A COMPARISON OF INSECT AND SPIDER SPECIES PRESENCE AND COMPOSITION ACROSS MULTIPLE VEGETATED ROOF SYSTEMS

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF ARTS

Environmental Design

2011

ABSTRACT

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With increased development of the built environment, the natural landscape continues to be lost and along with it much of the habitat necessary for invertebrate survival. One way to remedy this problem is through the use of vegetated or green roofs. Vegetated roofs possess the potential to turn the sterile, impervious, and oftentimes unused environments of rooftops into viable habitats for invertebrates. This study attempted to determine exactly how successful green roofs are at creating invertebrate habitat for insects and spiders and to identify the characteristics associated with green roofs that make them successful for invertebrate establishment. The principle field methods for invertebrate collection included sweep net and pitfall traps; sampling occurred over a seven-month period (April-October) in 2010. All spiders and insects collected were identified to family level and organized and counted to calculate species abundance and richness, Simpson's diversity index (D), Shannon Weiner diversity index (H'), and Evenness (E). Analysis resulted in significance between the percent of roof covered with vegetation and insect and spider species abundance and richness. The size (area) of a green roof also significantly influenced the richness of insects and spiders present. Roof height, roof age, media depth, and vegetation type were not found to be significant factors influencing insect and spider abundance and diversity. In all cases, green roofs provided habitat for a variety of insects and spiders.

ACKNOWLEDGEMENTS

There are many people to acknowledge for making this thesis possible. I would like to thank my advisor Dr. Joanne Westphal for her encouragement to enter into this program and her continual guidance and support throughout. I would like to thank those graduate students who came before me and played a role in establishing the “green roof team” and laying the foundation for this type of research. I would like to thank the other members of my committee, Dr. Henry “Rique” Campa and Dr. D. Bradley Rowe for their exceptional guidance in research design and all matters related to green roofs. A thank you is deserved to Gary Parsons and especially Daniel Swanson for the much needed assistance with insect identification. I would like to thank Dr. Deborah McCullough and Dr. Stewart Gage for their guidance in areas concerning insect collection and analysis. I would like to thank Dr. John Schweitzer and Pablo Reeb for their assistance with statistical analysis. I am grateful to all those responsible for granting me access to their green roof and allowing my research to be conducted. Most of all, I would like to thank my wife Hannah, for her patience and steadfast encouragement throughout this entire process.

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THESIS INTRODUCTION

Conventional rooftops are sterile impervious surfaces that have immense potential to bring nature back into the built environment. Green roofs, also known as vegetated roofs, living roofs, or eco-roofs, are capable of providing numerous beneficial environmental services to the built environment; these benefits include storm water management, energy conservation, extended roof life, reduced noise and air pollution, mitigation of the urban heat island effect, carbon sequestration, and aesthetics (Cantor, 2008). One area that appears to have potential, but little data exists, is wildlife habitat restoration via green roof design and use in built environments. This study proposed to build baseline data on the relationship between green roof design and the presence of existent insect and spider communities in urban areas. Specifically, the study calls for the observation of eight different green roofs and their capacity to support the presence of insect and spider communities. Discussion of how these invertebrate communities differ as a result of the varying vegetated roof characteristics will conclude the study.

LITERATURE REVIEW

History of green roofs. The concept of vegetating rooftops has been known for centuries. Ancient civilizations, such as the Babylonians and Romans, realized the benefits of ornamental roof gardens over built structures (Weiler & Scholz-Barth, 2009; Dunnett & Kingsbury, 2008). Turf roofs have been incorporated into local architecture for centuries, especially in geographic regions like Scandinavia. It was not until the development of modern building materials in the 20th century, with the widespread construction of flat roofs, that an extensive increase in rooftop gardens occurred (Dunnett & Kingsbury, 2008).

Vegetated rooftops on buildings are not a recent phenomenon. Although green roofs may seem like a pioneering consideration in the United States, in actuality vegetated roofs have had a common place in Europe and the Middle East for millennia. Advances in technology and design, however, have made them more practical. Germany has led the development of contemporary, manufactured green roof products over the past century; in 2003 Germany installed 13 million m^2 (140 million ft^2) of vegetated roofs (Grant et al., 2003). Green roof application has since spread throughout central Europe and the rest of the industrialized world (Dunnett & Kingsbury, 2008). Today, green roofs are divided into two main categories, intensive and extensive green roofs. Intensive green roofs generally have a media depth of 15.24 cm (6 in) or more, and often the roofs are designed for physical access by people. Because of the media depth, intensive green roofs allow for more options pertaining to vegetation selection and overall design features; in return, they require greater amounts of maintenance and stronger structural integrity. Extensive roofs typically have less media depth (10.16 cm [4 in] or less) and a limited amount of plant species. In general, extensive green roofs are not intended for human access/use, and as a result, they tend to require less maintenance and structural load capacity. Although these are the primary categories that presently exist for green roofs, gradations of each have lead to an intermediate third category, called a semi-extensive green roof, which generally has soil media at depths of 10.16-15.24 cm (4-6 in).

