plants for caterpillars. For instance, butterfly weed (*Asclepias tuberosa*) can support monarch caterpillars and moon carrot (*Seseli gummiferm*) can support black swallowtail caterpillars. However, by increasing the abundance of these species, we can increase the capacity of the green roof to support these caterpillar populations.

4. Add more species of larval host plants

By adding new larval host plants that support different caterpillar species, we can increase the diversity of the butterfly community. If we plant enough prairie violets (*Viola pedatifida*), we may be able to support variegated fritillary caterpillars. Similarly, if we plant enough New Jersey tea (*Ceonothus americanus*), we may be able to support robust populations of spring and summer azure caterpillars.

5. Increase the presence of woody plants and debris

Adding to the deciduous woody plant community will provide more shelter for insects, more woody stems for laying eggs, and more leaves to promote a significant leaf litter layer. Additionally, partially buried logs or tree cookies could add habitat for decay-dependent insects and overwintering sites for many other insects. The leaves and woody debris will also add nutrients to the soil medium over the years.

6. Maintain areas of exposed soil medium

By maintaining open areas where the soil medium is accessible and undisturbed (i.e. far from the main access path), we can promote ground-nesting bees and other ground-nesting insects. Nearly 70% of all bee species are ground-nesters and many prefer loose, sandy soils, for which green roof medium is a suitable substitute.

Target Species

Based on personal observation of insects present in the surrounding area, there are a few target species we might expect if the above management suggestions are implemented. Cicada killer wasps (*Sphecius speciosus*) are members of the family Crabronidae. These large, solitary wasps create burrows in sandy soils and specialize on cicadas. Females paralyze cicadas and bring them to their burrow for their young to consume when they hatch. Cicadas are likely abundant in the areas surrounding the green roof due to the prevalence of canopy trees, and if open spaces are maintained on the green roof, female cicada killer wasps may create burrows in the soil. Adults can also be attracted with the addition of nectar-producing plants. Another target species is the monarch butterfly (*Danaus plexippus*). If enough butterfly weed (*Asclepias tuberosa*) is planted, the green roof should be able to support multiple caterpillars. Additionally, more fall-flowering plants will attract adult monarchs and provide essential sustenance as they begin their migration south. A final target species is Pennsylvania leatherwing (*Chauliognathus pensylvanicus*), a member of the beetle family Cantharidae. As larvae, these beetles are predators that feed on small insects, such as aphids, which are plentiful on the green roof. Adults feed on nectar and pollen and are prevalent in the fall. Therefore, more fall-flowering plants would be beneficial in attracting this species. Repetition of this study in a few years, or careful observation, can confirm the presence of these species in the future.

Limitations

An important limitation with regards to applying these results to other green roofs is the unique situation of the Morris Arboretum green roof. Most green roofs are surrounded by highly urban landscapes with relatively low vegetative cover. If there is significant vegetation nearby, it is likely non-native, stressed, or both. At the Morris Arboretum, the green roof is surrounded on all sides by significant vegetation, including mature native trees and multiple acres of managed meadow habitat. In this situation, the green roof may act as supplementary habitat, rather than primary habitat for mobile insects, which is not likely the case for green roofs in highly urbanized areas.

An additional limitation is that the results of this study do not give a complete picture of the insect community. Firstly, the methodology used (i.e. vacuum sampling) is a general sampling technique. It gives a broad rather than deep view of the insect community. To obtain a deeper view would require multiple sampling methods that target specific types of insects.

However, to conduct these surveys would have been outside the scope of this study. Moreover, the sampling window for this study was quite narrow. In general, insects are most active between April and October, but different species are active at different times. We only sampled within a 1½ month period in late summer, so there are many species that were not active during our sampling period. However, when we view our results in the context of seasonality, we can still make the conclusion that the insect community lacks diversity and our management suggestions are still valid.

Table 2. Green roof planting suggestions and justification.

Species Name	**Common Name**	**Type**	**Bloom Period**	**Justification**
Amorpha canescens	lead plant	deciduous shrub	Jul–Sept	Attracts pollinators, provides woody substrate and debris
Asclepias tuberosa	butterfly weed	herbaceous perennial	Jun–Aug	Increase present population, attracts pollinators, attracts butterflies, host plant for monarch caterpillar
Ceanothus americanus	New Jersey tea	deciduous shrub	May–July	Attracts pollinators, attracts beneficial insects, provides woody substrate and debris, host plant for spring azure and summer azure caterpillars
Chamaecrista fasciculata	partridge pea	annual	Jun–Sept	Late-season bloomer, attracts pollinators, attracts beneficial insects
Liatris ligulistylis	meadow blazing star	herbaceous perennial	Jul–Sept	Late-season bloomer, attracts pollinators, butterfly nectar plant
Salvia azurea var. grandiflora	pitcher sage	herbaceous perennial	Jul–Oct	Late-season bloomer, attracts pollinators, attracts butterflies, competes well with grass
Seseli gummiferum	moon carrot	biennial	Jun–Sept	Late-season bloomer, attracts beneficial insects, host plant for black swallowtail caterpillar
Solidago nemoralis	gray goldenrod	herbaceous perennial	Aug–Sept	Late-season bloomer, attracts pollinators, attracts beneficial insects
Viola pedatifida	prairie violet	herbaceous perennial	Apr–Jun	Host plant for great spangled fritillary and variegated fritillary caterpillars

Appendix 1. Total individuals by taxonomic family.

Taxonomic Order	**Taxonomic Family**	**Total Individuals**
Hymenoptera	Formicidae – ants	302
	Parasitica – parasitoid wasps	106
	Halictidae – sweat bees	29
	Ichneumonidae – ichneumon wasps	7
	Apidae – honey and bumble bees	3
	Chalcididae – chalcid wasps	1
	Crabronidae – crabronid wasps	1
Hemiptera	Aphididae – aphids	264
	Cicadellidae – leaf hoppers	50
	Tingidae – lace bugs	35
	Cixiidae – cixiid planthoppers	27
	Delphacidae – delphacid planthoppers	5
	Pentatomidae – stinkbugs	4
	Aphrophoridae – spittlebugs	3
	Rhyparochromidae – dirt-colored seed bugs	3
	Miridae – plant bugs	2
	Berytidae – stilt bugs	1
	Derbidae – derbid planthoppers	1
	Geocoridae – big-eyed bugs	1
Coleoptera	Chrysomelidae – leaf beetles	16
	Coccinellidae – lady beetles	1
	Curculionidae – snout weevils	1
	Mordellidae – tumbling flower beetles	1
Lepidoptera	Lycaenidae – gossamer-winged butterflies	1
Mantodea	Mantidae – mantids	2
Neuroptera	Chrysopidae – green lacewings	2

Hemerobiidae – brown lacewings	1
Unknown	21

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