ABSTRACT

Title of Thesis: GREEN FAÇADES PROVIDE HABITAT FOR ARTHROPODS ON BUILDINGS IN THE WASHINGTON, D.C. METRO AREA

Serena Matt, Master of Science, 2012

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Green façades are a relatively new green building technology particularly relevant in urban areas where ground-level space is limited and vegetation is scarce. Increased wildlife habitat is often proposed as a benefit of the technology, but little experimental data exists supporting this claim. An observational field study tested whether green façades had a higher abundance or diversity of arthropods than non-vegetated building façades, and whether abundance and diversity values could be explained by specific vegetation characteristics. Green walls contained 16 to 39 times more arthropods per meter squared than adjacent blank walls. Measures of arthropod richness, Shannon-Wiener diversity, and order-area curve slopes were significantly higher on green walls than on blank walls. Arthropod abundance and richness were most strongly correlated with habitat availability and vine canopy thickness. Herbivores, predators, parasitoids, and detritivores were found on the green façades. Results indicate that green facades increase ecological habitat in urban environments.

GREEN FAÇADES PROVIDE HABITAT FOR ARTHROPODS ON BUILDINGS IN THE WASHINGTON, D.C. METRO AREA

by

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Associate Professor David Tilley, Chair
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Dedication

I would like to dedicate this thesis to assiduous graduate students everywhere.

Acknowledgements

Thanks to my committee members who were an exceptional group of professors- my advisor Dr. David Tilley for his guidance, support, and teaching style, Dr. Paula Shrewsbury for her positive encouragement, expertise, and logistical assistance, and Dr. Patrick Kangas for his enthusiasm and excellent ecological advice and ideas. Dr. Paul Leisnham was also very generous with his lab equipment.

Thanks to my colleagues Brandon Winfrey, Amy Hudson, Elliot Campbell, Casie Smith, and Brandon Scott for their invaluable advice and assistance in the field and in the lab.

Lastly, this project could not have happened without the cooperation of the folks at the following places: the Eastern Village Cohousing apartments in Takoma Park, MD, the Avalon apartments in Rockville, MD, the National Wildlife Federation headquarters in Reston, VA, Twinbrook Parkway in Rockville, MD, the RTKL office building in Washinton, D.C., the Finnish Embassy in Washington, D.C., Montgomery College in Takoma Park, MD, the Alaire apartments in Rockville, MD, and the Three Tree Flat apartments in Washington, D.C.

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CHAPTER 1: INTRODUCTION

Urban areas are expanding worldwide. From 1950-2011, urban populations have risen from 30 to 50% of the total world population. In the United States, 80% of the population resides in urban areas. (United Nations 2012). This percentage is projected to grow in the future, along with the associated impacts on the environment and human health.

Urbanization has resulted in habitat and ecosystem destruction, alteration, fragmentation, and isolation (Adams et al. 2005), and is second only to invasive species as the most frequently cited cause of species endangerment in the United States (Czech and Krausman 1997). The high human population density, high rate of material consumption and waste production associated with urban systems has impaired air, water, and soil quality both within and around cities (Adams et al. 2005). Increased hard-scape and limited vegetative coverage have influenced climate and the water balance, exemplified by phenomena such as the urban heat island effect, flash flooding, limited groundwater recharge, and limited evapotranspiration. Re-integrating vegetation into urban areas can help alleviate these problematic environmental responses. Green walls are one of many ways that cities can support plant growth. In addition, they have the advantage of providing large surface areas while using little space at ground level. This technology is particularly relevant for cities where development is dense and space is limited. Furthermore, if green walls create wildlife habitat, they can increase urban biodiversity, thus improving ecosystem health (Alberti, 2005) and providing urban dwellers with essential ecosystem services. Thus green wall research should be considered in the context of technologies used to improve the environmental quality of urban areas.

Terms

A green wall is a generic term used to refer to any vertical structure sustaining vegetation, such as a building façade or a free standing wall. A green or greened façade, as defined by industry standards, is a system for supporting woody or herbaceous climbers and vines which are typically planted in the ground or in planter boxes. The support system can be attached to a building façade or be free standing (Price, 2010). While green façades are the subjects of our actual study, we occasionally refer to green walls in their generic sense.

History

Green walls have only recently been incorporated into the American green building industry, though the practice of growing vines for shade, fruit, or for ornament is not a modern invention. As a new green building technology, green walls had their origin in Berlin in the late 1970's (Köhler 2008). Much of the scientific research examining their proposed benefits remains un-translated from the German language (Dunnett and Kingsbury 2008).

According to Peck et al. (1999) green walls can lower ambient air temperatures around buildings, reducing both the urban heat island effect and energy consumption, they can reduce storm water runoff thereby improving water quality, reduce noise, collect pollution from the air, provide wildlife habitat, lengthen the life of the building façade, provide insulation against wind, provide food, provide both recreational and employment opportunities, and improve aesthetics of stark urban landscapes. Scientific examinations of these proposed benefits have only just begun in the United States.

Many studies have examined these benefits as they relate to urban vegetation, including vines (see Table 1), but few have examined actual green façades. Of those green façade studies available in English, the majority either provide general overviews of the technology (Köhler 2008, Dunnett and Kingsbury 2008, Peck et al. 1999), often with reference to un-translated studies (Brandwein and Köhler 1993, Köhler and Schmidt 1997, Schröder 2003), or focus on modeling or measuring the cooling potential of the walls (Price 2010, Alexandri and Jones 2008).

Table 1. Articles demonstrating the benefits of incorporating vegetation into urban areas.

Topic	Related Publications
Cooling and energy savings of buildings	Abbott and Meentemeyer (2005), Ca et al. (1998), Dimoudi and Nikolopoulou (2003), Givoni (1991), Hoyano (1998), Stect et al. (2005)
Air filtration and air quality	Akbari (2001), Currie and Bass (2008), Ottelé (2010)
Noise insulation	Pal et al. (2000)
Health and Recreation	Fjeld et al. (1998), Fuller (2007), Miller (2005), Ulrich (1999)

Habitat studies

There are many studies on the ecology of free standing masonry walls supporting wild vegetation in urban areas. In an extensive literature review of such studies, Francis (2010) concludes that most studies examined plant succession and composition, though some also surveyed the walls for animals (Darlington, 1981). Moisture and exposure dictate the gradual colonization of free standing masonry walls by moss and lichen.

Substrate development and the subsequent growth of higher plants are much slower and the walls thus likely support less plant diversity than purposefully planted systems like green façades.

Other than these studies on naturally colonized free standing walls, to the author's knowledge Köhler (1998) has published the only green wall habitat study to date. Köhler examined arthropods inhabiting green walls on 9 buildings in suburban and urban neighborhoods in Germany using sweep netting and pitfall traps. Besides location, duration, and sampling method, the most notable difference between our studies was the manner by which the buildings supported vegetation. In the German study, vines grew directly on building façades, while in this study, vines grew on trellises fastened to, but separated from building façades. Trellis structures support a greater variety of vines because they accommodate more methods of attachment than the masonry of building façades. In fact, only two species of vines were sampled in Köhler's study (*Parthenocissus tricuspidata* and *Hedera helix*) compared to the 13 vine species in this study (Table 5 in Results).

While there appears to be little research on habitat provided by green walls, European, Canadian, and American studies have established that green roofs offer the potential for significant contributions to biodiversity (Lundholm and MacIvor 2010, Baumann 2006, Coffman and Davis 2005, Kadas 2006, Brenneisen 2006). Where once green roofs were installed primarily for insulation, water retention and recreation, designers can now use information from these studies to tailor green roofs for wildlife. Having similar information about green walls could prove useful during design and plant species selection.

Green roofs have been shown to attract and sustain rare and threatened species. A study conducted on installations in London concluded that 10% of invertebrate species found on green roofs were species designated as nationally scarce (Kadas 2006). Another survey found, in only the first year of a three year study, a total of 78 spider and 254 beetle species. Eighteen percent (18%) of the spider species were classified as "faunistically interesting" while 11% of the beetle species were listed in the International Union for Conservation of Nature (IUCN) Red List of threatened species. The study also showed that birds such as black redstarts were using roofs as alternative habitat to brownfields eliminated by redevelopment, while in Switzerland, northern lapwings and little ringed plovers were observed using flat green roofs as breeding habitat (Baumann 2006). Lundholm and MacIvor (2010) compared the species richness, composition, and abundance of insect assemblages between five green roofs and five adjacent ground-level habitats. They determined that no significant difference existed between the two; a green roof could act as a continuation of existing habitat. Findings from these studies suggest that isolated, purposefully planted green space in urban areas can support a variety of organisms.

Green walls take advantage of vertical space and can, for certain building shapes, provide greater surface area for vegetation than green roofs. Additionally, green roofs provide challenging growing conditions for plants. Green roofs commonly have shallow substrates and are highly exposed to wind, high temperatures, and fluctuating moisture levels (Dunnett and Kingsbury 2008, Lundholm 2006) whereas green walls might offer more protective shelter for animals and provide more optimal growing conditions for plants.

Though green walls only minimally interrupt a landscape dominated by concrete, fragmented urban green spaces have been recognized for their ecological value (Dickman 1987, Adams et al. 2005). Vegetation is especially important in urban areas for supplying food, breeding habitat and shelter for wildlife (Smith et al. 2006). For example, urban parks and refuges offer stop over points for migrant birds as well as nesting habitats for many avian species (Hadidian et al. 1997). There is growing interest in evaluating small fragmented urban green spaces as sources of biodiversity in urban areas but relatively few studies on the topic (Matteson and Langellotto 2010). Studies have determined that small gardens house abundant animal species (Miotk 1996), and provide floral diversity and vegetative complexity which can sustain or increase both vertebrate and invertebrate abundance and diversity (Matteson and Langellotto 2010, Smith et al. 2005, Smith et al. 2006).

If fragments of green dispersed throughout the city are connected, they can create corridors for wildlife. Corridors allow protected movement, promote genetic diversity, and seed dispersal (Bolen and Robinson 2006). In addition to contributing an added layer of vegetative structure and complexity and providing food, green walls could act as another connector in a patchwork of green space.

Lastly, we should note that wildlife habitat does not inherently improve city life. Urban wildlife can damage infrastructure, disrupt businesses, act as disease vectors, and even as physical threats. Urban wildlife management is as much about encouraging desirable species as it is about controlling nuisances (Adams et al. 2005). This study does not propose that green walls will inherently enhance desirable species. Hornets, wasps, and bees are examples of some animals that were observed to inhabit green façades, and while providing essential services, these may prove troublesome for building residents and passing pedestrians.

Urban Arthropod Studies

In a literature review of urban arthropod studies McIntyre (2000) concludes that most focused on pest control and epidemiology. Little exists on the ecology and diversity of arthropods in urban environments and there is no consensus on how arthropod taxa respond to urbanization. In the past, general ecological studies on urban arthropods have examined semi-natural and manmade habitats like parks, brownfields, gardens, natural habitat fragments, residential and commercial lawns, roadsides, roundabouts, railways, golf courses, green roofs and green walls (Kutschbach-Brohl et al. 2010). According to McIntyre, arthropods make effective subjects for ecological studies. They respond quickly to changes in vegetation and soil due to short generation times and thus can be used as indicators of development or environmental disturbance; they are relatively easy to sample, and they play important sociological, agronomical, and economic roles in human-dominated landscapes. Furthermore, they play a vital role in all ecosystems and while to the general public, arthropods may not serve as charismatic representatives of the animal kingdom, they are an essential food resource and necessary for regulating plant community dynamics, processing detritus and cycling nutrients, controlling pests, and pollinating plants (Lundholm and MacIvor 2010).

Green Façade research at the University of Maryland

This project, conducted in the summer of 2011, evaluated the arthropod habitat provided by 10 green façades in the Washington, D.C. metropolitan area. The objectives of the study were to determine if green façades supported significant arthropod habitat by comparing arthropod abundance and diversity to adjacent bare walls, to measure plant species composition and growth characteristics, and to evaluate whether specific vegetation characteristics of the green façades, and of the surrounding area, correlated with arthropod abundance or diversity. We expected to find significantly more arthropod diversity and abundance on the green walls, since the vegetation provides more structural complexity, food, and shelter than the bare walls. We also expected that leaf area index would be the most strongly related to both arthropod abundance and diversity, as leaf biomass feeds primary consumers, the building blocks of the food web.

Though wildlife habitat is often listed as a proposed benefit of green façade installations, little quantitative evidence supports the claim. In addition to expanding green façade research to include this largely unexplored topic, information from our study contributes to the body of work examining the ecological value of small urban green spaces, and to the general ecology of urban arthropods.

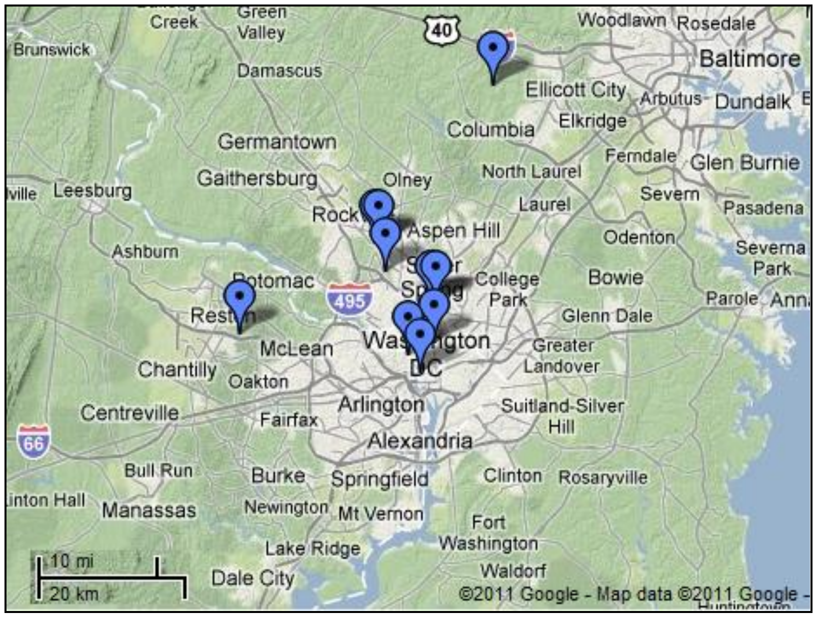
CHAPTER 2: METHODS

Site Selection

A list of 29 green façades in the D.C. Metro area was obtained from a sales representative from a trellis manufacturing company (Green-Screen Los Angeles, CA). Using the same trellis manufacturer provided some uniformity between sites. From this list, only systems that were planted, attached to buildings, and that we could gain permission to access, were included in the study. This resulted in the selection of 10 installations scattered throughout the Washington D.C. Metro area including suburban areas of Virginia and Maryland (Figure 1).

Except for the experimental green façade buildings in Clarksville, Maryland, installations were located on operating parking garages, office buildings, or apartment complexes. Each installation varied in the dimensions of its framing members, the arrangement and geometry of its panels, the number of panels, and the vine species planted, the orientation of the walls, the age of the system, and the degree of development and planted landscaping surrounding the installation. Despite this variety, all façades consisted of a series of steel mesh panels fastened to a steel frame, which were mounted to a building façade (Figure 2).

A control wall, a blank wall lacking a green façade, was selected at each site. With two exceptions, we selected blank walls that were from separate buildings, of similar orientation and building material, adjacent to similar landscaping, and were no less than 10 meters and no more than 60 meters away from any green façade installation (Figure 3).



Site Name	Site Number	Coordinates
Montgomery College parking garage	1	-77.0234, 38.98682
Eastern Village Cohousing	2	-77.0305, 38.98779
Three Tree Flat apartments	3	-77.0254, 38.93917
Finnish Embassy	4	-77.0652, 38.92437
National Wildlife Federation headquarters	5	-77.3313, 38.95173
Avalon apartments parking garage	6	-77.1027, 39.02617
Clarksville experimental buildings	7	-76.9305, 39.25445
RTKL D.C. offices	8	-77.0477, 38.90395
Twinbrook Parkway parking garage	9	-77.1144, 39.06418
Alaire apartments parking garage	10	-77.1189, 39.06316

Figure 1. Relative location (above) and exact coordinates (below) of the 10 green façades.