Typical construction of green roofs. A variety of different green roof systems exist today with continuous innovations leading to variations of each system. Conventional, modular, and vegetated mat green roof systems are the three universal structural categories of green roofs that are used throughout the world (Snodgrass & McIntyre, 2010). Conventional systems consist of multiple layers of different material, placed directly on a roof membrane. Typically the layers consist of a waterproof roof membrane laid directly on the roof decking; a root protection barrier; a drainage layer; filter fabric (to hold media); soil media; and vegetation. Modular systems refer to a containerized green roof system, the container of which is fashioned from a variety of different materials and formed into a range of shapes and sizes. The containers are filled with soil media and topped with vegetation. The modules are placed side by side on top of the roof membrane or other base layers (as desired), to produce a green roof. The third standard green roof system is a layered vegetated mat system, which is similar in concept to the way ordinary sod is grown. Blankets of green roof vegetation are pre-grown, cut and rolled (or stacked) in the field and transported to the application site. The mats are placed directly onto the roof after a waterproof membrane and drainage layer are installed on the structure. All of the above mentioned green roof systems perform well when “used appropriately”. Optimal performance is determined by the installation characteristics for each project. In this study, a profile of each green roof system was developed through field work, and this data was examined in detail for its influence on the presence of insects and spiders.

Benefits of Green Roofs

A large amount of research has been conducted on green roofs and the benefits they provide for the environment. The concept of adding pervious surface and usable open space to areas, without taking up additional land, seems logical. The incorporation of substrate and media to a roof greatly enhances the ecosystem services (ie., benefits that the natural environment provides towards human occupancy and environmental health), and as a result many designers, clients, building owners, and planners are beginning to consider green roofs as a key element in a step to improve environmental quality (Weiler & Scholz-Barth, 2009).

Storm water runoff. One of the most highly researched and well-documented ecosystem services provided by vegetated roofs is that of storm-water management (Berndtsson, 2010). This subject is particularly important when considering urban areas, which continue to rapidly increase in size and density. The amount of impervious surface in the contiguous United States for the year 2000 was estimated at 83,700 km^2 (32,317 mi^2) (Theobald, et al., 2009). This vast amount of impervious surface can result in intense storm-water runoff that can overload existing (and usually dated) combined storm-water and waste water management facilities (Oberndorfer et al., 2007). The overload to the facilities consequently allows for the combined storm-water and sewage lines to release pollutants directly into adjacent waterways. According to the US EPA (2004), 32 states still operate with combined sewer systems resulting in an estimate of up to 3,218 billion liters (850 billion gallons) of contaminated water discharged per year in the U.S.

The addition of media and vegetation to rooftops helps combat the overflow of storm-water to existing facilities by providing a porous media which retains water, and vegetation that ties up water in its roots and vegetative system through photosynthesis and evapotranspiration processes (Bliss et al., 2009). Depending on regional climate and environmental conditions, vegetated roofs have reduced total building runoff by as much as 70% to 75% compared to conventional roofs (Bliss et al., 2009; Köhler et al., 2002). The adoption of green roofs on structural entities assists in mitigating the negative environmental effects of storm-water produced by the construction of roads, buildings, parking lots, driveways, and other impervious surfaces.

Air and noise pollution. The air that we breathe could be considered one of the most essential natural resources to all inhabitants of planet Earth. The increase in industrialization, transportation, and rapid urbanization are generating numerous problems in regards to air and noise pollution that has an increasing affect on human health (Santosa, 2010). The levels of air pollution are dependent on geographic area with levels significantly increased as urban density increases. Air pollution can take the form of particulate matter, heavy metals, acid rain, and ozone (Dunnet & Kingsbury, 2008). Noise pollution also increases with urban density due to increased amounts of aircrafts, transit systems, industrial sites, street traffic, and echoes created by built-up structures forming street canyons (Van Renterghem & Botteldooren, 2008; Van Renterghem & Botteldooren, 2009). Both air and noise pollution can be reduced by the insulation and surface absorption properties exhibited with green roof media, and by the filtration, dry deposition process, and cooling effect demonstrated via green roof vegetation (Rowe, 2011; Yang et al., 2008).

Urban heat island effect. The urban heat island effect refers to urban areas that have higher temperatures than their surrounding suburban and rural areas, particularly at night. The increases in temperature can have many detrimental effects on human health, energy use, air pollution, water use, biological activity, and flooding from ice and snow (Heisler & Brazel, 2010). These negative effects are commonly caused by the construction of dark colored, impervious-surfaced structures with high heat absorbing qualities in the form of buildings, roofs and paved areas (Dunnet & Kingsbury, 2008). The heat island also is intensified by the general lack of vegetation within urban areas; therefore, increases in vegetation have shown to have positive effects on urban heat island mitigation (Susca et al., 2011) by offsetting the high heat transmitted from rooftops through evapotranspiration.

Economics of roof life & insulation. Although vegetated roofs provide numerous ecosystem services that are a benefit to human health and the environment in general, for some that is not enough. Green roof adoption is a matter of economics. By shielding exposed roofs from the extremes of climate, vegetated roofs are able to function well for longer periods of time than conventional roofs (Carter & Keeler, 2008b). In many cases green roof longevity is double or triple the life expectancy of conventional roofs, and in certain cases, green roofs have functioned well over 100 years with minor repair and/or maintenance (Dunnett & Kingsbury, 2008). The extended life cycle of a vegetated roof provides a viable justification to the initial cost of green roof installation, especially when long-term costs of roof replacement, installation, and waste disposal are considered in real time dollars (Clark et al., 2008).