Figure 2. Installations varied in their configuration but all consisted of steel mesh panels fastened to steel frames, which were then mounted to a building façade. Some installations consisted of continuous panels (top images) while others consisted of panel broken up along the length of a building wall (bottom images).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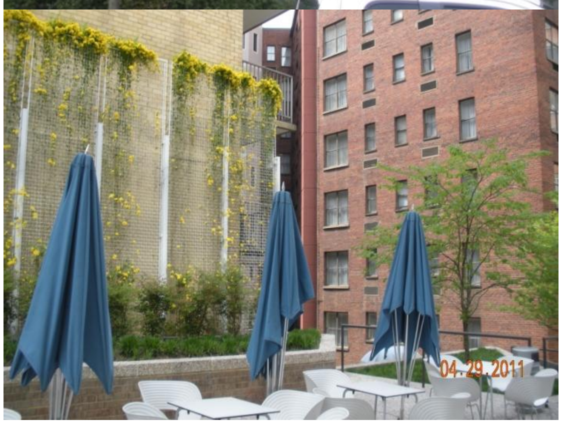
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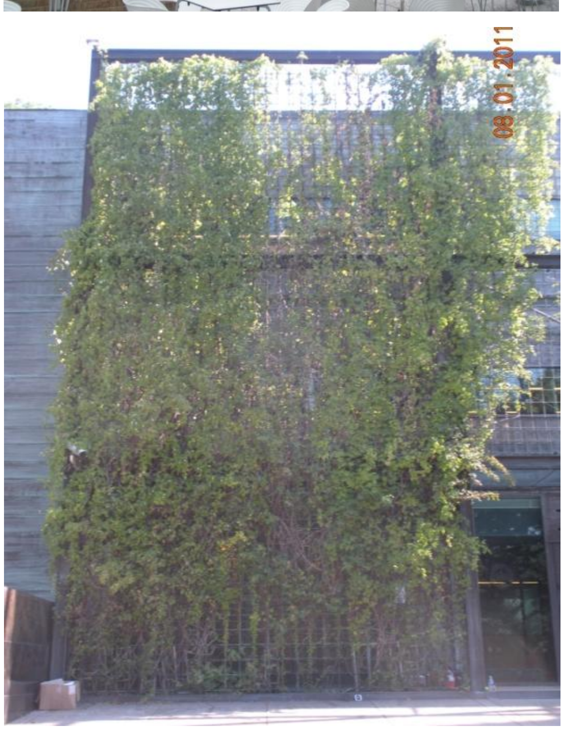
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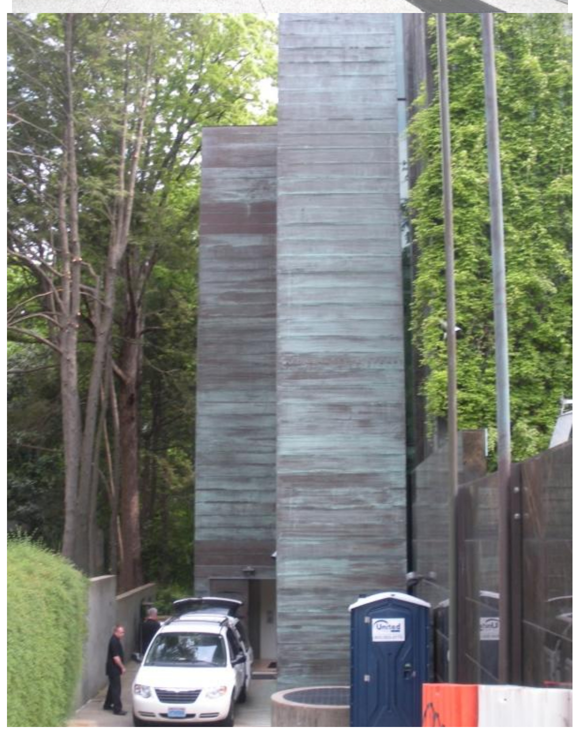


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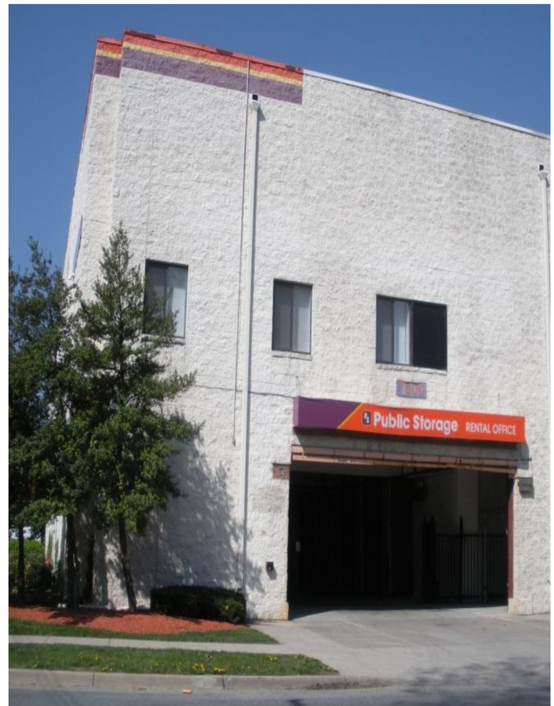
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Figure 3. Green façades(left) and their associated control walls (right), from top to bottom: Eastern Village Cohousing apartments Takoma Park, MD; Avalon apartments parking garage Rockville, MD; National Wildlife Federation headquarters Reston, VA; Twinbrook Parkway parking garage Rockville, MD; RTKL office building Washinton, D.C.; Finnish Embassy Washington, D.C.; Montgomery College parking garage Takoma Park, MD; Alaire apartments parking garage Rockville, MD; Three Tree Flat apartments Washington, D.C.; experimental green façade structures Clarksville, MD.

Experimental Design

This was a stratified observational study, mimicking the arrangement of a randomized complete block design. There was one treatment, that of façade greening, with two levels, the presence or absence of a green façade. The experimental unit was defined as a single building wall. Each site location acted as a block, and contained one replicate of each treatment level, one green wall and one blank wall. Blocking was used to help remove variations caused by site differences, which might otherwise have veiled the effects of the factor of interest. There were ten sites and thus 10 blocks and 10 replications.

The ten sites were randomly numbered and then randomly selected for visitation in June, July, and August. During each month, one site was visited each day, over the course of 10 days. If it rained, sampling did not occur and the site was re-visited at the end of the sampling period. We did not consider ten days a long enough period of time to significantly alter the arthropod populations inhabiting the different walls and assumed that one month would be enough time to allow arthropod recovery between sampling periods.

Arthropod Sampling

At approximately 11 am each day arthropods were sampled from 0.56 m^2 quadrats, which were located on the portion of the wall that, by visual estimation, had the most vegetative coverage (Figure 4). Additionally, only the portions of the wall which were safely reachable with a 6-foot (1.8 m) step ladder were sampled. Each green façade was sampled using ten quadrats, or subsamples, while each control wall was sampled using three, resulting in unequal sub-sampling. Equal sub-sampling would have been preferable but we were limited to these numbers by the expense of sampling equipment. The order in which green walls or blank walls were sampled was randomized each day.

Figure 4. A typical quadrat sampling maximum vegetative coverage of the green façade (left). Quadrat positions were marked with tape so that the same areas could be re-sampled in subsequent sampling visits (right).

To conduct a comprehensive study of invertebrates, many sampling methods must be employed to account for their diversity of habitats, sizes, and diel activities (Murkin et al. 1994). Most green roof habitat studies used some combination of pan traps, pitfall traps, and sweep netting to sample insects (Lundholm and MacIvor 2010, Colla et al. 2009, Coffman and Davis 2005, Kadas 2006). A conservative budget and limited assistance on the project left insufficient resources for multiple sampling techniques. Vacuum sampling is considered an effective method for determining complete inventories of a given area, although vacuums vary in efficiency for certain species (Biologic Survey of Canada 1994). A gasoline-powered, 2-cycle leaf blower, run in vacuum mode, was used to suction arthropods from within a given quadrat into small bags labeled by date, site, treatment, and subsample number. These bags were placed in kill jars containing ethyl acetate and later refrigerated. Each quadrat was vacuumed for 2.5 minutes. This value balanced efficiency estimates proposed by Brook et al. (2008) with the sampler's physical ability to operate the vacuum. The nozzle of the vacuum was moved slowly across the quadrat and periodically pressed in to the vegetation (Figure 5).

Figure 5. The quadrat was temporarily placed on the wall to define the area of sampling, and then the defined area was vacuumed.

Arthropod Identification

Arthropods were sorted from debris, counted and identified to order using the taxonomic keys of Triplehorn and Johnson (2005). The exceptions to this were Diplopoda, which were identified beyond the class level. Individuals were sorted into morphologic reference specimens, photographed, and stored in ethyl alcohol to allow for potential finer identification at a later date (Figure 6).

Figure 6. Example photographs of reference specimens: a weevil beetle from the Coleoptera order (left) and an orb weaver spider from the Araneae order (right).

Indices

Abundances and order identifications were used to calculate order richness (S) and density, the Shannon-Weiner Diversity Index (H') (Magurran 1988), and the z parameter of species-area curves which, according to Désilets and Houle (2005), can be used as 'spatial' measure of diversity. Richness requires minimal data manipulation and both richness and Shannon-Weiner are commonly used, facilitating comparison with other studies. Species-area curves originated in island biogeography theory but, as noted by McIntyre (2000), can also be applied to fragmented or isolated "islands" of green space in urban areas. The curves describe the rate at which new species are discovered in areas of increasing size. When an area is first sampled, the number of new species found increases rapidly. As more of that area is sampled, the number slows until, theoretically, an asymptote is reached in which a complete inventory of all species has been obtained. Among many applications, species-area curves are used in the design of conservation areas and the determination of sampling size adequacy. In this study, we used the slope of the curves as an indicator of arthropod diversity. A steep slope meant that new species, or orders, were frequently found, thus suggesting higher diversity than a shallower slope.

To construct order-area curves for a green or control wall, increasing numbers of quadrats were randomly selected from the total pool, with replacement, and the number of new orders within those selected quadrats recorded. This procedure was repeated three times for any given wall so that new order values could be averaged, and the plot smoothed. Final plots consisted of area increasing by increments of 0.56 m^2 on the x-axis and the cumulative number of new orders obtained on the y-axis (Figure 7). An exponential function was used to fit the curve of the plotted data:

$$O = Z\ln(A) + C$$

where O is the cumulative number of new orders, A the area, and Z and C are constants (He and Legendre, 1996 modified to represent order rather than species from). By log transforming area, the curve was made linear, and slope simply estimated by the z parameter. Before transformation, 1 was added to all values so that zeros would not be excluded from the plots. Species-area plots can also be fit with power and logistic curves but He and Legendre (1996) suggest that species-area curves of communities sampled over small areas are best represented by the exponential model.

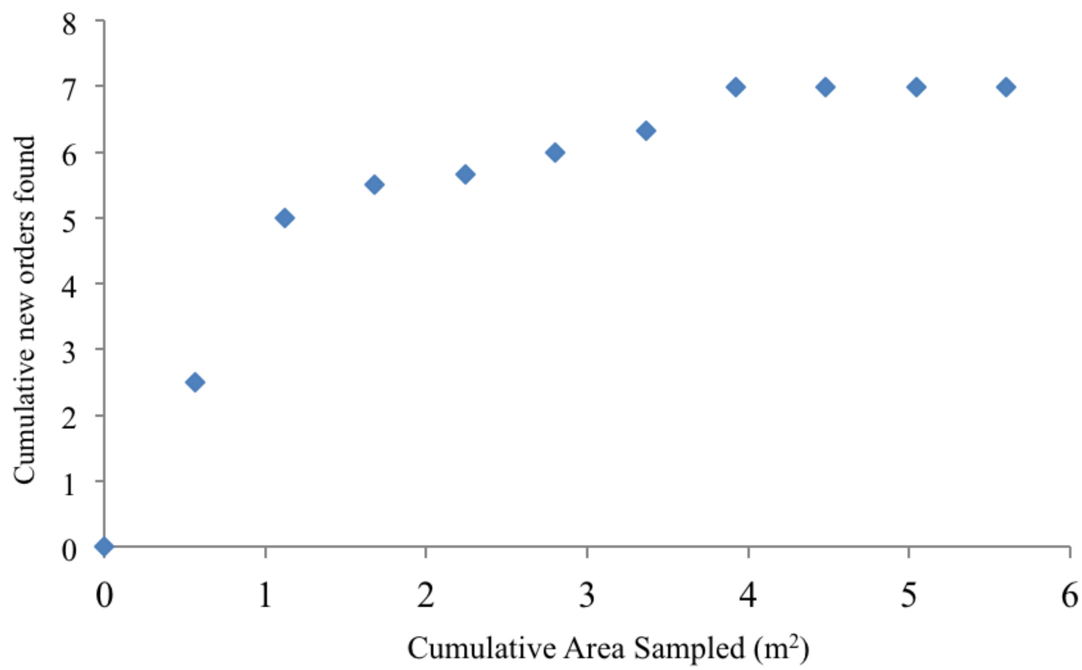


Figure 7. Example species-area curve plot, before log-transformation, generated from the 10 sampled quadrats of the Finnish Embassy green façade in July. The number of new orders found in each sampled area is an average of three separate trials of random selection.

Taxonomic Resolution

Due to limited resources, arthropods were only identified to order. Some authors promote the use of coarse taxonomic resolution, such as order and family, because identification can be performed confidently and it facilitates the rapid assessment of biodiversity, which might be useful for land use planners and government agencies (McIntyre et al. 2001). Rapid assays of terrestrial arthropods could be compared to the benthic macroinvertebrate indices used by many departments of natural resources for assessing stream water quality. Beyond this, there are many studies which have experimentally examined the efficacy of using coarser taxonomic resolutions. Báldi (2003) determined that family, genus, and species richness were all strongly correlated for Diptera, Acari, and Coleoptera while Schipper et al. (2010) and Biaggini et al. (2007) determined that both order- and species-based Shannon-Weiner indices were equally able to differentiate between different environments. However, similar studies reviewed by Schipper et al. (2010) yield inconsistent results. The authors concluded that coarse taxonomic resolutions should sufficiently differentiate heterogeneous environments, in which organisms likely display distinct adaptations, but may be inadequate for detecting gradational differences between similar environments. When comparing green façades to blank walls, we could thus presume that order will adequately differentiate these distinct environments but perhaps will be unsuitable for detecting gradational differences between green façade sites.

Feeding Guilds and Community Interactions

To better characterize arthropods inhabiting green façades, feeding guild distributions were approximated for all specimens. When trophic designations could not be generalized for an entire order, the order was assigned its most common trophic level (Table 2). Furthermore, due to their high abundance and ease of identification relative to Coleoptera, Diptera, and Hymenoptera, Hemipterans were identified to family (see Figure 28 in Results) and, except for Pentatomidae (stink bugs), assigned trophic designations. For some orders, particular families or morphologies were recognized and used to assign a trophic level (Table 2). Because the orders of Coleoptera and Diptera, and the family of Formicidae represent species from a large variety of feeding guilds, they could not be easily categorized without finer identification. As a result, these taxonomic groups were combined into a single “mixed” category (see Figure 27 in Results).

Table 2. Feeding guild designations for arthropod orders and families with notes explaining the method by which guilds were assigned,

Order[1] Family	Feeding Guild Designation	Notes
Plecoptera	…	Adults do not feed
Gastropoda	Herbivore	Most common trophic status
Orthoptera	Omnivore/Herbivore	Specimen seemed dominated by Gryllidae (omnivore) and Tettigoniidae (herbivore) with occasional Acrididae (herbivore) (see Figure 8). Split 50/50 between omnivore and herbivore.
Thysanoptera	Predator	All specimen identified as Phlaeothripidae (predaceous) (see Figure 9)
Neuroptera	redator	All specimens identified as either Chrysopidae or Hemerobiidae (see Figure 10).
Dermaptera	Omnivore	All specimens identified as Forficulidae (omnivore) (see Figure 11).
Opilione	Omnivore	All specimens identified as Phalangiidae (omnivore) (see Figure 12).
Lepidoptera	Herbivore	Most common trophic status
Araneae	Predator	[2]
Odonata	Predator	[2]
Mantodea	Predator	[2]
Diplopoda	Detritivores/Scavengers	Most common trophic status
Isopoda	Detritivores/Scavengers	Most common trophic status
Isoptera	Detritivores/Scavengers	[2]
Psocoptera	Detritivores/Scavengers	[2]
Hemiptera		
Membracidae	Herbivore	[3]
Dictyopharidae	Herbivore	[3]
Piesmatidae	Herbivore	[3]
Tingidae	Herbivore	[3]
Aphidae	Herbivore	[3]
Cixiidae	Herbivore	[3]
Miridae	Herbivore	[3]
Cicicadellidae	Herbivore	[3]
Acanaloniidae	Herbivore	[3]
Flatidae	Herbivore	[3]
Pentatomidae	Herbivore	Specimen seemed dominated by *Halyomorpha* halys (herbivore) (see Figure 13).
Rhopalidae	Herbivore	
Anthocoridae	Omnivore	
Reduviidae	Predator	
Hymenoptera		
Formicidae	Variable	
Non-ant Hymenoptera	Parasitoid	All specimens except for a few individuals identified as Apocrita (see Figure 14).[4]
Coleoptera	Variable	
Diptera	Variable	

[1] Diplopoda and Gastropoda are classes, not orders.
[2] Trophic designations can be generalized for the entire order.
[3] Trophic designations can be generalized for the entire family.
[4] All minute non-ant hymenoptera were assumed to be from superfamily Apocrita, dominated by parasitoids.

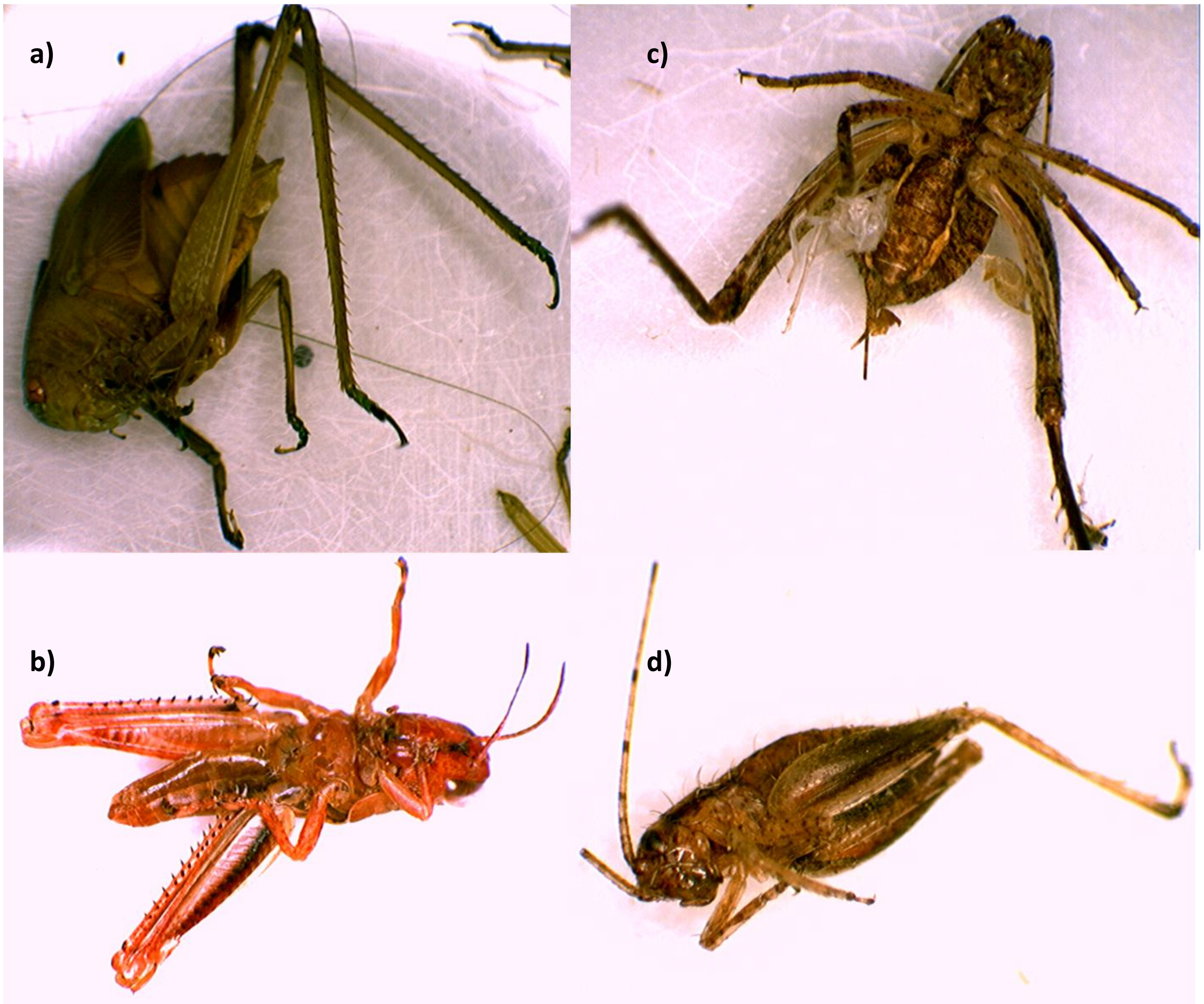


Figure 8. Example specimens of Orthoptera assumed to be Tettigoniidae (a) (Katydid), Gryllidae (cricket) (c and d) and Acrididae (grasshopper) (b).