Another direct economic benefit provided by green roofs is the energy conserved through roof insulation. Energy used for heating and cooling buildings is the largest single source of energy consumption within the residential sector (U.S. Department of Energy, 2011). By applying a layer of media and vegetation, a building is insulated from the heat of summer and the cold of winter, thereby reducing energy consumption. Depending on the size of the building and amount of media applied, significant reductions in energy can be achieved. Studies have proven that even the smallest amounts of media and vegetation added to a roof will contribute to decreases in energy consumption (Kosareo & Ries, 2007; Carter & Butler, 2008a).

Aesthetics. The aesthetic value provided by vegetated roofs offers one of the most direct benefits. It can be safely stated that the majority of conventional roofs present unattractive views. This can be particularly true in urban areas, or on large commercial and industrial roofs. The addition of vegetation to a roof softens and greens its exterior surface improving the scene that is normally experienced with asphalt or steel material on roof areas (Snodgrass & Snodgrass, 2006). The increased aesthetics produced from vegetated roofs also have been shown to generate favorable impressions on communities by increasing property value in areas surrounding green roofs (Köhler et al., 2002). Kats (2010) also has shown in certain contexts, green roofs and environmentally friendly surroundings, in general, help to improve worker productivity.

The extent of aesthetic value that green roofs provide is of course quite subjective and relies entirely on personal preference. It is accurate to state that in general, vegetation on a roof is preferred to a conventional rooftop (Köhler et al., 2002). The question then becomes, what type of vegetation expresses the greatest aesthetic value. In some areas (particularly in Europe), aesthetic value is associated with other benefits provided by vegetated roofs, such as habitat creation, and therefore, the vegetation appearance is not required to be over-maintained and manicured. In other areas, such as the United States where green roofs are relatively new, aesthetics demand that the vegetation be properly maintained, and this may entail excessive albeit unnecessary amounts of maintenance. The novelty of green roofs in the U.S. can result in them being perceived as unsightly or ugly because the indirect ecological benefits are not known and/or perceived. It is thought that as knowledge and education is increased, a more desirable relationship between aesthetics and ecology will be found (Gobster et al., 2007).

Green Roofs and Biodiversity

The term biodiversity refers to the overall richness of species that exist on the planet (Lovejoy, 1997). The diversity of living organisms can be broken down into very specific or very broad categories. Biodiversity not only refers to the forms of life present on earth, but it also includes the functions provided by each of the different forms of life (Millennium Ecosystem Assessment, 2005).

No matter the scope of category, species diversity has proven to stabilize and maintain ecosystem processes, which provide goods and services to human societies through the form of ecosystem services (Millennium Ecosystem Assessment, 2005). With the continuous movement of populations toward the extremely altered ecosystems of urban areas, (ie, 70 percent of the world population is expected to be urban by 2050 according to the United Nations [2008]), caution needs to be maintained to protect the elements supporting natural diversity. This is particularly important because extinction is a permanent end-result. Green roofs provide a simple solution by incorporating key elements (ie., shelter and food) that support a diversity of living organisms within the built environment.

Green roofs essentially function as small habitat patches, counteracting the damage caused by construction of the built environment. The challenges of creating viable habitat for wildlife and invertebrates in green roof design are considerable, especially in terms of extreme temperature, moisture conditions, and lack of deep media profiles. Despite these challenges, green roofs exhibit similar characteristics comparable to rock barren ecosystems such as cliffs, steep slopes, and limestone pavements (Lundholm, 2006). Increased research and education efforts on green roof design will continue to transform green roofs into diversely functioning habitats.

Wildlife value of green roofs. Vegetated roofs possess vast potential to facilitate wildlife by creating new habitat in areas currently lacking foraging and shelter opportunities. Green roofs can provide wildlife corridors, which in turn promote movement and dispersal of wildlife (Kadas, 2006). Due to inaccessibility of most green roofs, limited types of wildlife species are able to effectively colonize the roofs. Once roofs are accessed, however, wildlife is very adaptable and will quickly colonize and establish communities on green roofs (Kadas, 2006). A few of the wildlife target species likely to colonize green roofs are birds, lizards, and possibly, small mammals.

Wildlife habitat design on green roofs. Two of the most important criteria for successfully attracting wildlife are increasing the structural complexity and diversity of vegetation. Ideally, the complexity of elements should be taken beyond vegetation to include diversity of soils, topography, and micro-climates (Brenneisen, 2006). Other beneficial elements encouraging wildlife would be native soils, rocks ranging in size, and debris ranging from logs to snags. The incorporation of these additional elements would increase habitat opportunities for invertebrates, with subsequent increases to avian, reptile, and mammal species.

Benefits of Insects

The importance of insects and the benefits they provide to the global economy may seem to be a topic of little relevance or significance to green roofs. But a world without insects is truly a world without higher forms of life. Invertebrates generally receive a bad reputation as being “creepy, crawly” pests, but the truth is that of the roughly four million insects present on this earth, only a mere one percent interact negatively with humans (Tallamy, 2009). The worth of insects to mankind is estimated in the billions of dollars through the many ecosystem services that they provide: pollination, seed dispersal, food sources, defense mechanisms, and recycling dead plants and animals (Waldbauer, 2003). There is no doubt that a world without insects would be radically different; their absence could result in the demise of mankind who would not able to survive for an extended period of time without their activity (Wilson, 1987). Our interdependence with insects is so important that it is crucial we mitigate the destruction to invertebrates’ habitat being caused by human development. One effort would be to incorporate the principles of ecological design into vegetated roof design.