Figure 9. Reference specimens of sampled Thysanoptera, assumed to be predaceous Phlaeothripidae (tube thrips).

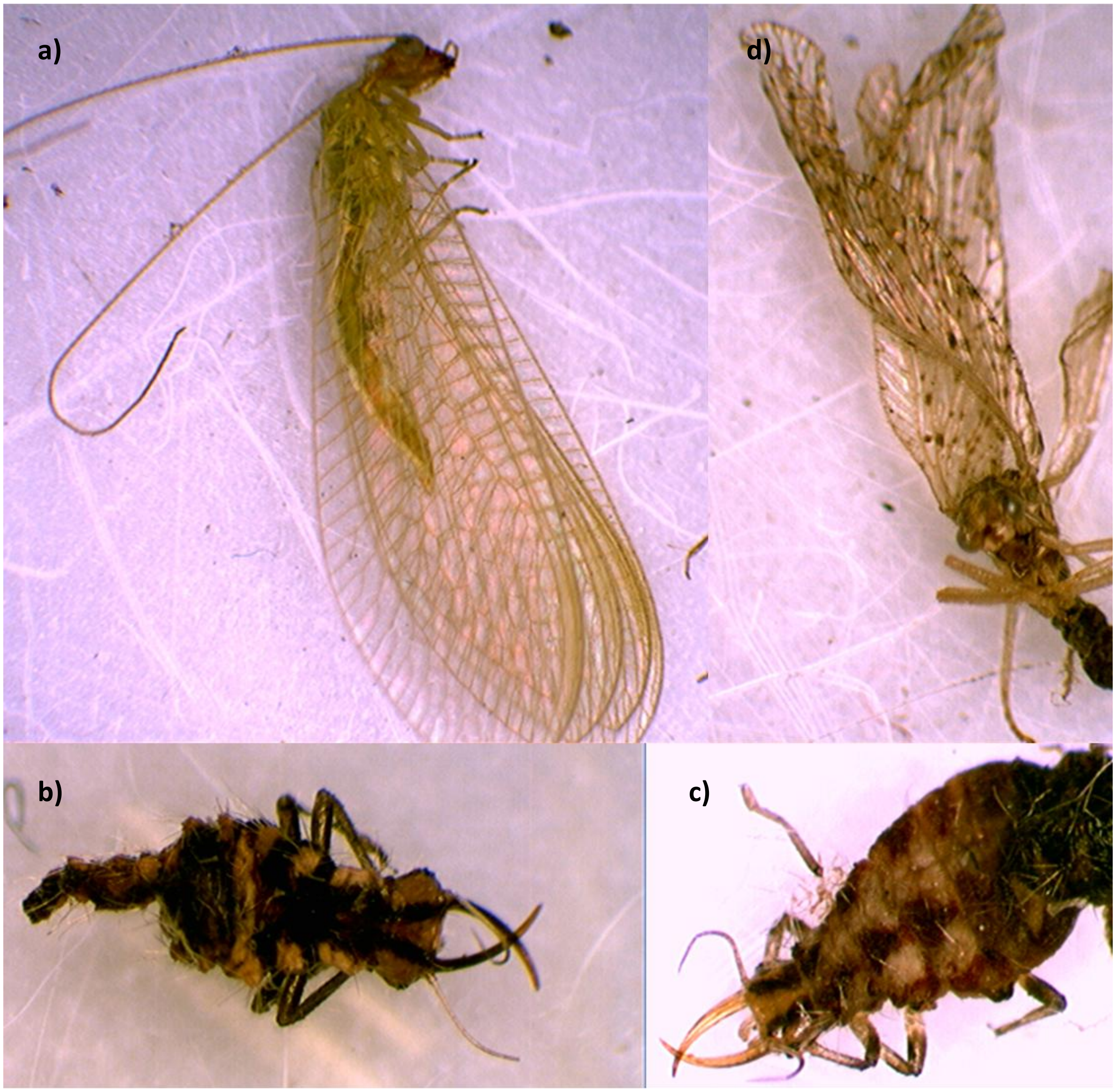


Figure 10. Reference specimens of sampled Neuroptera assumed to be adult (a) and larval (b and c) Chrysopidae(green lacewings) or Hemerobiidae (d) (brown lacewings).

Figure 11. Example specimen of Dermaptera assumed to be Forficulidae (European earwig).

Figure 12. Example specimen of Opiliione assumed to be Phalangiidae (daddy-long-leg).

Figure 13. Example specimens of Pentatomidae assumed to be *Halyomorpha halys* (brown marmorated stink bug),

Figure 14. Example specimen of Hymenoptera assumed to be Apocrita (Suborder dominated by parasitoids)

Vegetation Measures

There are many environmental variables which influence terrestrial arthropod diversity and abundance. This study focused only on vegetation measured at three spatial scales –the vines which were supported by, and comprised the green façades, the landscaping adjacent to the green façades, and the vegetation which grew within a 200 meter radius of the green façades (Table 3).

Table 3. A summary of all vegetation characteristics measured or calculated at each green façade site during the course of the study

Vegetation Characteristic	Abbreviation	Unit	Scale	Sampling Notes
Vine leaf area index	Vine LAI	m^2/m^2	Vine	Measured monthly per quadrat
Maximum vine canopy thickness	Vine Thickness	cm	Vine	Measured monthly per quadrat
Vine percent cover of building wall	Vine Percent Cover	%	Vine	Measured monthly across the entire building wall of each green façade
Aerial extent of vines on building wall	Vine Area	m^2	Vine	Calculated based on vine percent cover measures
Vine species richness	Vine Richness	-	Vine	Measured at each site once during the summer
Vine composite index	Vine Index	-	Vine	Calculated based on vine LAI, vine thickness, and vine species richness
Structural complexity of adjacent landscaping	LC	-	Adjacent landscaping	Measured at each site once during the summer
Neighborhood habitat availability	%NH	%	Neighborhood	Calculated for each site using Arc GIS 9.2

Vine Measures

Within each quadrat, leaf area index (LAI) was measured at 6 evenly spaced intervals using the point intercept method (Schumann 2007, Price 2010), in which a half-inch (12 mm) diameter rod is placed within the canopy at a perpendicular angle, and the points of contact between leaves and the rod, along its entire length, are counted. Maximum vine canopy thickness, which was the horizontal distance between the steel trellis and the most extreme member of the vine canopy, was also measured within each quadrat. Vine percent cover of each green façade panel was visually estimated. Where facades consisted of one continuous panel, percent cover was estimated in sections. (Figure 2 distinguishes between continuous-panel and spaced-panel green façade installations). LAI, thickness, and percent cover were measured during each sampling visit. Vine species richness at each site was measured once during the summer and was defined as the total number of different vine species planted on the entire green façade installation.

Vine percent cover was used to estimate vine area, or the two dimensional extent of vine growth on the entire building wall. This was calculated by multiplying vine percent cover by the total panel area of the green façade. Because panel areas were summed, this calculation did not indicate whether an installation was comprised of one continuous panel or of multiple panels spaced across the building wall.

A composite index of LAI, thickness, and vine richness was also created as a proxy for structural complexity of the vines by ranking and then summing the ranks of each measure for each site. Vine area was kept separate from this composite index because it represented spatial scales that seemed too large to include as a local measure of vegetation (up to 300 m^2).

Adjacent Landscaping

Shrewsbury and Raupp (2000) define structural complexity as an index of structural intricacy of a landscape based on the amount or frequency of vegetation in the three-dimensional space of the habitat. We modified Shrewsbury and Raupp's rating system to quantify the structural complexity of landscaping planted adjacent to the green façades (referred to as LC). Nine by nine (9 x 9) meter grids**,** divided into nine one meter squared sections, **w**ere centered about the green façade panels (Figure 15). Vertical strata were evaluated within each m^2 space by scoring the presence or absence of five vertical categories: soil or groundcover, annual or perennials, shrubs, understory, and overstory. A grid could thus have a score ranging from 0 to 45. Because landscaping was fairly homogenous, only one or two grids were necessary to capture a representative sample. Although the grids encompassed the green façades, vines supported by the panels were not scored.

Figure 15. Marking out a 9 x 9 meter grid to measure structural complexity of landscaping adjacent to the green façade at Eastern Village Cohousing in Takoma Park, MD. Grids were centered about the green façade panels.

` *Neighborhood Habitat Availability*

The percent of "unsealed" or pervious surfaces within a 200 meter buffer of each site was calculated using aerial photographs and Arc GIS 9.2. This was the study's largest scale measure of vegetation, and was intended to be a proxy for available habitat within the area. Summer 2010 Google Earth aerial photographs with 0.13 to 1 m pixel resolution were georeferenced in ArcMap and all vegetation, water and bare soil were outlined within a 200 m radius of each site. The area of these outlined polygons was then summed and taken as a percentage of the overall 200 m radius circle (Figure 16). "Unsealed" areas were predominantly vegetated since soil in construction sites and water in swimming pools made up insignificant percentages of the total. This value is referred to as percent neighborhood habitat availability (%NH).

In a review of 10 articles discussing landscape effects on arthropod abundance and diversity, buffer distances ranged from 25-8,000 m, though 200 m was frequently included (McIntyre et al. 2001, Jeanneret et al. 2003, Stoner and Joern 2004, Kruess and Tscharntke 2000, Batáry et al. 2007, Batáry et al. 2008, Sattler et al. 2010, Woodcock et al. 2010, Savage et al. 2011, Schüepp et al. 2011). Often these buffer distances were tailored to the range of a particular taxonomic group. Landscape effect on biodiversity is a rich and complex area of research. Studies consider not only net habitat availability within different sized buffer zones but also fragmentation and patchiness, patch size, age and heterogeneity, and distance to natural areas. Percent neighborhood habitat availability is intended to be a simple measure of vegetation at the neighborhood scale and a proxy for total habitat; it does not tackle these nuances.

Figure 16. Aerial photograph of site 6 in Rockville, MD georeferenced in ArcMap a) indicates 200m buffer surrounding the site b) "unsealed" surfaces have been outlined and overlaid by yellow polygons using the Editor tool in ArcMap.

Data Analysis

To test whether arthropod abundances and diversity indices H', S, and Z, were significantly different between green and blank walls, analyses of variance (ANOVA's) were performed using the PROC MIXED and PROC GLIMMIX procedures in SAS 9.2 with an alpha level of 0.05. PROC GLIMMIX is a generalized linear mixed model which fits statistical models to data and allows non-Gaussian distributions to be specified (Littell et al. 2006). PROC GLIMMIX also generates fit statistics which allow the user to evaluate the goodness of fit of their specified distribution. In this procedure, data is not transformed; rather the expected parameters generated by the model are transformed. Expected means and variances can then be back transformed using the log-link function (Littell et al. 2006). PROC GLIMMIX was used to analyze abundance data, which, as counts, tend to follow a Poisson distribution. The presence of many zeros in our dataset caused overdispersion, in which the variances were greater than the means. Overdispersed count data is better fit by a negative binomial distribution (O'Hara and Kotze 2010). This was confirmed by GLIMMIX generated fit statistics.

PROC CORR was used to test correlations between green wall vegetation characteristics and arthropod abundances and diversities using alpha levels of 0.05 and 0.10. Normality of all variables was tested and the Spearman rank correlation option was used when non-Gaussian variables were included. Despite the multiple pair-wise comparisons made in this analysis, Bonferroni adjustments were not applied to alpha levels, due to the exploratory nature of the study. Regardless, the number of pair-wise comparisons did not exceed our sample size.

CHAPTER 3: RESULTS

Vegetation Characteristics of Green Façades

Averages of the 10 sites suggest that vine growth peaked in June and July but stayed relatively stable (Table 4).Over the course of the summer, LAI remained unchanged at 60% of the sites and decreased at 40%. Vine thickness remained unchanged at 80% of the sites and decreased at 20%. Vine percent cover remained unchanged at 40% of the sites, increased at 30% and decreased at 30%. Changes in vine thickness occurred mainly between June and July, while changes in vine LAI and percent cover occurred between both June and July, and July and August (Figure 17).

The age of the vines planted on the ten green façades ranged from newly planted to 17 years old, with a mean of 5.2 years. Structural complexity of landscaping planted adjacent to the green façades (LC) ranged from scores of 3.5 to 27 (out of possible scores of 0 to 45), with a mean of 11.9. Neighborhood habitat availability within 200m radius of the green façades (%NH) ranged from 7.4 to 70%, with a mean of 39.2%. One to six vine species were planted at any individual green façade representing a total of 13 different species (Table 5).

Older green façades were found to support vines covering larger areas than younger green façades in all three months (p=0.04, p=0.10, p=0.05, respectively) (Figure 18a). However, only for August did older green façades also have thicker vine canopies than younger green façades (p=0.1) (Figure 18b). In June and August, vines with thicker canopies had higher LAI's (p=0.02, p=0.01). In July and August, vines with thicker canopies were found at sites with higher %NH (p=0.08, p=0.04). (Table 6).

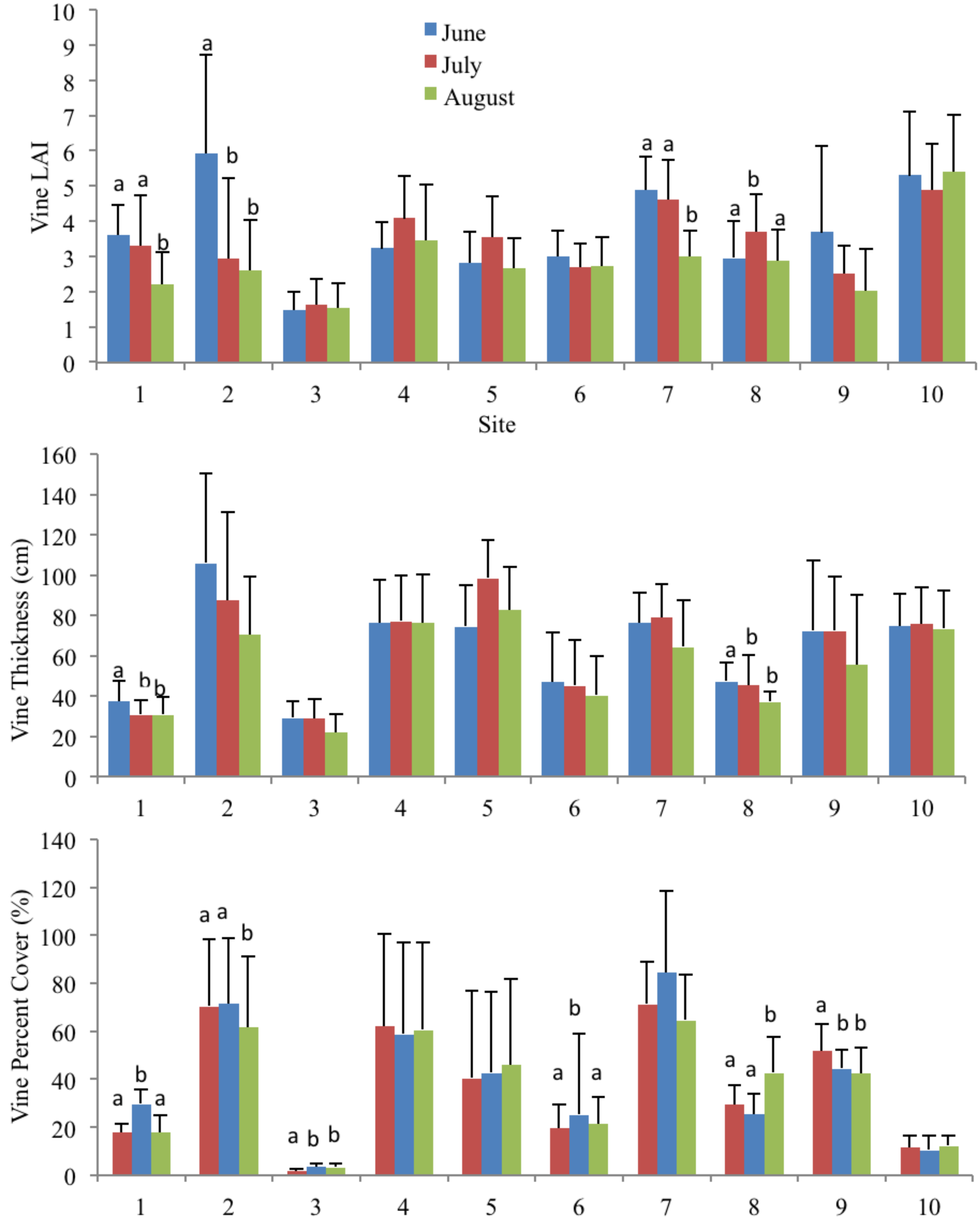


Figure 17. Mean measures of vine LAI, maximum canopy thickness and percent cover for each green façade site during June, July, and August, 2011. Letters only displayed where significant differences between months occurred. Error bars represent 1 standard error.

Table 4. Pooled mean, minimum and maximum measures of vine LAI, percent cover, and maximum canopy thickness for all ten green façade sites in June, July and August, 2011.

	Vine LAI	LAI Min	LAI Max	Vine Percent Cover (%)	Cover Min	Cover Max	Vine Thickness (cm)	Thickness Min	Thickness Max
June	3.7	1.5	5.9	38	1.5	70.4	64	29.2	105.9
July	3.4	1.6	4.9	40	3.5	84.5	64	30.7	98.2
August	2.9	1.5	5.4	37	3.2	64.5	55	30.6	82.8

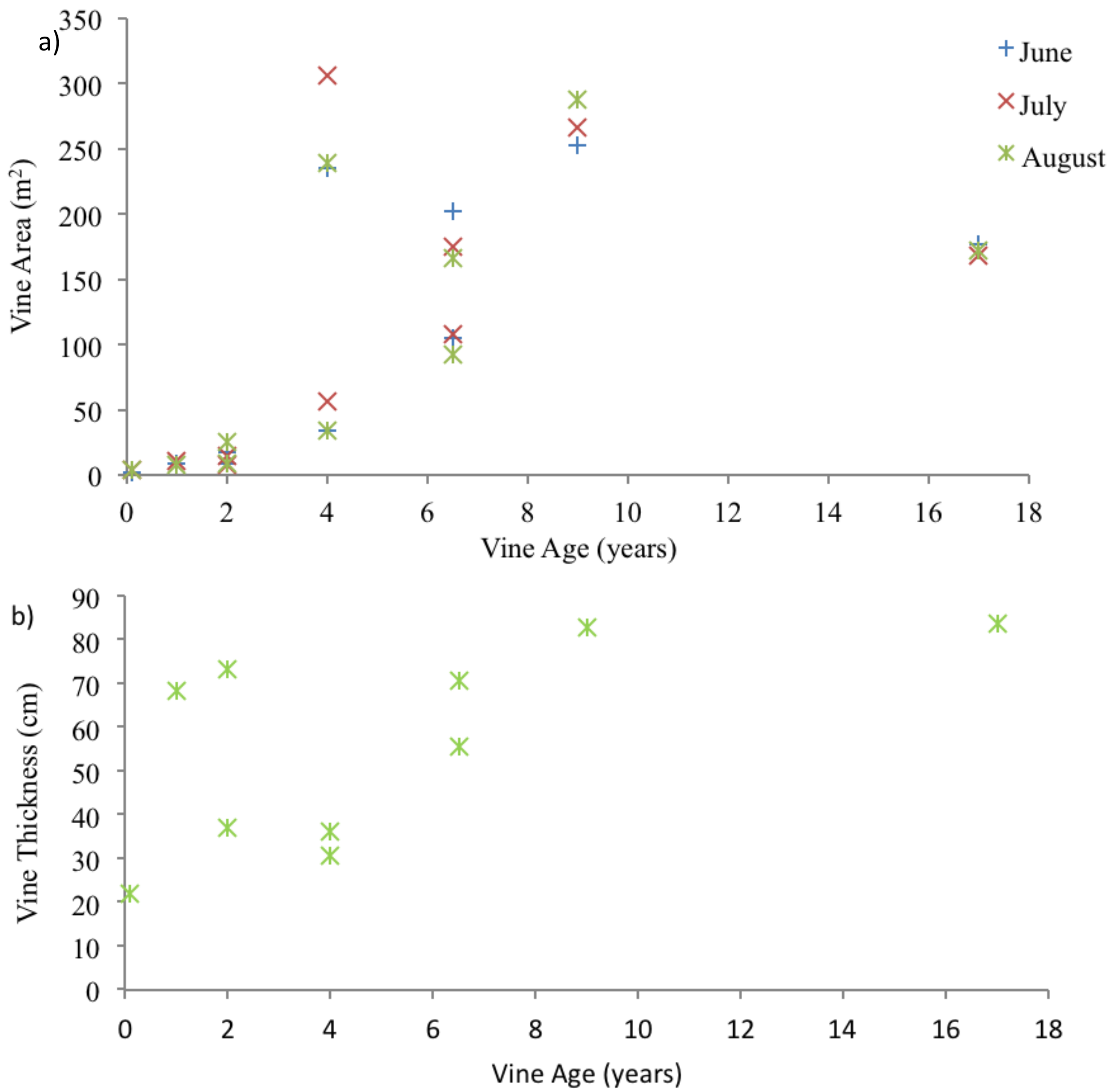


Figure 18. A positive relationship was found between vine age and vine area (a) and between vine age and vine canopy thickness (b)

Table 5. Vegetation characteristics of the ten green wall installations including structural complexity of landscaping directly adjacent to the vines (LC) and percent of habitat availability within a 200 meter buffer of the site (%NH).

Site	Age	LC	%NH	Pesticide	Vine Species
1	4	12.5	33	No	*Parthenocissus tricuspidata*
2	6.5	20.0	31	No	*Akebia quinata, Campsis radicans , Lonicera sempervirens*
3	0.1	10.0	18	No	*Akebia quinata, Campsis radicans , Parthenocissus quinquefolia Lonicera sempervirens, Clematis terniflora, trachelospermum jasminoides*
4	17	3.5	70	Yes[1]	*Akebia quinata, Rosa*
5	9	27.0	68	No	*Campsis radicans , Lonicera sempervirens, Parthenocissus quinquefolia, Celastrus scandens, Gelsemium sempervirens*
6	4	7.0	41	Unknown	*Campsis radicans , Lonicera sempervirens, Parthenocissus quinquefolia, Bignonia capreolata*
7	1	11.0	76	No	*Bignonia capreolata, Lonicera sempervirens, Celastrus scandens, Gelsemium sempervirens, Wisteria frutescents, Vitis rupestris*
8	2	9.0	7	No	*Gelsemium sempervirens*
9	6.5	8.0	20	No	*Bignonia capreolata, Campsis radicans*
10	2	11.0	28	No	*Campsis radicans, Lonicera sempervirens, Gelsemium sempervirens*

[1]Contact at the site confirmed occasional, non-annual use of pesticide. I observed the localized application of bee poison in July.

Table 6. Correlation matrix exhibiting the relationships between vegetation characteristics of the ten green wall sites in June, July, and August. Correlation coefficients were significant at *p≤0.1 **p≤0.05

June	LC	%NH	Vine LAI	Vine Richness	Vine Thickness	Vine Area	Vine Age	Vine Index
SC	1.00	0.19	0.20	0.29	0.36	0.19	-0.02	0.26
%VC		1.00	0.13	0.42	0.39	0.35	0.49	0.50
Vine LAI			1.00	-0.18	0.72**	-0.20	-0.03	0.78**
Vine Richness				1.00	-0.02	-0.01	-0.31	0.37
Vine Thickness					1.00	0.23	0.46	0.82**
Vine Area						1.00	0.65**	-0.04
Vine Age							1.00	0.10
Vine Index								1.00

July	LC	%NH	Vine LAI	Vine Richness	Vine Thickness	Vine Area	Vine Age	Vine Index
SC	1.00	0.2	-0.01	0.30	0.45	0.19	-0.02	0.53
%VC		1.00	0.51	0.42	0.58*	0.35	0.49	0.57*
Vine LAI			1.00	-0.09	0.50	-0.25	0.12	0.51
Vine Richness				1.00	0.15	0.03	-0.31	0.39
Vine Thickness					1.00	0.25	0.53	0.83**
Vine Area						1.00	0.55*	0.02
Vine Age							1.00	0.22
Vine Index								1.00

August	LC	%NH	Vine LAI	Vine Richness	Vine Thickness	Vine Area	Vine Age	Vine Index
SC	1.00	0.19	-0.12	0.29	0.33	0.27	-0.02	0.40
%VC		1.00	0.19	0.42	0.65**	0.40	0.49	0.66**
Vine LAI			1.00	-0.15	0.55*	-0.14	0.09	0.39
Vine Richness				1.00	0.08	0.05	-0.31	0.56*
Vine Thickness					1.00	0.36	0.61*	0.67**
Vine Area						1.00	0.63**	0.27
Vine Age							1.00	0.32
Vine Index								1.00

Arthropod Composition

During the entire sampling period, a total of 4407 arthropods representing 18 taxonomic orders and classes (Diplopoda) were collected from the green façades (Figure 19a) while only 50 arthropods representing 7 orders were collected from the blank walls (Figure 19b). (Table 7). Less than 2% of all captured arthropods were too damaged to be identified.

On the green façades in June, 1710 arthropods representing 15 orders and classes (Diplopoda) were sampled. The most abundant orders captured were Hemiptera (48% of total), Diptera (16%), Hymenoptera (16%), and Araneae (9%) (Figure 19a). The most frequently found were Hemiptera (100% of walls), Diptera (100%), Araneae (100%), Hymenoptera (90%), and Coleoptera (90%) (Figure 20a).

On the blank walls in June, 17 arthropods representing 7 orders were sampled. The most abundant orders captured were Diptera (41%), Hemiptera (12%), Coleoptera (12%), Araneae (12%), Psocoptera (6%), Mantodea (6%), and Hymenoptera (6%) (Figure 19b). The most frequent were Diptera, Hemiptera, and Coleoptera (30%) (Figure 20b).

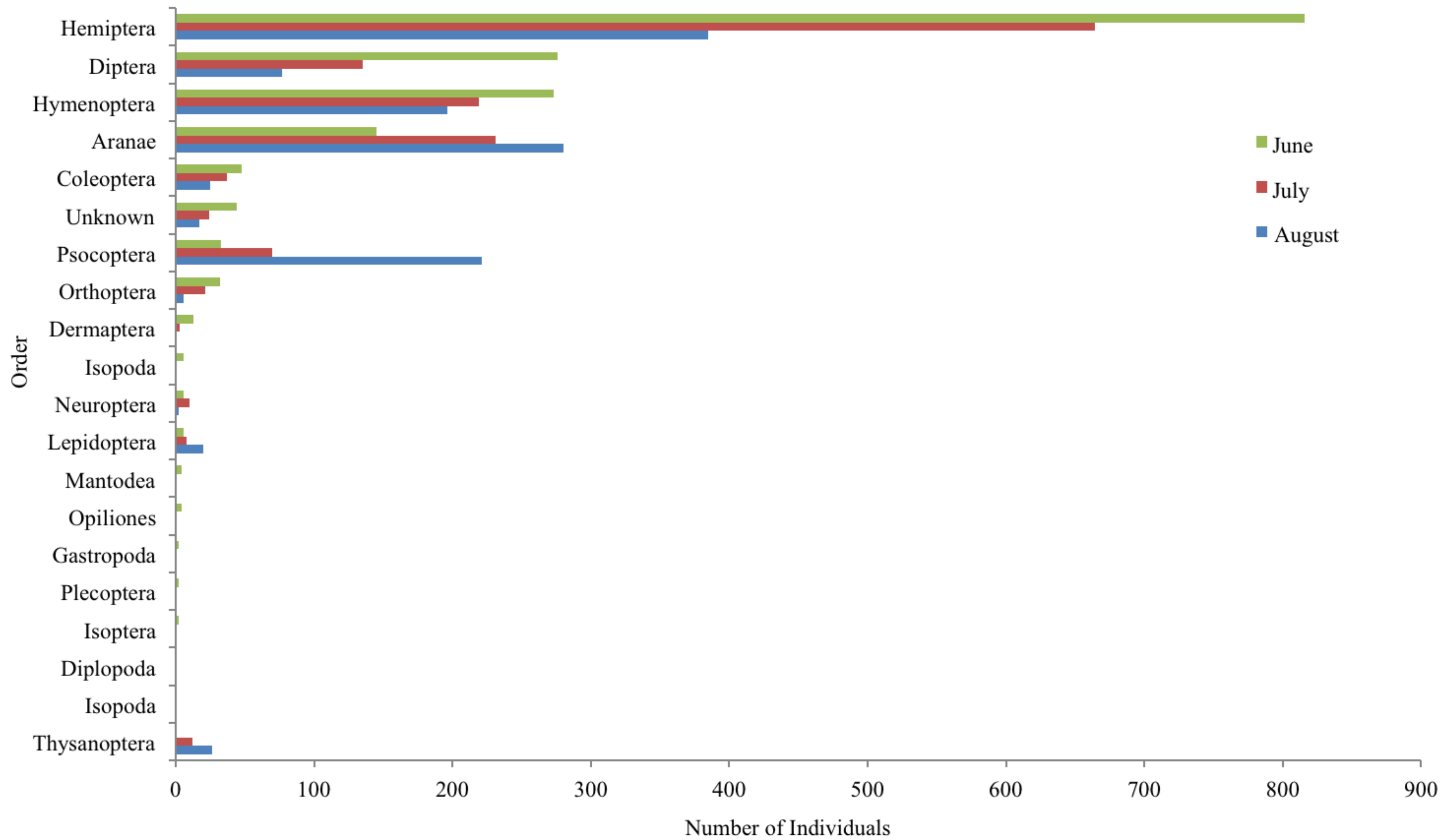
On the green façades in July, 1438 arthropods representing 14 orders and classes (Diplopoda) were sampled. The most abundant orders captured were Hemiptera (46%), Araneae (16%), Hymenoptera (15%), Diptera (9%), and Psocoptera (5%) (Figure 19a). The most frequent were Hemiptera (100%), Hymenoptera (100%), Diptera (100%), Araneae (90%), and Psocoptera (80%) (Figure 20c).

On the blank walls in July, 27 arthropods representing 5 orders were sampled. The most abundant orders were Diptera (63%), Hemiptera (22%), and Hymenoptera (7%) (Figure 19b). The most frequent were Diptera (50%) (Figure 20d).

On the green façades in August, 1257 arthropods representing 12 orders were sampled. The most abundant orders captured were Hempitera (31%), Araneae (22%), Psocoptera (18%), Hymenoptera (16%), and Diptera (6%) (Figure 19a). The most frequent were Hemiptera (100%), Araneae (100%), Hymenoptera (90%), and Diptera (90%) (Figure 20e).

On the blank walls in August, 6 arthropods representing 1 order (Diptera) (Figure 19b) were captured at one site only (Figure 20f).

a)


Hemiptera
Diptera
Hymenoptera
Aranae
Coleoptera
Unknown
Psocoptera
Orthoptera
Dermaptera
Isopoda
Neuroptera
Lepidoptera
Mantodea
Opiliones
Gastropoda
Plecoptera
Isoptera
Diplopoda
Isopoda
Thysanoptera
Order
0
100
200
300
400
500
600
700
800
900
Number of Individuals
June
July
August

b)