Despite all of the well-documented benefits insects provide to human health, the conservation of insects is not a priority for most individuals. This failure to be concerned about insect conservation is due to a lack of education on the benefits provided by insects. An important step in education and promotion of insect conservation on green roofs is to relay the information in terms with which the general public can connect. An example would be to discuss the biodiversity aspects of green roof design into the public’s understanding of aesthetic appeal (Hunter & Hunter, 2008). Another method for insect conservation on green roofs would be to incorporate a flagship species into the process, which may garner public sympathy (Samways, 2005). An example of this was showcased in the green roof design of the Nueva School in Hillsborough, CA, that exhibited native ecosystem elements to support the endangered Bay Checkerspot Butterfly habitat in San Francisco (Greenroofs.com, 2010).

Invertebrates on Green Roofs

Although a great deal of research and information exists on the benefits provided by green roofs, to date only small amounts of research is available regarding invertebrates on green roofs. Most of this research is being conducted primarily in Europe and Canada. For example, research conducted by Brenneisen (2005) has led to amendments in the building and construction codes in Basel, Switzerland; there all new buildings with flat roofs are required to be constructed with a green roof following biodiversity guidelines calling for varying substrate depths of natural soils. Research in Europe also has shown vegetated roofs to be a valuable means of preserving rare or threatened plants, wildlife, and invertebrates (Jones, 2002; Gedge & Kadas, 2005; Baumann, 2006).

Invertebrate habitat design on green roofs. Whether intentionally designing for habitat or not, it is understood that all living roofs are going to provide habitat for some form and amount of invertebrates. The question is why do some roofs attract more invertebrates than others, and are there ways to design green roofs to support greater invertebrate habitat? If one assumes that transformed landscapes, of all kinds that are as close as possible structurally, compositionally, and functionally to the untransformed ones (Samways, 2005), will support the greatest diversity of organisms, then researchers have a starting point for designing wildlife and invertebrate habitat in the built environment.

According to Brenneisen (2006), substrate depth and structural diversity of vegetation are the most important elements when designing vegetated roofs for invertebrate diversity. The thin substrates of most extensive green roofs provide a challenge for ground-dwelling organisms to establish permanent habitats (Brenneisen, 2006). Favored substrate sources would consist of material recycled directly from areas surrounding the vegetated roof. This substrate would potentially be imbedded with seeds of the surrounding area and ideally generate a habitat on top of a roof similar to the surrounding landscape. To go one step further, the natural substrate would favorably be fashioned into different forms of hills, small valleys, and ravines, creating an environment with multiple microhabitats similar to invertebrates' natural territory. This type of media and 3-dimensional structure would support periods of water saturation and periods of drought due to drainage characteristics, which over time should be similar to conditions found in nature (Brenneisen, 2006).

Both plant structural diversity and plant species diversity play a role in determining invertebrate species diversity (Murdoch et al., 1972; Tews et al., 2004). Research suggests that more vegetation diversity will result in higher invertebrate diversity based on the fact that higher vegetation species correlates with higher diversity of specialized herbivores (Siemann et al., 1998). Similar to the relationships found with avian species, high correlation should exist between structural complexity of vegetation and insect species presence (Lawton, 1983). An example of this is shown in the specific case of web spider species, where diversity is highly correlated with vegetation tip height density (Greenstone, 1984).

There is no generalized habitat template that can be applied to all green roofs when attempting to attract invertebrates. The essential elements needed to develop successful establishment of organisms on vegetated roofs are dependent upon locality and may vary significantly. Invertebrate communities may vary greatly depending on the specific design of a green roof (Kadas et al., 2008). In certain circumstances it may be beneficial to establish specific plant species preferred by specialized insects, since the specialist species are generally the first to become endangered with the threat of extinction. Other circumstances may call for a design that supports “generalist” species, attracting multiple species into one design.

An obvious question in establishing invertebrate communities on green roofs is how will the organisms gain basic access to the roofs? Flight is an essential ancestry trait of insects that allow them to colonize a wide range of habitats, including hard to access green roofs (Hellman & Sanders, 2007). In urban areas, most insects colonize vegetated roofs actively by flying or passively by air transport such as ballooning (Schrader & Boning, 2006). Another possible answer would be that organisms are establishing themselves during the grow-in period that exists for most commercial green roof products. Typically with commercial modular and vegetated mat products, a period of weeks to years exists for plant establishment before installation. Plausibly during this time period, invertebrates could establish themselves within the media and vegetation, and they would therefore be transported in the green roof during installation.

Green roofs, however, are not suitable for all invertebrate organisms. For certain organisms, the issue of accessibility creates an obstacle, and for others, the extreme microclimate environment demonstrated on green roofs does not allow for successful establishment. With that being said, recent research has shown invertebrate presence on green roofs to be similar to invertebrate presence in the surrounding landscape (MacIvor & Lundholm, 2010). This suggests, despite the barrier created by elevated roof systems, local invertebrates often manage to find ways to successfully establish themselves on green roofs.