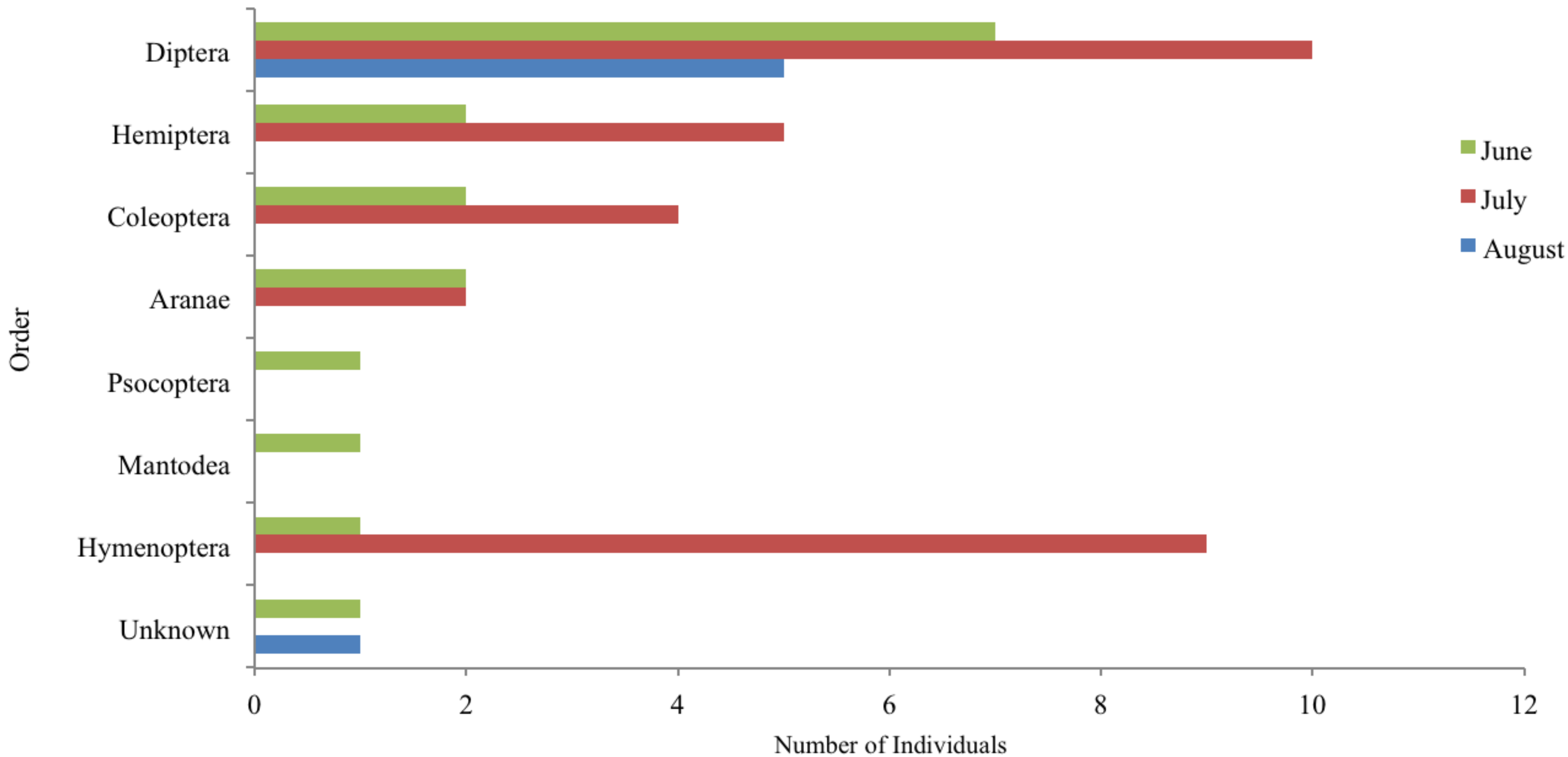
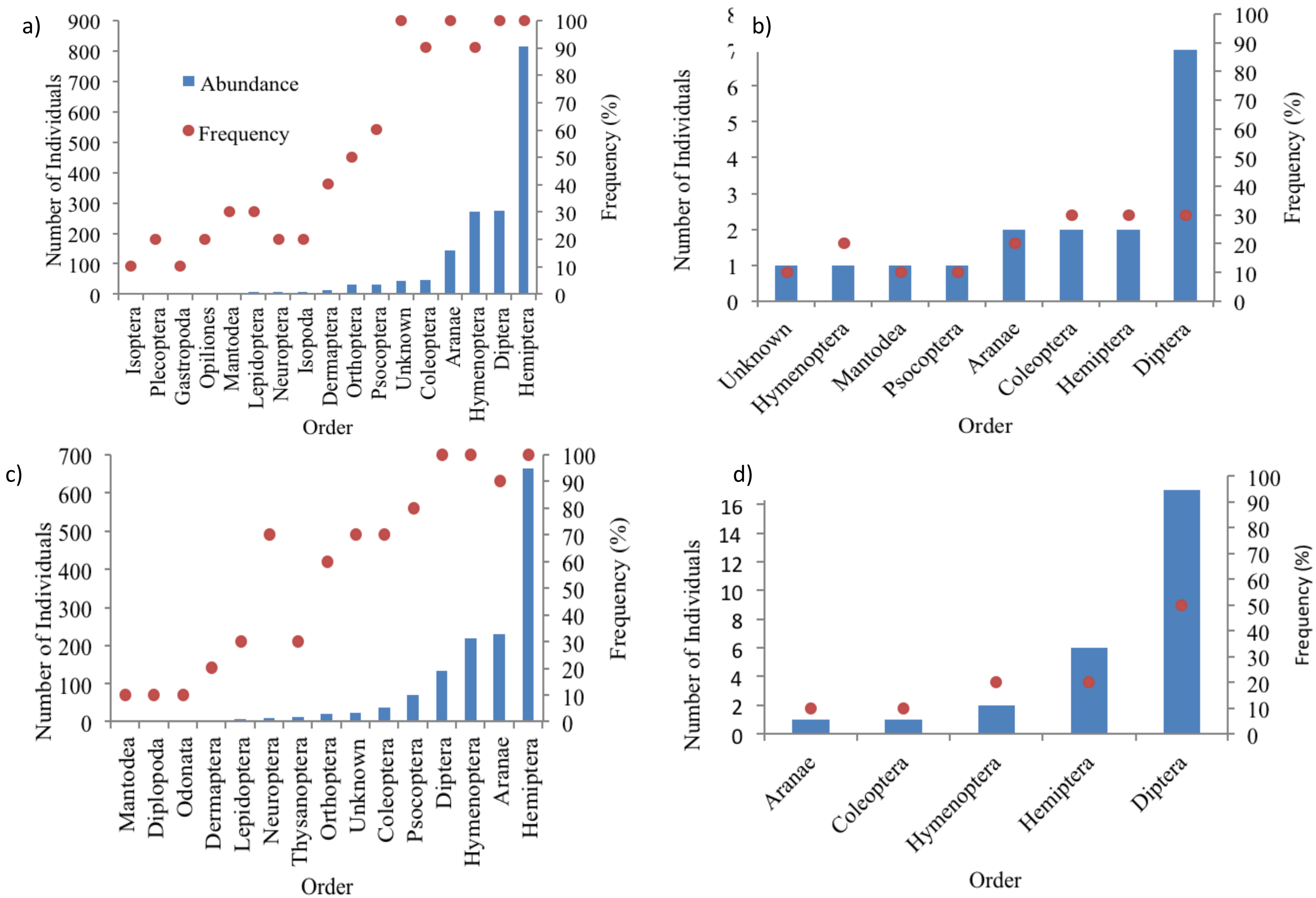
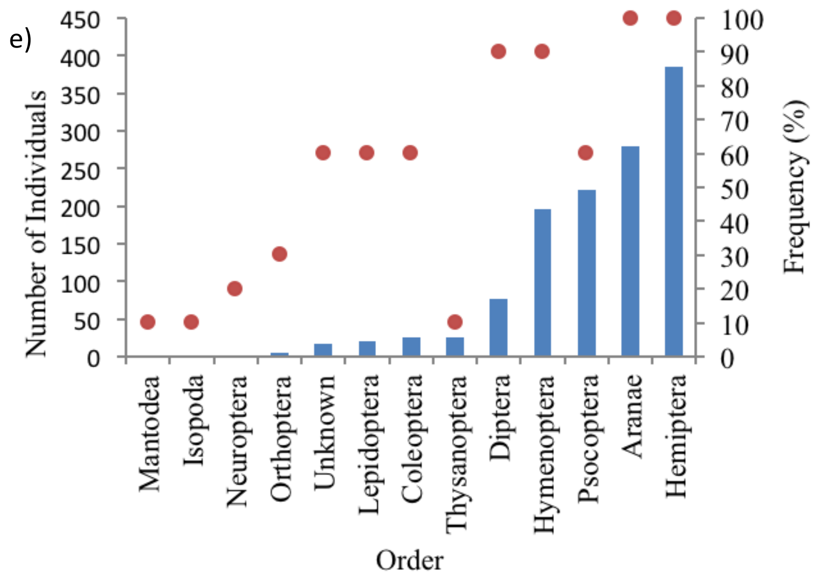


Figure 19. Combined counts of individuals, grouped by taxonomic order, sampled at all ten green façade (a) and blank wall (b) sites in June, July, and August 2011.


a)
Abundance
Frequency
Number of Individuals
Frequency (%)
Isoptera
Plecoptera
Gastropoda
Opiliones
Mantodea
Lepidoptera
Neuroptera
Isopoda
Dermaptera
Orthoptera
Psocoptera
Unknown
Coleoptera
Aranae
Hymenoptera
Diptera
Hemiptera
Order
b)
Number of Individuals
Frequency (%)
Unknown
Hymenoptera
Mantodea
Psocoptera
Aranae
Coleoptera
Hemiptera
Diptera
Order
c)
Number of Individuals
Frequency (%)
Mantodea
Diplopoda
Odonata
Dermaptera
Lepidoptera
Neuroptera
Thysanoptera
Orthoptera
Unknown
Coleoptera
Psocoptera
Diptera
Hymenoptera
Aranae
Hemiptera
Order
d)
Number of Individuals
Frequency (%)
Aranae
Coleoptera
Hymenoptera
Hemiptera
Diptera
Order



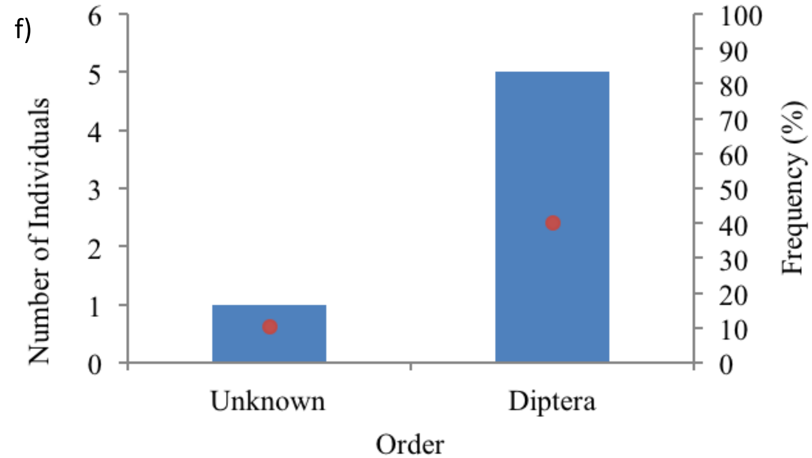


Figure 20. Total numbers of individuals from each taxonomic order collected from all ten sites and frequency with which orders were sampled, 100% meaning that order was sampled at all ten sites. a) Green walls in June b) blank walls in June c) green walls in July d) blank walls in July e) green walls in August f) blank walls in August.

Table 7. Taxonomic orders[1], with common names, of all arthropods obtained from both green and blank façades during June, July, and August 2011.

Taxonomic Order	Common Name
Araneae	Spiders
Dermaptera	Earwigs
Diplopoda	Millipedes
Diptera	Flies
Hemiptera	True bugs
Hymenoptera	Sawflies, wasps, bees, and ants
Isopoda	Pill bugs, sow bugs, woodlice
Isoptera	Termites
Lepidoptera	Moths and butterflies
Mantodea	Preying Mantids
Neuroptera	Lacewings, alderflies, dobsonflies, fishflies, snakeflies, antlions, owlflies
Odonata	Dragonflies, damselflies
Opiliones	Harvestmen or daddy-long-legs
Orthoptera	Grasshoppers, locusts, crickets, katydids
Plecoptera	Stoneflies
Psocoptera	Barklice, booklice
Thysanoptera	Thrips
Coleoptera	Beetles

[1]Diplopoda class also included

Arthropod Abundance

Green façades contained more arthropods per quadrat than blank walls during sampling in June, July, and August (p=0.0051, p<0.0007, p<0.0001) (Figure 21). Because data followed a non-Gaussian, negative binomial distribution, interpretations of arithmetic means and standard errors are not straight forward. Expected means modeled by the GLIMMIX procedure, then back-transformed with asymmetrical confidence intervals, better describe the mean and spread of the data (Table 8).

Arthropod Diversity

Green walls contained higher arthropod richness and Shannon Weiner diversity than blank walls during sampling in June, July and August (Richness: p=0.0031, p<0.0001, p=0.0001; Shannon-Weiner: p<0.0001, p<0.0001, p=0.0004) (Figure 22). To standardize unequal sub-sampling (recall that 10 and 3 quadrats were used for each green and blank wall respectively), indices for individual walls were calculated using only 3 pooled quadrats. For each green façade, these 3 quadrats were randomly selected from the 10 original quadrats.

Steeper slopes of "order-area" curves indicated higher diversity on green walls than on blank walls for all three sampling months ($p<0.0001$, $p=0.0013$, $p<0.0001$) (Figure 23). As above, only arthropod order numbers obtained from 3 quadrats were used to construct green and blank wall curves. If both green and blank wall order-area curves had approached an asymptote, standardization of unequal sub-sampling would have been unnecessary. Asymptotes would have suggested that a complete inventory of arthropod orders inhabiting both types of walls had been obtained. Although the average order-area curves of green and blank walls look distinct (Figure 24), and inflexion points are evident on all individual plots, asymptotes were not reached (Figure 25).

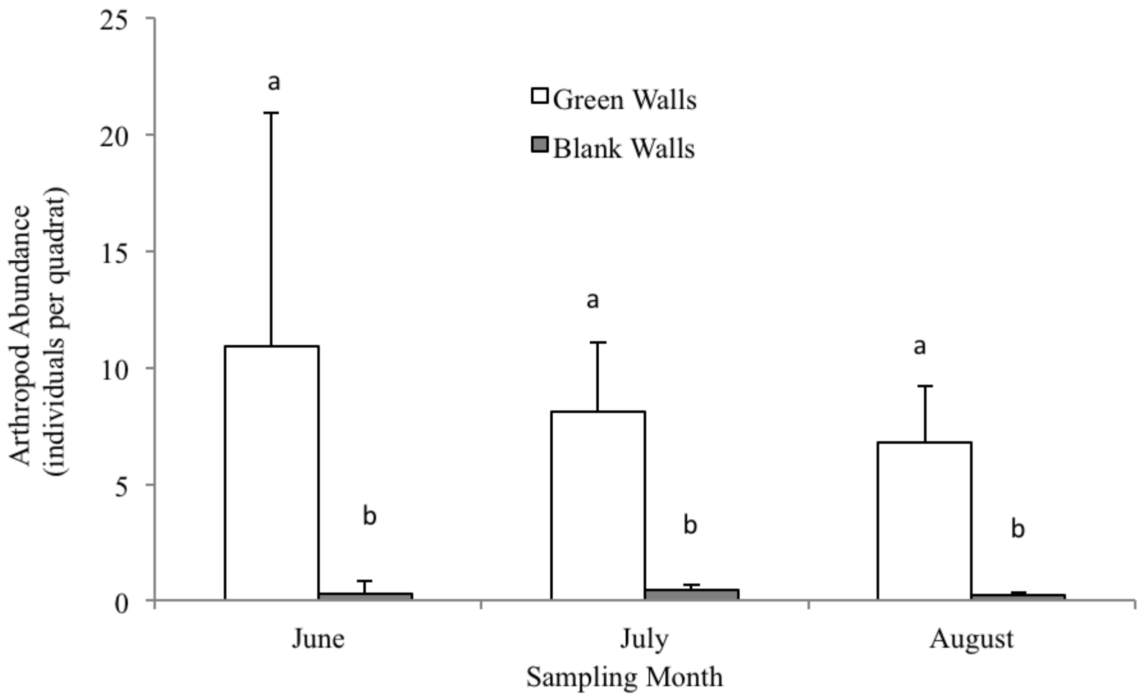


Figure 21. Least squares means of arthropods vacuum sampled per 0.56 m^2 quadrat from 10 green walls and 10 blanks walls in the Washington, D.C. metro area during the summer of 2011. Statistical differences between the means were tested separately for each sampling month. Error bars represent 1 standard error. Means and standard errors have been back-transformed from GLIMMIX-generated log expected means and standard errors using an inverse-link function.

Table 8. A comparison of arithmetic means and standard errors (SE) to log-link expected means and standard errors, and to back-transformed expected means and standard errors, of arthropod abundance, per quadrat, on 10 green and 10 blank walls in the Washington, D.C. metro area sampled in June, July, and August, 2011. Log-link and inverse-link parameters were generated by the GLIMMIX procedure. Asymptotic confidence intervals for back-transformed means are also presented. The GLIMMIX procedure allows analysis of variance to be performed on non-normally distributed arthropod abundance values. Back-transformed means and confidence intervals are the most appropriate statistical descriptors of the raw count data of arthropods sampled from the walls.

Treatment	Mean (± SE)	Log-link LS-means[1] (±SE)	Inverse-link[2] LS-means (±SE)	Lower confidence interval	Upper confidence interval
June					
Green Wall	18.3 ± 7.36	2.4 ± 0.92	10.9 ±10.0	1.4	87.5
Blank Wall	0.53±0.22	-1.2±1.85	0.3 ± 0.56	0.005	20.2
July					
Green Wall	15.1±6.93	2.1 ± 0.37	8.1 ± 2.99	3.5	18.7
Blank Wall	0.9±0.44	-0.75±0.48	0.47 ± 0.22	0.16	1.38
August					
Green Wall	12.43±7.32	1.92±0.35	6.8 ± 2.4	3.13	14.91
Blank Wall	0.32±0.13	-1.49±0.52	0.23 ± 0.12	0.07	0.73

[1]Expected means in log- link and inverse-link scale are estimated using least squares means (LS-Means)
[2]The Inverse-link function back-transforms log scale expected means and standard errors

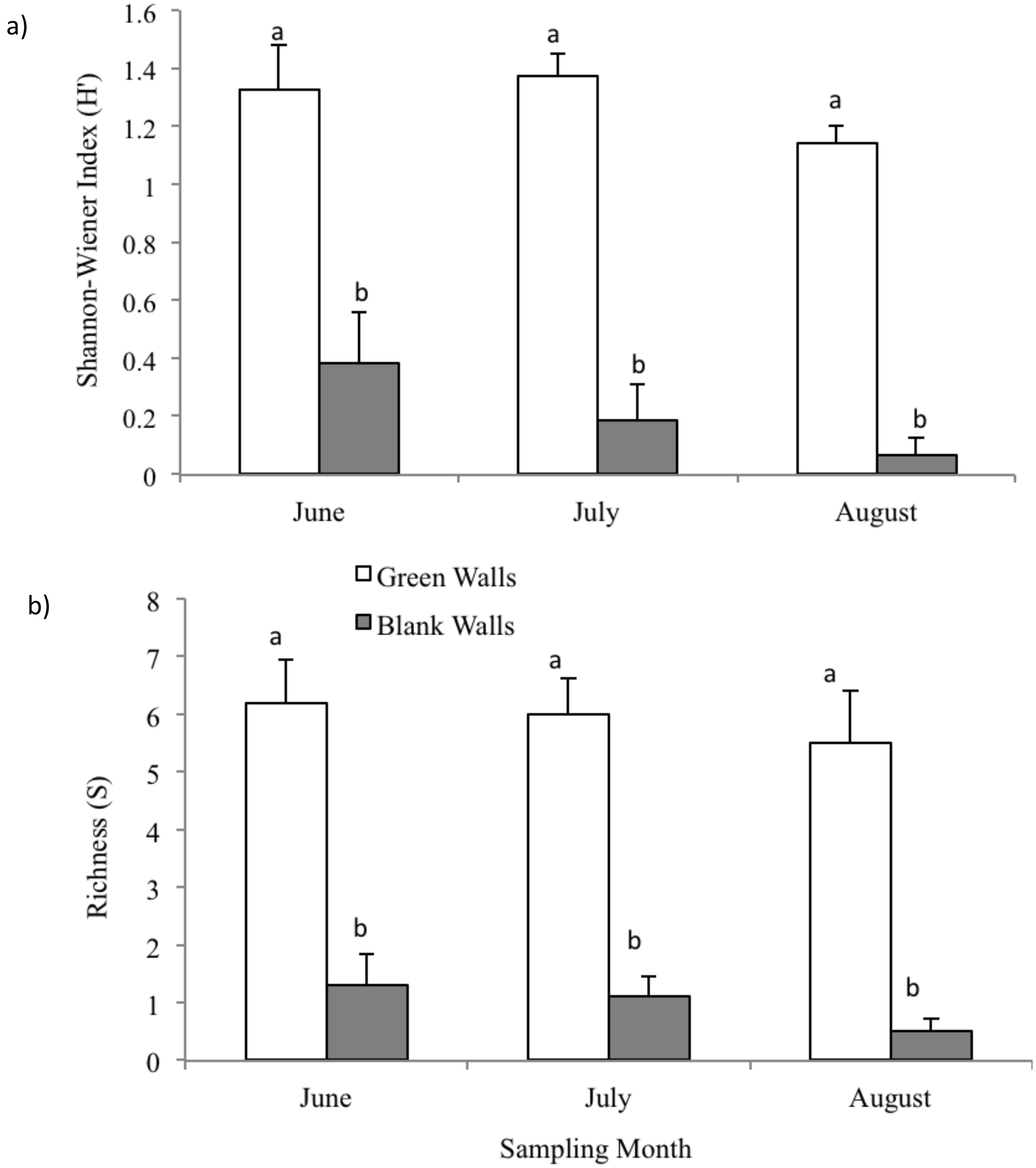


Figure 22. The mean Shannon-Wiener diversity index (a) and mean richness (b) of arthropod orders vacuum sampled from 10 green walls and 10 blank walls in the Washington, D.C. metro area in the summer of 2011. Statistical differences between the means were tested separately for each sampling month. Error bars represent 1 standard error.