Michigan State University Research

Michigan State University (MSU) has become established as a leading university in the field of green roof research. The green roof research program began at MSU in 2000 when the Ford Motor Company requested consulting expertise for the installation of a 4.2 hectare (10.4 acre) extensive green roof on its new truck assembly plant. Since then, MSU has continued to develop its green roof program into a diverse green roof team of professors and graduate students. The MSU Green Roof Team has contributed greatly to the green roof industry through research that has evaluated plant species propagation and establishment, plant succession, carbon sequestration, water and nutrient requirements, stormwater quality and quantity, energy consumption, and urban agriculture. (Getter et al., 2011; Whittinghill & Rowe, 2011; Getter et al., 2009a; Getter et al., 2009b; Getter & Rowe, 2009; Getter et al., 2007; Durhman et al., 2006; Rowe et al., 2006; VanWoert et al., 2005; Monterusso et al., 2004). Green roof research continues to progress at MSU in the areas of slope effect on plant establishment, temperature and moisture, and storm water management. Research also is ongoing in the subject areas of real and perceived biases to green roof adoption, and in green roof suitability for avian and invertebrate habitation on green roofs, with invertebrate habitation being the focus of this paper.

Future of Green Roofs

In Europe the green roof industry has continued to grow each year for the past several decades. While the green roof industry in the United States maintains a steady growth rate (Greenroofs.org, 2011), the industry is still young with many areas needing advancement. Several of the barriers to green roof expansion in the U.S. include: limited performance standards, lack of awareness and education regarding green roofs, higher installation costs, lack of government incentives, and limited data quantifying green roof benefits. These barriers can be easily overcome through research and innovation in design by the green roof industry, a likely future occurrence.

One subject area that has received little research attention to date is the matter regarding wildlife and invertebrate habitat on green roofs, with even less information regarding the influence of interactions between wildlife species (e.g., the potential relationship between invertebrates and avian fauna) (Coffman & Davis, 2005; Coffman, 2007). It seems safe to assume, since birds heavily rely on invertebrates as their primary source of food (Tallamy, 2009), a correlation will exist between bird and invertebrate presence on green roofs. The results of this study will contribute in part to a better understanding of this relationship concerning green roofs.

Conclusion

The benefits of green roofs are numerous and have been well documented. In fact, certain benefits of vegetated roofs are to the point of becoming so well defined that they can no longer be ignored as a viable roofing alternative. The aim of this study is to assist in defining one of the not as well documented areas-ie., the benefits green roofs provide for invertebrate habitat, specifically insects and spiders. Invertebrates collected and compared between eight different green roofs, will provide insight into fundamental design characteristics of green roofs that potentially optimize biodiversity on these roofs.

MATERIALS AND METHODS

In the Midwest, adult insect reproduction is active during different times of the growing season (Wellington et al., 1999). Therefore, invertebrate collection for this study was performed beginning in April and ending in October 2010. Collection of invertebrates occurred one time a month at each study site. Invertebrate activity is at its highest during the day between 10:00am and 5:00pm and on days with favorable weather conditions (ie. warm temperatures, sun, and low wind) (Wellington et al., 1999). Sampling was targeted for these times and weather conditions.

Collection methods. Invertebrates were collected using a set of collection methods on each of eight green roofs (Figure 1). The first method involved a sweep net, which was used to collect insects through sweeping the ground vegetation (Figure 2). A 38-centimeter (15-inch) polyester Great Lakes IPM sweep net was selected because it had the size and durability needed to sweep a variety of different types of vegetation.

Each roof was systematically divided into transects along which the sweep net was applied (Figures 5-12). The amount and size of transects differed between each roof depending on the size and shape of the roof; this was to ensure maximum vegetation coverage by the sweep net. After each green roof sweep, the collected invertebrates were placed and stored in a sealed killing jar. The killing jars were placed in a freezer until proper identification of the specimens took place (typically 1 to 4 weeks).

The second method of invertebrate collection utilized pitfall traps. The pitfall traps were selected to examine the presence and diversity of ground dwelling invertebrates (Paulson, 2005). Clear plastic cups, 266 milliliter (9 oz) in volume were used for the pitfall traps. The cups were cut down in size on roofs where media depth was not sufficient to accommodate the height of the cup. Ten pitfall traps were randomly placed throughout each roof to obtain representative samples of invertebrates on each roof (Figure 3). A small garden trowel was used to displace the media, and the top of the cup was made flush with the surrounding soil. Two cups were placed within one another when positioned in the media; this allowed the inner cup and its contents to be removed without disturbing the outer cup and the surrounding media. Each trap was filled with propylene glycol (chosen for its ability to preserve the specimens, non-toxicity, and slow evaporation rate) and left to trap the ground dwelling invertebrates that fell into the cups. A 12.7x10.16 cm (5x4 in) clear plastic cover was placed above the pitfall traps to prevent intrusion of water and other foreign substances into the traps (Figure 3). The amount of propylene glycol varied between study sites depending on media depths and its capacity to hold a full 266-milliliter cup. The invertebrates within the traps were cleared one time a month and placed into a separate container. The collected invertebrates were then cleaned of the propylene glycol and stored in a labeled glass jar containing a solution of 70% isoproply alcohol until identification took place.

A third method of invertebrate collection was the use of sticky traps, but these traps proved to be an inefficient means of determining invertebrate populations on the roofs. The traps were tested for two months of sampling and then removed. The sticky traps consisted of a 15.24 x 30.48 cm (6 in x 12 in) piece of yellow plastic, coated on both sides with specially formulated sticky glue. The traps were attached to a flexible piece of steel wire that was placed into the roof media allowing the traps to protrude one meter or less (2-3 ft) into the air (Figure 4). Five sticky traps were placed in random locations throughout each roof. At times the traps were placed in areas out of view to the general public per request of the roof managers. Traps were removed and replaced with new sticky heads one time a month. The invertebrates collected on each trap were removed and placed into a separate container. The sticky traps were removed after two months of installation because they were inefficient at collecting a diversity of flying invertebrates. Collections of species from the order *Diptera* (flies) constituted the great majority of invertebrates being trapped, rather than random flying invertebrates passing through, as was the objective. The sticky traps also were removed due to their difficulty in standing up to the windy conditions found on green roofs, and per request of the building owners who found the aesthetics of the traps undesirable.