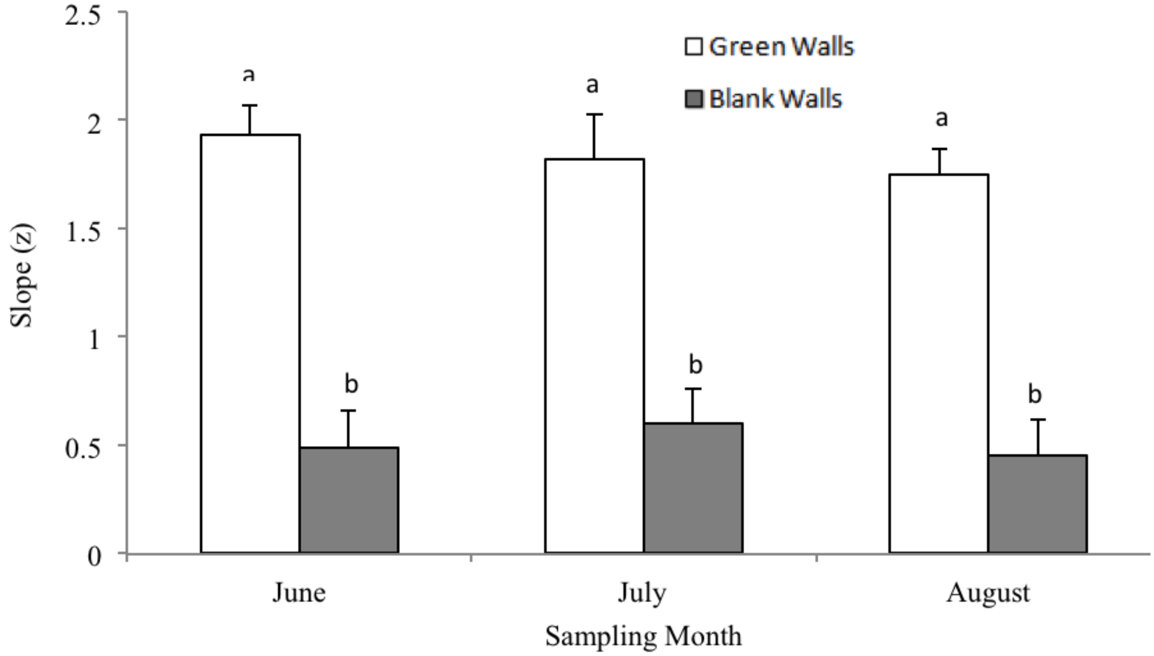


Figure 23. The mean order-area curve slopes derived from arthropods vacuum sampled from 10 green and 10 blank walls in the Washington, D.C. metro area in the summer of 2011. Statistical differences between the means were tested separately for each sampling month. Error bars represent 1 standard error.

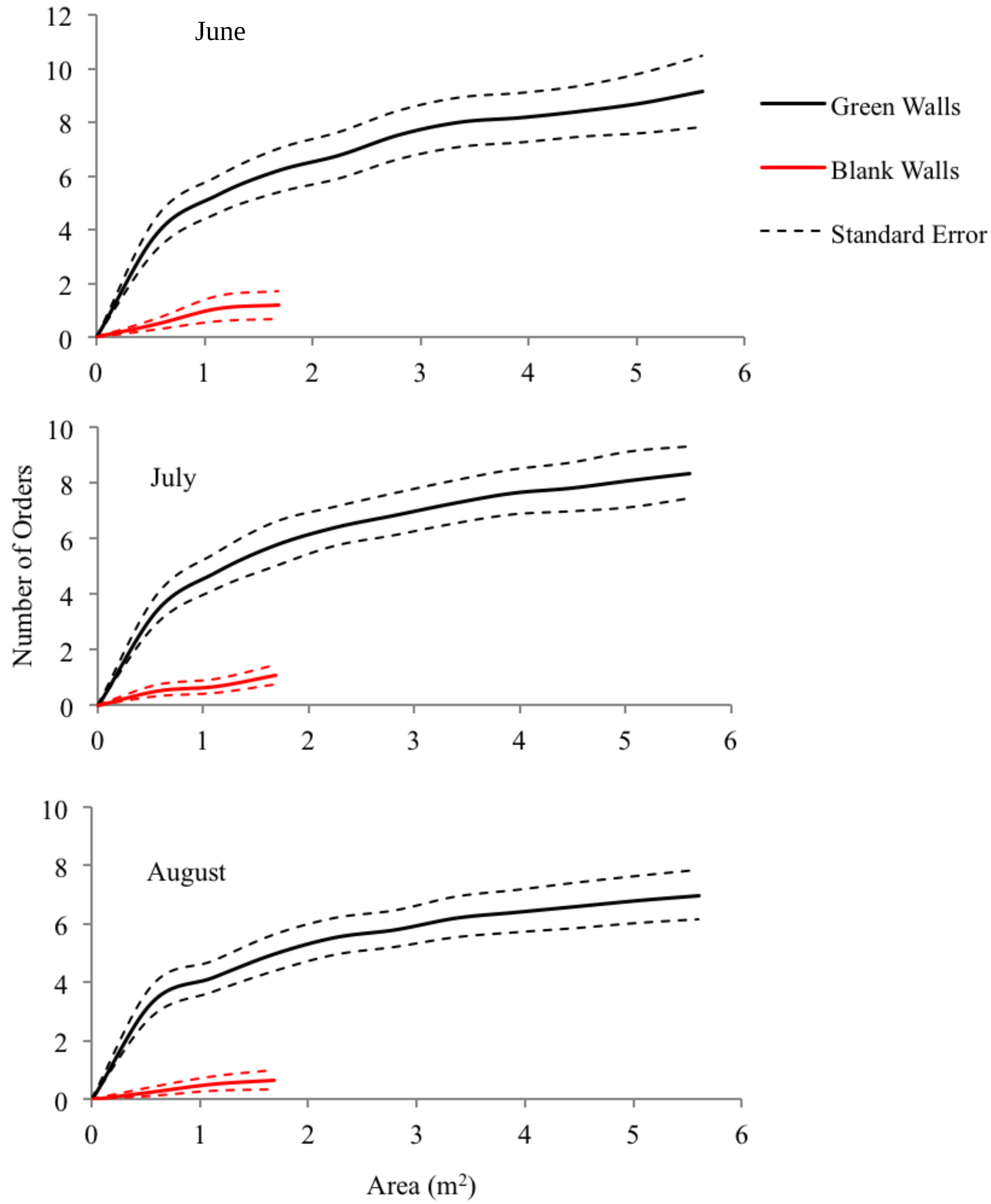


Figure 24. Mean Order-area curves of the ten green and blank walls. The y-axis shows the cumulative number of new orders found in each additional sampled quadrat and the x-axis shows the cumulative area sampled with each additional sampled quadrat. Dotted lines are ± 1 SE.

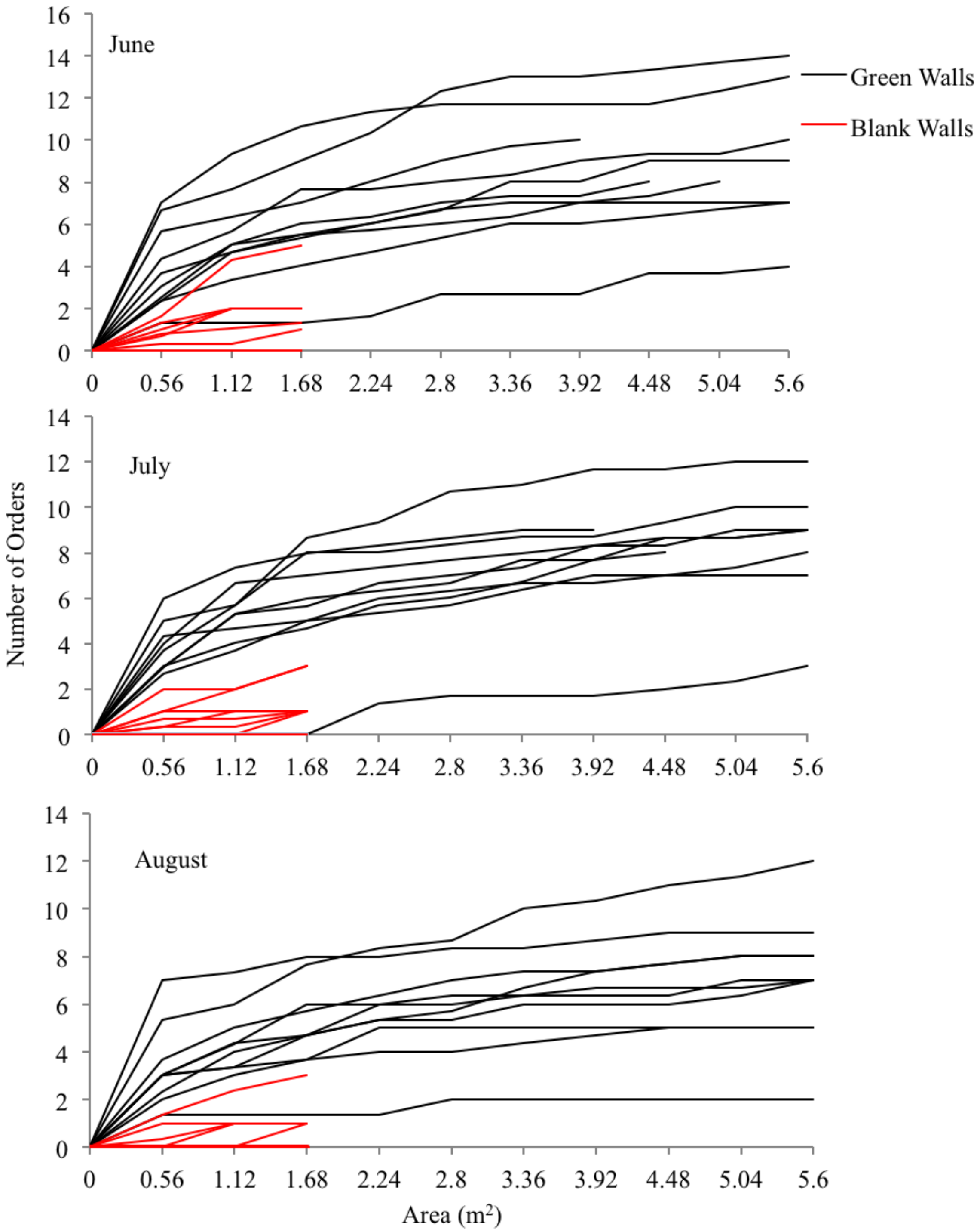


Figure 25. Order-area curves of all 10 individual green and blank walls. Multiple blank wall curves with slopes of zero overlap.

Green walls contained a higher number of taxonomic orders per quadrat than blank walls during sampling in June, July, and August ($p<0.0001$, $p<0.0001$, $p=0.0004$). Similar to arthropod count data, order density followed a non-Gaussian, Poisson distribution. Thus back-transformed expected means are presented in lieu of arithmetic means (Figure 26).

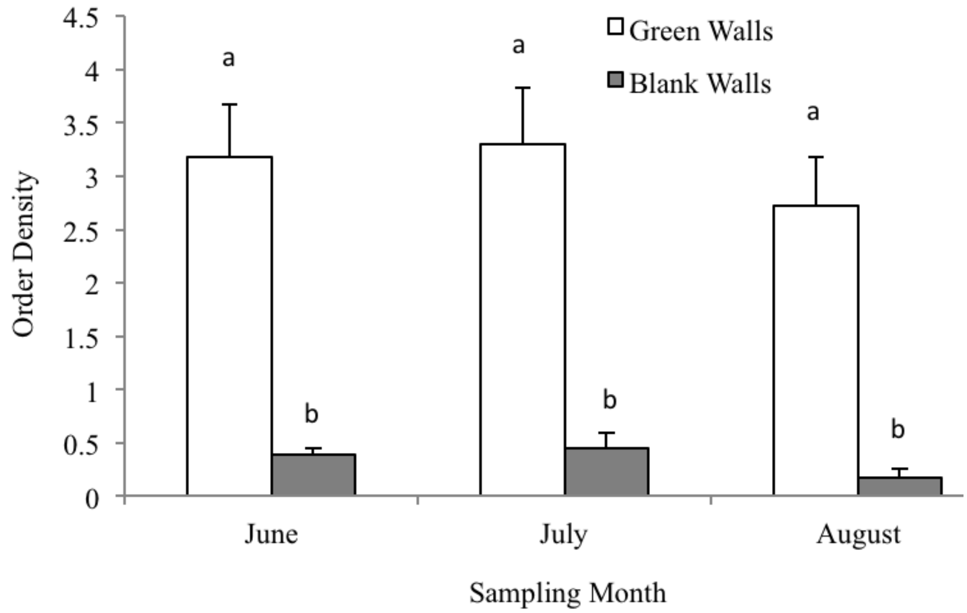


Figure 26. Least squares mean number of taxonomic orders per quadrat ($0.56m^2$) collected from green and blank walls during the summer of 2011. Statistical differences between the means were tested separately for each sampling month. Error bars represent 1 standard error. Means and standard errors have been back-transformed from GLIMMIX-generated log expected means and standard errors using an inverse-link function.

Multiple diversity indices were compared because different indices provide different information about the population. For instance, sites that have high arthropod richness might have low Shannon-Wiener diversity (see site 5 in Table 9) and sites with lower arthropod richness might have a higher Shannon-Wiener diversity (see site 4 in

Table 9). Both indices are a measure of diversity but richness measures how many species or orders are present while Shannon-Weiner additionally measures their evenness. Furthermore, any individual index has limitations. For instance, the Shannon-Weiner index is often reported as a unitless index derived from base 10 logarithms, but it was originally developed using base 2 logs which has physical units based on the mean number of bits per individual, where bits represent a binary decision required to classify the organisms into categories. Because there are limitations to any individual index, results are made more robust when multiple indices support similar conclusions.

Table 9. Abundances and diversity indices of arthropods sampled from the ten green façades in June, July, and August 2011. Indices are calculated from 10 pooled quadrats for each site.

June

Site	Richness (S)	Order Density[1]	Shannon Diversity (H')	Order-Area Curve Slope (z)	Insect Density (individuals/m^2)
1	8	2.56	1.45	1.04	8.14
2	8	3.22	1.77	1.10	13.29
3	4	0.40	0.94	0.75	1.79
4	7	3.00	1.65	0.90	9.82
5	14	5.40	0.79	1.12	138.75
6	9	4.10	1.61	1.00	25.18
7	10	6.14	1.64	1.24	61.99
8	7	1.90	1.61	0.93	3.93
9	10	4.70	1.79	0.98	25.00
10	13	6.30	1.88	1.00	38.75

[1]Mean number of arthropod orders per quadrat at a site

July

Site	Richness (S)	Order Density[1]	Shannon Diversity (H')	Order-Area Curve Slope (z)	Insect Density (individuals/m^2)
1	8	3.1	1.40	1.10	14.96
2	9	2.9	1.77	0.99	10.71
3	4	0.4	1.39	0.85	0.71
4	9	3.2	1.79	1.00	11.07
5	12	6.2	1.18	1.10	135.71
6	7	3.5	1.34	0.83	24.82
7	9	5.4	1.61	1.17	31.12
8	8	3	1.66	0.96	9.11
9	10	4.3	1.81	1.01	18.04
10	9	4.4	1.96	0.93	12.86

August					
Site	Richness (S)	Order Density[1]	Shannon Diversity (H’)	Order-Area Curve Slope (z)	Insect Density (individuals/m^2)
1	5	1.7	0.88	0.72	7.86
2	7	2.7	1.65	0.87	9.29
3	2	0.6	0.64	0.47	1.07
4	5	2.1	1.35	0.81	6.96
5	12	5.8	1.32	1.05	75.36
6	8	3.9	2.14	0.96	20.00
7	9	6.3	1.46	0.83	72.50
8	7	2.7	1.45	0.93	6.73
9	7	2	1.35	0.87	6.43
10	8	3.6	1.40	0.91	15.71

Arthropod Richness and Abundance Correlations

Arthropod richness was not significantly correlated with any vegetation characteristics in the month of June. However, in July and August, a greater richness of arthropods was found in green façades with thicker vine canopies (p=0.004, p=0.075), and in August, in green façades which had more structurally complex adjacent landscaping (LC) (p=0.09) (Table 10).

More arthropods were found at sites with higher neighborhood habitat availability (%NH) in all three months of sampling (p=0.07, p=0.03, p=0.02) (Table 11). In June and August, more arthropods were found at sites with higher vine composite indices (p=0.05, p=0.08), and in July, more were found at sites with more vine area (p=0.1) (Table 11).

Arthropod abundance varied directly with arthropod richness in June and August (p=0.0001, p=0.0015), but not in July (Table12).

Table 10. Correlation coefficients measuring the linear association between arthropod richness and vegetation characteristics of the ten green wall sites in June, July, and August. Correlation coefficients were significant at *p≤0.1 **p≤0.05

	LC	%NH	Vine LAI	Vine Richness	Vine Thickness	Vine Area	Vine Age	Vine Index
June	0.50	0.38	0.41	0.10	0.43	0.36	0.09	0.38
July	0.50	0.47	0.51	-0.19	0.82**	0.40	0.49	0.49
August	0.57*	0.46	0.34	0.18	0.59*	0.50	0.09	0.41

Table 11. Correlation coefficients measuring the linear association between arthropod abundance and vegetation characteristics of the ten green wall sites in June, July, and August. Correlation coefficients were significant at *p≤0.1 **p≤0.05

	LC	%NH	Vine LAI	Vine Richness	Vine Thickness	Vine Area	Vine Age	Vine Index
June	0.32	0.6*	0.29	0.44	0.46	0.41	0.23	0.63**
July	0.21	0.67**	0.21	0.28	0.36	0.55*	0.28	0.22
August	0.47	0.71**	0.47	0.41	0.44	0.35	0.16	0.58*

Table 12. Correlation coefficients measuring the linear association between arthropod abundance and arthropod richness at the ten green wall sites. Correlation coefficients were significant at *p<0.01 and **p<0.001

June	July	August
0.9297**	0.52696	0.85817*

Feeding Guilds

Arthropods sampled from the green façades represented herbivores, predators, omnivores, detritivores/scavengers, and parasitoids (Figure 27). Araneae comprised the majority of positively identified predators (92-94% of total predators), while Psocoptera comprised the majority of the detritivores/scavengers (80-98%), and Hemiptera comprised the majority of herbivores (94-97%). Predators were 3 to 6 times more abundant than parasitoids. Herbivorous insects were the most abundant feeding guild in June and July, but feeding guilds became more evenly distributed in August (Figure 27). Hemipteran families of Flatidae and Acanoloniidae were found in great abundance in June, but decreased in subsequent sampling months (Figure 28) (Figure 29). Abundances suggest that orders representing detritivores/scavengers and predators (Psocoptera, Thysanoptera and Araneae) increased over the summer, while most other orders decreased (Figure 19a).

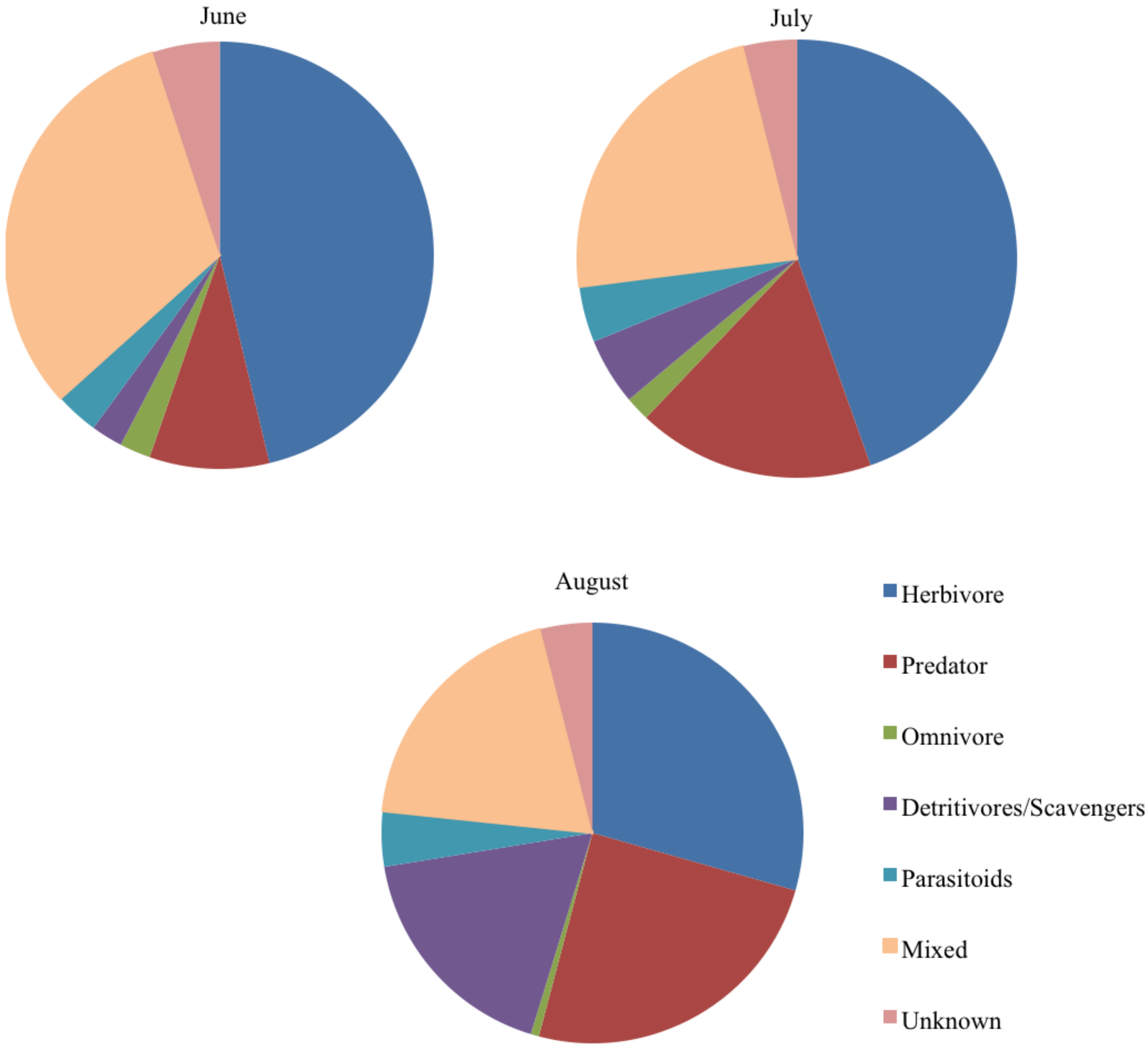


Figure 27. Combined feeding guild proportions of arthropods sampled from all ten green walls over the summer of 2011. The mixed category consists of Coleoptera and Diptera orders, and the Formicidae family. These taxonomic groups contain a complex array of trophic types which could not be easily assigned without finer identification. The category is included to show that all arthropods are accounted for.

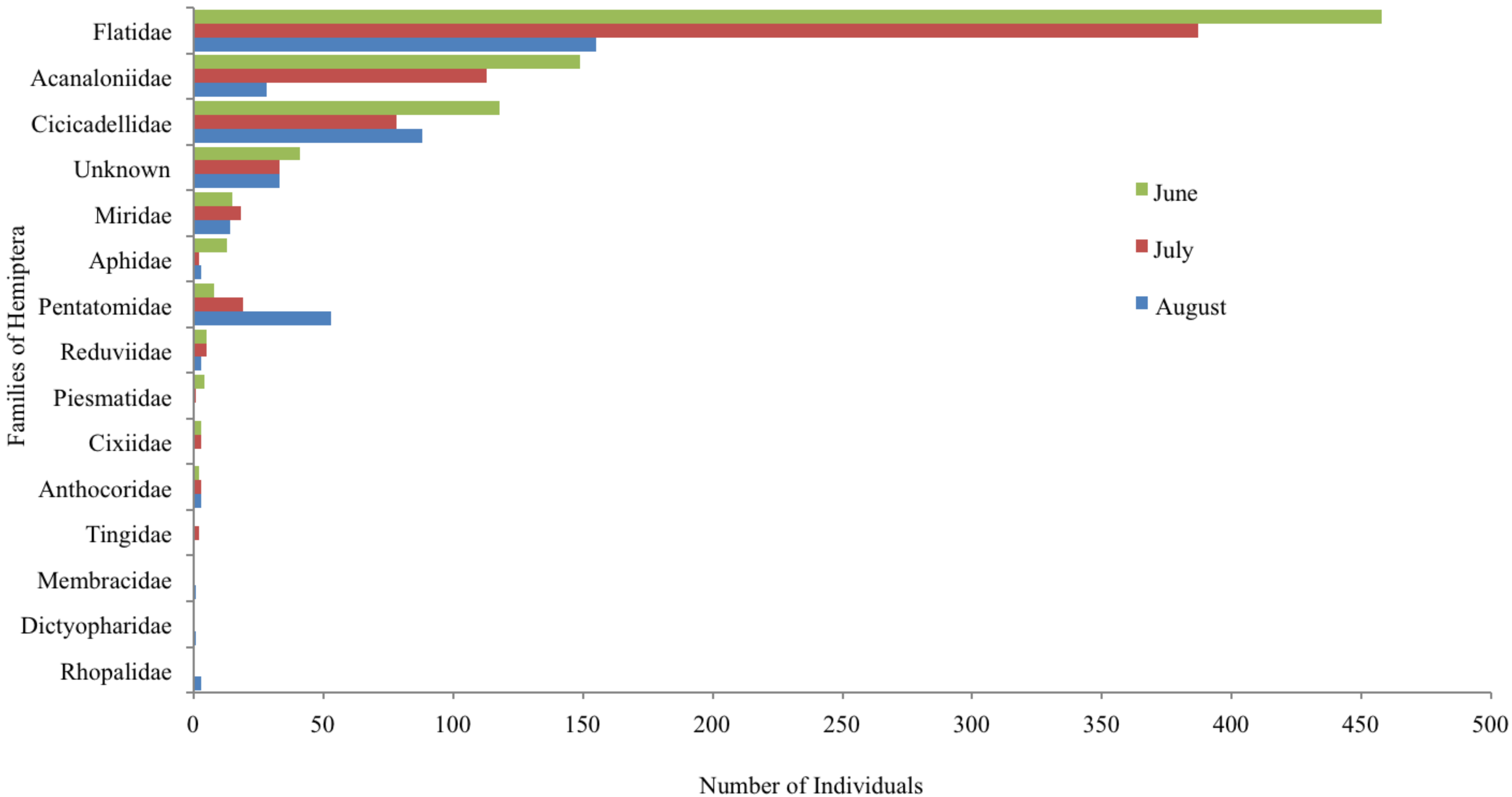


Figure 28. Combined counts of individuals grouped by taxonomic family, from the order Hemiptera, sampled throughout the summer of 2011 at all 10 green wall sites.

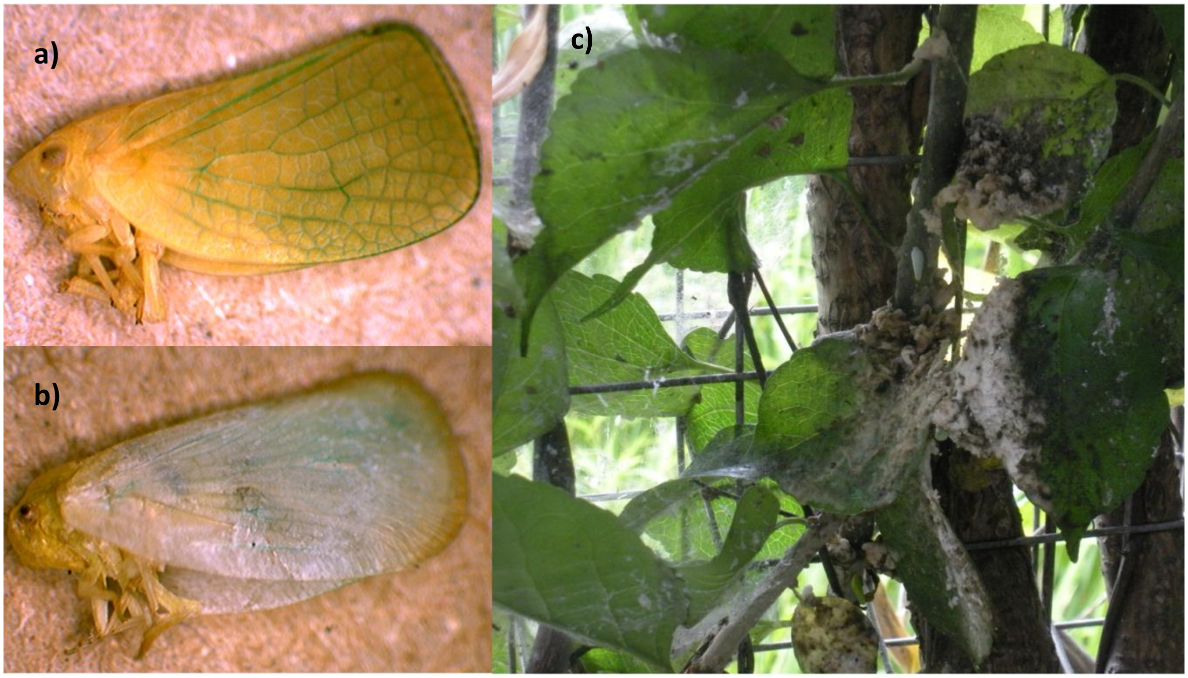


Figure 29. Reference specimen of Hempiteran plant-hopper families Acanaloniidae (a) and Flatidae (b) and image of web like structures in which many Flatidae were observed (c)

CHAPTER 4: DISCUSSION

Vegetation Growth

Schumann (2007) studied growth characteristics of green cloaks, which are similar to green façades, except that their support systems guides vines over the roof of a structure, in addition to its walls. Schumann compared the growth characteristics of experimental green cloaks to those of mature wild vine communities growing on 9 barns in Maryland.

Schumann reported that the barns supported 8 vine species (Japanese honeysuckle, Virginia creeper, blackberry, common greenbrier, grapevine, poison ivy, trumpet creeper, and wild hydrangea), with 1 to 4 species at any given site. Our study observed a total of 13 vine species, with 1 to 6 species on any green façade. It is not surprising that green façades supported slightly higher vine richness than the bare walls of the barns, as the green façades are cultivated and further, their trellis structures accommodate more methods of attachment. Schumann also reported LAI's of the wild vine communities with a mean of 3.14, a minimum of 1.47, and a maximum of 5, which was comparable to the LAI values of the green façades in our study (Table 4). We concur with Schumann's conclusions regarding green cloaks; engineered systems are able to sustain vine growth comparable to growth in wild systems.

Abundance and Diversity Values

Köhler (1998) obtained 338 and 1134 arthropods from 9 vine-covered buildings, using beating and pitfall traps respectively. Beating results are more readily compared to our study, as both beating and vacuuming collect arthropods at discrete intervals in time, while pitfall traps cumulatively and continuously collect arthropods. Köhler did not specify the number of samples taken at each site thus differences between our studies might be a function of sampling effort rather than biological or environmental variables. Regardless, the dominant orders sampled were similar between the studies with Köhler reporting Araneae (32%), Hemiptera (29%), Diptera (23%), and Hymenoptera (7%). Mean abundance of arthropods on our green façades (1469) far exceeded those reported by Köhler (338). In addition, our mean order-richness of 14 was double Köhler's observation of 7.

Green roofs create comparable habitat to green walls, consisting of relatively small patches of cultivated vegetation, installed on buildings, usually in highly developed areas. Coffman and Davis (2005) sampled arthropods on a single green roof in Michigan by sweep netting along transects throughout July and August, obtaining 9 orders, the most abundant of which were Diptera (51%) and Hemiptera (47%). Abundances were not comparable to our study due to differences in sampling effort. Jones (2002) vacuum-sampled arthropods from 8 green roofs in London in May and August, and obtained 12 orders, the most abundant of which were Coleoptera, Hemiptera, and Araneae. Abundances were not provided in his study.

The dominant orders obtained by these studies represent mobile species of arthropods, the winged insects Hemiptera, Diptera, and Hymenoptera. Jones found that Carabidae (ground beetles) dominated, and while individuals rarely fly (Triplehorn and Johnson, 2005) they are able to colonize areas as far away as 1 km (McIntyre, 2000). In addition to these arthropods, our study found winged Psocoptera, or barklice (Figure 30) and Araneae, which despite being wingless, can also be quite mobile. Small or immature Araneae can travel long distances when individuals releasing strands of silk are caught and transported by air currents. Arthropod mass was not measured, but observationally, most Araneae in this study were very small or immature and thus capable of this ballooning mechanism. It makes sense that mobile arthropods would dominate green spaces isolated by urban landscapes, which contain few continuous corridors for more sessile species to readily pioneer these sites.