Insect identification. After the invertebrates were collected they were counted and classified down to the family level or to morphospecies (groups of organisms distinguished solely on morphological traits); this latter technique is proven to be an effective time and cost substitute for professional species identification (Oliver and Beattie, 1996). Identification was completed through personal knowledge and the use of invertebrate identification materials (Evans, 2008; Daniels, 2005; Borror and White, 1970; Borror et al., 1989). Gary Parsons, the Collection Manager for the A. J. Cook Arthropod Research Collection, along with others within Michigan State University's Entomology Department, provided assistance with specimen identification. Daniel Swanson, a plant and insect lab technician at the University of Michigan Museum of Zoology Insect Division conducted the majority of insect identification. The identified invertebrate species were recorded on a spreadsheet, and each roof was compared on a month-by-month basis for insect and spider total abundance (number of individuals), richness (number of different individuals) and diversity.

Green Roof Characteristics

Eight structurally different green roofs in the Midwest (U.S.) were selected for this study. Each roof was located either in Michigan or Illinois (Figure 1). The roofs differed in size, height, location, plant species, media depth, surrounding landscape, shape, and maintenance applications (Table 1). Each roof was chosen for specific characteristics so the roof could be compared later with other roofs to determine discernible differences between roof characteristics and invertebrate presence. The ultimate goal was to provide a set of design guidelines for future green roof construction, with an emphasis on increasing insect and spider biodiversity.

Green roofs characteristics reflect the desired habitat qualities of invertebrate species. Therefore, the selection of each study site was carefully measured to identify the physical properties that made them unique. Using these defining characteristics, a template was developed to identify the most important properties that attract the greatest diversity of insects and spiders on green roofs. The green roof characteristics of: roof age, roof height, roof area, media depth, vegetation type, vegetation structure and vegetation cover were grouped into like characters for the purpose of data analysis. The characteristics of: weather condition, media composition, site location, and adjacent landscape context, were detailed but not included in the data analysis due to the difficulty in quantifying such characteristics. The green roof characteristics and method of measurement are defined below, with the recorded data being represented in Table 1.

Roof age. All the roofs selected for the study were installed less than ten years ago, and all the sites were installed within five years of each other. Due to the infancy of the green roof industry within the Midwest region, it was difficult to locate green roofs with a wide range of age diversity. The age of a roof is an important factor due to the fact that the longer a roof exists, the more its structure will modify and in turn allow for more organisms to colonize it. Research has shown that species diversity of invertebrates increase with the age of living roofs—a phenomenon that is found in natural ecosystems following a disturbance (Brenneisen, 2006). To compare differences in insect and spider abundance and diversity, the roofs were grouped into two categories; the five roofs installed in the years 2003-2005, compared to the three roofs installed between 2007-2008.

Roof height. The height of a roof holds the potential to influence how organisms access a green roof and their ability to colonize the roof. The green roof heights varied from those connected to ground level to roofs over ten stories tall. The height of the green roofs were recorded according to the individual project specifications or from the project database provided by Greenroofs.com, 2010. On the occasion that roof height data were not available, measurements were taken with a 100-meter long tape measure or estimated based on building stories.   For comparison purposes, roof heights were categorized into roofs with ground connection, roofs 10-20 m (33-66 ft), and roofs over 20 m (66 ft) in height.

Vegetated roof area. The area covered by vegetation on a structure varied substantially in this study. The smallest green roof was roughly 325 m^2 (3500 ft^2), while the largest green roof was over 4 hectares (ten acres) in size. The area of the green roofs were recorded according to the individual project specifications or from the project database provided by Greenroofs.com, 2010. The data analysis compared the three roofs with large vegetated roof area (over 20,000 m^2 [215,000 ft^2]) against the five roofs with a smaller vegetated roof area (under 5,000 m^2 [54,000 ft^2]).

Media depth. Within this study a variety of media depths were found, ranging from a few centimeters, to over a meter in depth. The media depths were recorded according to the individual project specifications or from the project database provided by Greenroofs.com, 2010. Investigation into the accuracy of depth was applied when possible, through the elementary process of inserting a wooden skewer into the media and measuring the depth. To determine the influence media depth has on insect and spider abundance and diversity, the roofs with shallow media depth (2.5-10 cm [1-4 in]) were compared and contrasted to the roofs with a deeper media profile (greater than 10 cm [4 in]).

Vegetation structure. Vegetation structure refers to the vertical differences seen in a green roof due to the species morphology of plants; vegetation structure contributes in a significant way to the diversity and abundance of invertebrates (Brose, 2003). The different roofs within this study exhibited multiple types of vegetation structure. The vegetation structure was organized into five different categories: overall structural profile (total height range); *Sedum* (range: 0-0.5 m or 0-2 ft); grass/perennial (range: 0-1.5 m or 0-5 ft); grass/perennial/shrub (range: 1.5-3 m or 5-10 ft); and tree (range: 5-10 m or 16-33 ft). A relative percent was given to each category based on measurements taken from established transect lines. The transects were the same as those delineated for the sweep net (figures 5-12), with the overall vegetation structure representing the range of vegetation height from lowest to highest found along the transects. The percent vegetation structure was determined by measuring length of the vegetation type found along the transects and dividing those lengths by the total length of the transects to achieve a relative percent for each vegetation category. The vegetation structure was recorded one time for each roof during the month of July (Table 3).

Vegetation type. While the structure of vegetation is important, the diversity of vegetation also can serve as a critical determinant of invertebrate diversity (Jones et al., 2011). Although a vegetation diversity analysis of each roof was not conducted, vegetation richness was estimated based on the original planting list of each green roof. The vegetation analysis of the study sites grouped the roof vegetation types into two categories: *Sedum* only green roofs (four study sites) compared with the four study sites with mixed vegetation composition (ie, *Sedum*, grasses, and perennials). This analysis inherently included vegetation structure with the *Sedum* only roofs exhibiting less structure (less than 0.5 m [2 ft]), compared to the mixed vegetation roofs exhibiting greater structure (greater than 0.5 m [2 ft]).

Vegetation cover. The amount of impervious surface compared to the amount of vegetation, or green roofed area, (including bare media) was measured for each of the vegetated roofs. The measurements were recorded with aerial photographs that were brought to scale and then measured to determine the percent impervious surface for each site. Each portion of vegetation found on the roof was measured for its total area initially; this measurement was subtracted from the total roof area. The amount of impervious surface to be found on the roof was the difference. Areas such as walking paths, infrastructure (eg. air conditioning units, etc.), roof membrane, and other hard surfaced objects were all regarded as impervious surface.

Although most vegetated roofs make an attempt to cover the entire roof when possible, there are still elements and infrastructure that prevent a seamless covering of vegetation over an entire roof. At times, only portions of the roof are covered with vegetation because of budget or perhaps structural limitations. The broken patches of vegetation on the roof hold the potential to isolate habitat for invertebrates and make it a less hospitable environment for establishment. The amount of impervious surface on each vegetated roof was analyzed to determine if a potential effect was being seen in invertebrate presence and diversity. Vegetation cover was analyzed by comparing the roofs with greater than 50 percent vegetation cover compared to the roofs with less than 50 percent vegetation cover.

Weather data. All of the sites were located in Michigan or Illinois, with similar geographic climate environments. Data were gathered regarding the average precipitation and temperature for each of the different states, and where possible, for each specific site where a green roof was located. All of the data were obtained from the National Oceanic and Atmospheric Administration website (http://www.sercc.com/nowdata.html). The data represents average precipitation and temperature on a monthly basis for 2010, the year of the study (Figure 20).

Media composition. Concentrations of soil minerals, organic matter, and particle size possess the ability of media to support vegetation; this, in turn, affects the plant composition of a community (Snodgrass & McIntyre, 2010). Soil-forming processes occur over time, which can improve the environments of soil dwelling organisms (Schrader & Boning, 2006). Therefore, it was important to determine the media composition of each roof to see if it contributed to vegetation composition and ultimately increased invertebrate presence. Soil samples were taken from three different locations within each study site. Each of the three soil samples was taken from locations with close proximity to the installed pitfall traps. A minimum of two cups of total soil was dug away from the top of the media using a small garden trowel. The media was then sent to the MSU Soil and Plant Nutrient Laboratory for analysis. The laboratory conducted a regular field soil test (pH, lime requirement, P, K, Ca, Mg & recommendations), an organic matter analysis, and a particle size analysis (percent sand, silt, and clay) (Table 2).

Site location and adjacent landscape context. The location of a study site allows the opportunity to influence the presence of invertebrates. Sites located in densely built urban areas, typically are surrounded by vast amounts of impervious surfaces; whereas sites located away from such areas tend to have more vegetation and landscape elements conducive to supporting invertebrate communities. An increase in invertebrate richness has been recorded on vegetated roofs and their surrounding landscapes in areas with less urban development (MacIvor & Lundholm, 2010).

The adjacent landscape context is described in the *roof comparison* section as a general overview of the adjacent areas to the different green roof sites. The immediate context refers to areas within 100 m (328 ft) adjacent to all sides of the green roofs and includes a general description of the natural and man-made elements. The descriptions were recorded through observations while on top of the green roof study sites and from field reconnaissance at the ground level surrounding each roof. The extended context refers to the general type of area where the green roofs were located. It offers some insight towards the degree of building density, total impervious area (TIA), and infrastructure elements present around each site location.

Data Analysis

The study focused on insects and spiders, and in that sense, not all invertebrates were included in the data analysis. The collected insects and spiders were organized to count the family abundance (total amount of insects and spiders present), family richness (the number of different families present), and insects and spiders per square meter (insects/m^2) (abundance divided by roof area). Calculated from abundance and richness, three other diversity indices were examined: the Shannon-Weiner index (H'), the Simpson's diversity index (D) as described in (Pielou, 1966; Whittaker, 1972), and species evenness (E), which involves measuring how evenly the species are distributed within a community as described in Southwood & Henderson (2000) (Appendix 1).