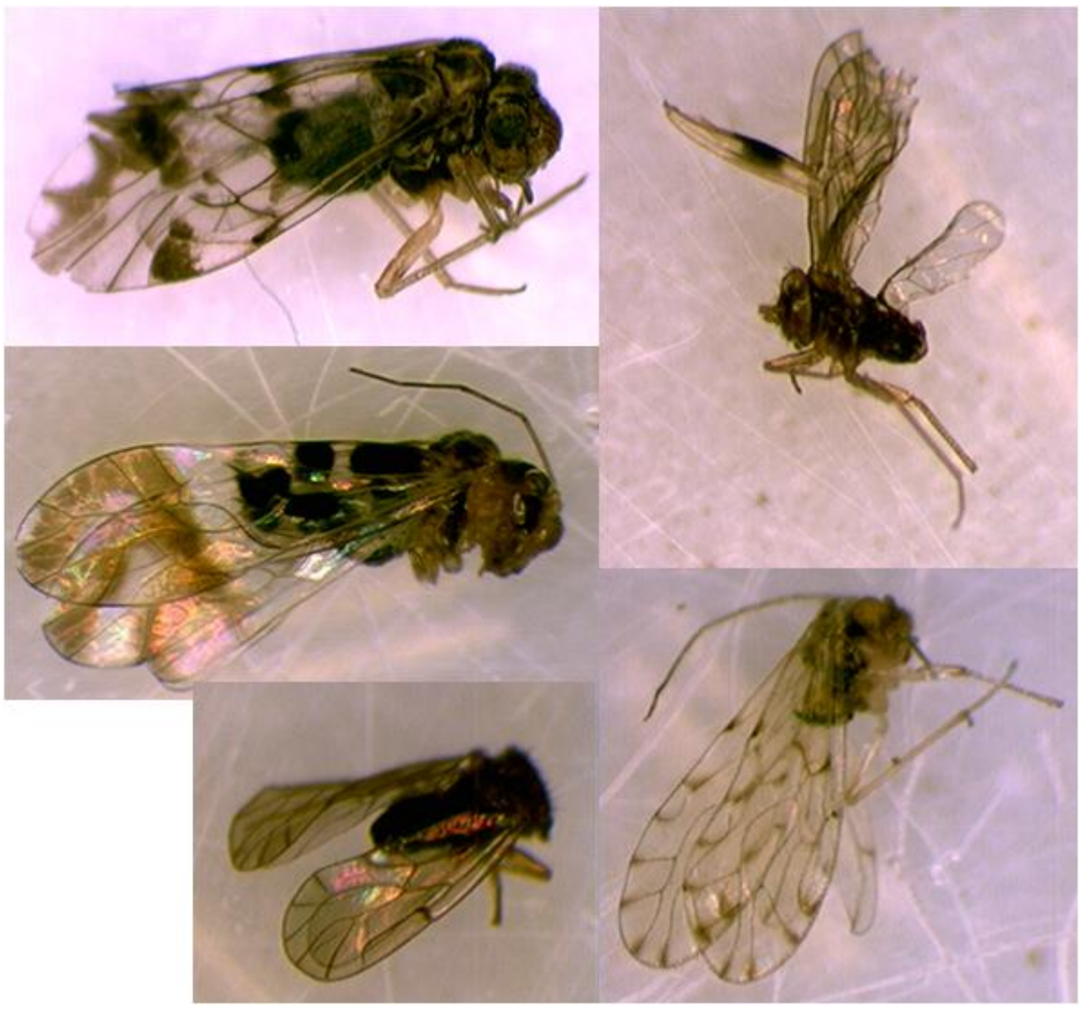


Figure 30. Reference specimens of Psocoptera (barklice) displayed well developed wings.

Semi-natural fragments, parks, gardens, roadside vegetation, lawns, and brownfields are examples of some of the many diverse urban habitats in which arthropod communities have been studied (Kutschbach-Brohl et al. 2010). The relative quality of habitat provided by green façades could be determined by comparing our diversity and abundance values to these other studies. Unfortunately, few of these studies used similar sampling techniques. Kutschbach-Brohl et al. (2010) vacuum sampled arthropods in 5 fragmented grassland habitats from May through September at the JFK airport in New York. These grassland fragments ranged in isolation from nearby runways and most patches were mowed twice seasonally. Although mowing can reduce Hemipteran diversity (Helden and Leather 2004), Kutschbach-Brohl et al. (2010) considered mowing at JFK minimal compared to residential and commercial gardens or lawns, and concluded that the grasslands held substantial conservation value for arthropod communities in urban areas. They collected 1467 arthropods from 17 orders, the most dominant of which were Hemiptera (47%), Orthoptera (18%), Diptera (14%), Hymenoptera (7%), and Coleoptera (6%). Despite having used smaller quadrat sizes than our study (0.34 m^2 vs. 0.56m^2), the mean number of individuals per quadrat still seemed considerably lower than our values (2.3-3.5 individuals vs. 17-12). Order richness and order-dominance, except Orthoptera, were similar.

Bolger et al. (2000) vacuum sampled arthropods from urban scrub habitat fragments in San Diego, California during the month of May. Though these scrublands of dendritic canyon systems were fragmented and isolated by urban and suburban development, they represented relatively large contiguous tracts of land (0.3-91 hectares) which were neither maintained nor mowed. Bolger et al. obtained 17 orders with a mean of approximately 7 orders and 65 individual arthropods per sample, which far exceed our abundances and order densities but was comparable to our order-richness. Their dominant orders were Hemiptera (~46%), Coleoptera (~20%), Araneae (~16%), and non-ant Hymenoptera (~7%). Dominant orders were somewhat similar to ours except for the abundance of Coleoptera and deficit of Diptera.

Our arthropod abundance and diversity values fall between the values obtained by Kutschbach-Brohl et al. (2010) and Bolger et al. (2000). The sites examined in their studies were larger, less integrated into the built environment, less cultivated and furthermore, by supporting a soil and canopy layer, they likely contained higher habitat heterogeneity. The comparability of our abundance and diversity values suggests that, though not at the higher end, green façades support habitat consistent with less managed urban areas.

Feeding Guild Diversity

The diversity of feeding guilds, paired with observations of nests, webs, eggs and breeding (Figure 31), suggests that ecological interactions such as predation, competition, reproduction and oviposition occurred on the green walls. Decreasing herbivore abundances paired with increasing predator abundances throughout the summer provide evidence for top down regulation of phytophagous insects, suggesting that the walls are not simply acting as hosts to insects which might feed on and damage the vines, but rather as hosts to a variety of organisms which are perhaps promoting natural suppression of potential pests Our results suggest that herbivores did not decrease in response to plant resource availability because plant abundance did not change dramatically throughout the summer.

Increased Psocoptera abundances may have been the result of increasing plant litter as the summer progressed, although leaf litter was not measured. Predation by higher level organisms like birds is not considered here, though preliminary avian observations are described in Appendix 1.

Figure 31. Examples of webs, nests, eggs, and breeding observed in the field: unidentified webs (a and b), paper wasp's nest (c), hornet's nest (d) hatching eggs of Reduviidae (e), eggs of Mantodea (f), parasitic Hymenoptera likely feeding on honeydew (nutritional resource) produced by aphids (g), breeding grasshoppers (h).

These guild dynamics hint at a commonly proposed successional model in which plant seasonal dynamics drive arthropod succession dynamics (Siemann et al. 1999). Plant growth and grazer abundance peak in June, followed by an increase in predators which feed on the grazers, and then detritivores, which appear as the plants begin to senesce. Classical ecological succession occurs over much longer time periods than a three month study. However, the seasonal sequence implied by our trophic proportions could be viewed as an analog of the longer term process, in so far as both show that directional community development creates a web of symbiotic interactions between organisms and their environment. Our seasonal snapshot suggests that these walls are able to support healthy ecological succession and ecological services. Furthermore, the presence of detritivores suggests that these systems are more complex than the linear plant-herbivore-carnivore sequences of early succession (Odum, 1969).

Correlates of Arthropod Abundance and Richness

This study found that habitat availability within a 200 meter buffer zone (%NH), structural complexity of adjacent landscaping (LC), vine canopy thickness, vine area, and the vine composite index all positively influenced arthropod richness and abundance. This contrasted with Smith et al. (2006), who found that few consistent correlates existed across taxa for either arthropod richness or abundance, when examining environmental variables in 64 urban gardens across Sheffield, UK.

Arthropod richness varied directly with structural complexity of adjacent landscaping in August, and with vine canopy thickness in July, and August. In a literature review examining the relationship between animal diversity and habitat heterogeneity, small scale architectural complexity was found to be related to richness of arboreal arthropods, web spiders, grasshoppers, epigaeic beetles, and drosophilids (Tews et al. 2004). Gardner et al. (1995) determined that architectural complexity and vertical diversity of vegetation influenced ground arthropod diversity, while in another review, Lawton (1983) observed positive effects of architectural complexity on phytophagous insects. As used by Lawton (1983), architectural complexity of vegetation considers size, growth form, seasonal development, and variety of above ground parts. This is a broader operational definition than the structural complexity measure used in this study but suggests results consistent with ours. Results suggest that making landscaping adjacent to the green walls structurally diverse i.e. mixing groundcover, perennials/annuals, shrubs, etc (Figure 32), could create more diverse arthropod habitat and associated arthropod biodiversity.

Vine richness, LAI, thickness, and area were measured in lieu of the vine's structural complexity. Of these measures, thickness was most strongly related to arthropod richness. Perhaps thickness is best for creating habitat heterogeneity, with the layered and intertwining branches of the vines (Figure 33) creating varying microclimates and microhabitats for oviposition and refuge.

Figure 32. The National Wildlife Federation headquarters in Reston, VA had the most structurally complex adjacent landscaping- a mixture of groundcover, annual and perennials, shrubs, and understory trees were planted in front of the building.

Figure 33. Eastern Village cohousing apartment complex in Takoma Park, MD supported a thick vine canopy.

Arthropod abundances varied directly with %NH, across taxa, in June, July, and August. Similarly, Davis (1978) found that open space within a 1 km radius was the best single predictor of arthropod abundance in urban gardens of London, though open space within smaller buffer areas were only weakly correlated. The dominance of mobile arthropods (winged or ballooning specimen) sampled in this study could explain this consistent relationship between abundance and our measures of larger scale habitat availability. If more specialized, sessile organisms had dominated samples, perhaps relationships between abundance and smaller scale measures of vegetation, like vine richness and LAI, would have been stronger.

Arthropod abundance also varied directly with vine area in July, and the vine composite index in June and August, though less strongly than %NH. A positive association between vine area and arthropod abundance has been observed in other studies (Helden and Leather, 2004, Bolger et al., 2000). Correlation with the vine composite index, intended to be a proxy for the structural complexity of the vine, is also consistent with many other studies which have determined a strong relationship between arthropod abundance and structural complexity (Shrewsbury and Raupp, 2000). Unlike arthropod richness, arthropod abundance was not related to any individual component of the vine composite index. The results suggest that vegetation measured at multiple scales- the neighborhood, the overall expanse of the vine, and the specific growth characteristics of the vine- were important correlates of arthropod abundance, though land cover was the strongest and most consistent.

Smith et al. (2005, 2006) and Davis (1978) determined that arthropod abundance and richness shared common correlates. In our study, abundance and richness varied directly with each other in June and August, but were dependent on different environmental correlates. However, while they shared no exact correlates, both arthropod richness and abundance were related to features of the vine canopy.

Given that LAI has been found to be strongly correlated with biomass (Schumann 2007) and thus the availability of food for phytophagous insects, the building blocks of the food chain, it was surprising that there was no relationship between abundance or richness and LAI.

Although no relationship between vine age and arthropod abundance or richness was found, age did vary directly with vine area and canopy thickness during parts of the summer. With age, the area the vine grows upon expands and the stems thicken, although this growth is limited both by the size of the support trellis and by any horticultural maintenance (i.e. pruning, cutting back). Age of fragmented green space has been found to be both negatively and positively correlated with arthropod abundance depending on the taxonomic group (Bolger et al. 2000). While our results did not show that vine age was directly indicative of arthropod abundance, vegetation characteristics that were related to age were also indicative of abundance, suggesting that age was indirectly relevant.

Correlate Summary

The relationships between arthropod richness, abundance, and vegetation found by this study were in accordance with results from other studies. Available habitat within 200m of the sites (%NH) stood out as the strongest and most consistent correlate of arthropod abundance, likely due to the dominance of mobile arthropods in our samples. Smaller-scale vegetation characteristics were also found to be correlated to abundance, though less strongly than the larger-scale %NH.

Correlates of arthropod richness consisted of the smaller-scale structural measures of vegetation, such as vine canopy thickness, and structural complexity of adjacent landscaping, perhaps because they enhance microhabitat and microclimate diversity. Both richness and abundance were related to some measure of the vine canopy and perhaps indirectly to vine age.

It would be interesting to test some correlates by taxa as opposed to across taxa as certain taxonomic groups will respond differently to the same measure (Smith et al. 2006). However, due to the small sample size of this study, the additional pair-wise comparisons would not be statistically appropriate. Additionally, many correlation coefficients seemed to indicate moderate to strong linear associations between vegetation and arthropod measures, but were not statistically significant. The small sample size of this study may have shielded these relationships of potential significance from detection.

For Further Consideration

The coarse taxonomic resolution used in this study (i.e., order) does not allow us to draw any conclusions regarding the presence of rare, beneficial, pestilent, native, exotic, or invasive species of arthropods. It does not allow us to recognize specific pairings between specialized insects and plants nor affirm the presence of rural, urban, or eurytopic species, except where generalizations have been made for larger taxonomic groups (parasitoid Hymenoptera for example). Though this study established a baseline, future studies would benefit from the ability to more finely identify sampled specimens. Furthermore, though vacuum sampling is considered suitable for obtaining complete inventories, by sampling the vine canopy alone, this study presents a biased sample of the overall arthropod community. For example, sweep netting, pitfall traps or colored pan traps could have targeted butterflies and moths, ground arthropods and pollinators respectively. Pollinators, commonly featured in other urban habitat research, might be of particular interest for subsequent studies. Sampling occurred predominantly after the vines had blossomed thus a future study should consider sampling during this period (Figure 34).

Figure 34. Vines in bloom at Eastern Village Cohousing and the National Wildlife Federation (*Akebia quinata Campsis radicans*) during preliminary visits to the sites in May, 2011.

Due to the limited scope of this study a small number of vegetation based correlates were examined. Light exposure, pollution, human disturbance, microclimate, and avian presence are some other variables which, though likely correlated with vegetation variables, would be worth examining in future studies. Future studies might also consider comparing green walls to adjacent vegetation to determine if green walls act as a continuation of existing habitat or perhaps provide habitat for a unique assemblage of arthropods. For example, some suggest that green roofs, exposed to sun and wind, mimic cliff habitats thus providing a niche for unique organisms in urban areas (Lundholm, 2006).

CHAPTER 5: CONCLUSION

Green façades supported significantly higher arthropod abundance and diversity than similar building walls lacking vegetation. Hemiptera, Hymenoptera, Araneae, Diptera, and Psocoptera were the most common orders sampled. Arthropod abundance was most strongly related to habitat availability within a 200 meter radius, perhaps due to the high range of mobility of most of the sampled specimens, and less strongly related to vine area and a composite index of vine canopy structure. Arthropod richness was most strongly related to vine canopy thickness and the structural complexity of adjacent landscaping, relevant perhaps via their enhancement of microhabitat and microclimate. Abundance and diversity values consistent with other urban habitat studies, and the variety of feeding guilds represented by sampled specimens, suggest that green facades support a healthy community of arthropods relative to other urban habitats. Further studies would benefit from finer taxonomic resolution and sampling adjacent habitats for comparison.

APPENDIX 1

Avian Observations

Prior to sampling for arthropods, green walls were surveyed for birds for 10 minutes and then scanned for nests. Casual observations of birds interacting with the walls were recorded throughout the day. Birds were observed at 70% of the sites in June, and at 40% of the sites in July and August. Of the nine species of birds recorded throughout the summer (Table 13), House Sparrows were the most common. Nests were found at 50% of the sites. Some nests were embedded within the trellis mesh (Figure 35) while others were found on the support beams of the trellis (Figure 36). Birds were observed feeding on berries and flowers (Figure 37), attending to their young in nests (Figure 38), perched on the trellis itself (Figure 39) sitting within the vine itself (Figure 40), and often moving between adjacent street-side trees and buildings and the walls (Figure 41). Future studies could extend observation times and could commence earlier in the morning or in the evening to more specifically observe feeding or roosting habits. During senescing months of the vines, the trellis structures could be thoroughly surveyed for nests.

Figure 35. Nest of *Passer domesticus* found within the trellis mesh of green wall experimental structures at Clarksville, MD.

Figure 36. Unidentified nests found on trellis support beams at the Montgomery College Parking Garage installation in Takoma Park, MD.

Table 13. Avian species and families observed over the course of the summer

Site	Species/Families Observed			Activities observed	Nests observed?
	June	**July**	**August**		
1	*Passer domesticus* (House Sparrow)	*Passer domesticus*	*Passer domesticus*	Mainly sitting within mesh of trellis or on support beams of trellis beyond the range of vegetation, often flying between trellis and adjacent street-side trees.	Yes
2	*Passer domesticus*, *Turdus migratorius* (American Robin), *Mimus polyglottos* (Northern Mocking Bird)	*Dumetella carolinensis* (Grey Catbird), *Passer domesticus*, Trochilidae (Hummingbird Family), *Cardinalis cardinalis* (Northern Cardinal)	*Dumetella carolinensis, Passer domesticus, Cardinalis cardinalis*	Seen in both vines and on trellis alone, often flying to adjacent street-side trees. Hummingbirds feeding on honeysuckle blossoms, Catbird feeding on berries of honeysuckle, Cardinal observed feeding young in a nest within the vines. Some birds observed within the empty gaps of trellis support beams.	Yes
3	……………………..	……………………..	…………………..	………………………………………………..	No
4	*Carpodacus mexicanus (*House Finch)			Seen flying into vines.	Yes
5	Gold finch, Icteridae (Grackle Family), *Passer domesticus*			Seen sitting in vines and atop trellis.	No
6	*Passer domesticus*, *Turdus migratorius*	*Passer domesticus*, Trochilidae, *Mimus polyglottos*	*Carduelis tristis* (American Goldfinch), *Passer domesticus*, Trochilidae	Seen sitting in both vines and on trellis alone, hummingbird feeding on honeysuckle blossom.	No
7	*Mimus polyglottos Passer domesticus,*			Seen on roof of house and in vines.	Yes
8	*Carpodacus mexicanus, Passer domesticus*		*Passer domesticus*	Seen in both vines and on trellis alone. Finches seemed to be taking twigs from the vines and flying to an adjacent building.	No
9	*Carpodacus mexicanus, Passer domesticus,* Trochilidae	*Carpodacus mexicanus, Passer domesticus,* Icteridae	*Passer domesticus*	Seen perched atop trellis and in vines. Birds fly from adjacent street-side trees to vines. Hummingbird seen feeding on honeysuckle blossom.	Yes
10	*Passer domesticus*	*Carpodacus mexicanus*	*Carpodacus mexicanus*	Seen only on trellis alone	No

Figure 37. Bird observed feeding on berries of Lonicera Sempervirens at Eastern Village Cohousing in Takoma Park, MD.

Figure 38. Female cardinal observed feeding its young at their nest.

Figure 39. Birds observed perched on the trellis and its support beams rather than the vegetation

Figure 40. Birds observed perched upon the vines.

Figure 41. Birds observed moving between the green walls and adjacent buildings or street-side trees.

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