Collected data were initially profiled using descriptive statistics like frequency, mean and median values, and range of values for insect and spider families found on each green roof. Because part of the intent of the study was to determine whether physical characteristics of the individual roofs were determinants of the types and numbers of insect and spider families present at a site, the data were analyzed further using ANOVA models for two purposes. First, the ANOVA models were used to determine the differences found between the collection methods of pitfall trap and sweep net. The diversity indices (H', D, E) and insects/m^2 were modeled with linear models using PROC MIXED of SAS version 9.2, SAS institute, Cary, NC. Abundance and richness were modeled with generalized linear models (GLM) using a poisson distribution with overdispersion using "PROC GLIMMIX" of the same statistical package. Second, an ANOVA was used to analyze the effect roof characteristics had on abundance, richness, insect/m^2 and diversity indices (H', D, E) for insect and spider families found at a particular site. In this case, the above models incorporated a particular roof characteristic and the interaction with the specified variable of abundance, richness, insect/m^2 and diversity indices (H', D, E). The roof characteristics included: roof height, roof area, vegetation type, media depth, and vegetation coverage. Nymphs, larvae, and un-identified immature insects and spiders were not included in the analysis or counted because of difficulty in proper identification.

RESULTS AND DISCUSSION

During the collection period of seven months (April-October 2010), a total of 91 samples were taken with 44 samples occurring from pitfall traps and 47 from sweep netting. The sampling of the eight different vegetated roofs resulted in a total of 17,352 invertebrate specimens collected, representing 115 families from 18 different orders (Table 9). Of the total invertebrates collected, adult insect and spider specimens totaled 8,727 representing 110 families from 13 different orders (Table 8). Insects and spiders were the primary focus of this study; other arthropods collected (eg. centipedes, millipedes, and woodlice) on the vegetated roofs were noted but further data analysis was not conducted. This is because they composed nearly 50% of all specimens collected, which would skew the focus of the study away from insects and spiders, as originally intended in the study.

Data on the insects and spiders showed no significant differences among the green roof characteristics of roof height, vegetation type, and media depth when compared to insect and spider family richness, abundance, insects/m^2, Simpson's diversity index, Shannon-Weiner index, or Evenness. There was, however, significant differences in family richness and abundance when comparing the factor of percent vegetation cover to total roof area (Table 6). Total roof area in square meters also demonstrated significant differences when compared to family richness. Finally, significant differences in family abundance were found when comparing the collection methods of pitfall traps and sweep net (Table 7). A discussion of the significant relationships found in the study follows.

Because of the range of roof areas covered with vegetation, the percent vegetation characteristic was organized into two categories. Four roofs had over 50% vegetation coverage and these roofs were contrasted to the four roofs with under 50% vegetation coverage. There was a significant difference between the two groups in terms of family richness and abundance. Roofs having greater than 50% vegetation cover had significantly higher family richness; likewise, these roofs also had higher abundance numbers of insect and spider families (Figures 17 & 18). The amount of impervious surface on a roof certainly has the capability of dictating suitable habitat for invertebrates, which in turn, influences family richness and abundance. However, the organization of the vegetative cover (i.e., its continuity, fragmentation, and edge characteristics) in relation to the hardscape of the remaining roof area will influence family richness and abundance as well. Areal images (Figures 5-12) of the roofs in both categories help to illustrate how percent vegetative cover as well as continuity of vegetative cover influences the data shown in Figures 17 and 18 and Table 6. This data supports the work of Schindler et al. (2011), who found that the amount of vegetation cover was shown to have a positive correlation with arthropod diversity. This can be especially true if impervious surfaces surround vegetated areas, in effect isolating and fragmenting potential habitat for invertebrate populations (Helden & Leather, 2004).

Comparing the green roof sizes, one would expect to find results similar to the well-documented species-area relationship, which suggests larger areas contain more habitat for species, therefore, resulting in greater species richness and abundance (Lomolino, 2001). Although there were no differences in abundance when comparing the green roof areas, there were significant differences between total roof area in vegetative cover and family richness. The total roof area in vegetative cover (square meters or feet) for the eight study sites were grouped into two categories: three roofs with an area over 20,000 m^2 vegetative cover (215,000 ft^2), and five roofs with an area under 5,000 m^2 vegetative cover (54,000 ft^2). The roofs with an area over 20,000 m^2 vegetative cover (215,000 ft^2) showed significantly higher family richness numbers compared to those roofs with an area under 5,000 m^2 (54,000 ft^2) (Figure 19; Table 6).

When comparing the different methods of collection (pitfall vs. sweep net), there were significant differences between the two in family abundance numbers (Table 7). Pitfall traps collected a greater abundance of insects and spiders on the majority of the study sites, and in certain cases, significantly higher abundances (Table 4). There was, however, no significant differences found between the collection methods for family richness and the diversity indices (H', D, E). The results, therefore, suggest that pitfall traps are the superior collection method for obtaining the broadest information on insect and spider family abundance, while sweep netting will generate comparable data collection when establishing insect and spider family diversity on green roofs.

Descriptive Roof Profiles

Although there were few significant differences among the roof characteristics in the statistical analysis, there were observable differences that were recorded for each roof. A brief descriptive summary of each roof follows with a more in-depth analysis found in Tables 1, 4 and 5.

Aquascape. The Aquascape green roof was originally planted with a variety of grasses and perennials. The vegetation species included: *Allium cernuum, Aster azureus, Aster ericoides, Aster sericeus, Bouteloua curtipendula, Carex gravida, Coreopsis palmata, Echinacea pallida, Heuchera richardsonii, Koeleria cristata, Lespedeza capitata, Liatris cylindracea, Lupinus perennis occidentalis, Monarda* *fistulosa, Monarda punctata, Rudbeckia subtomentosa, Rudbeckia hirta, Schizachyrium scoparium, Solidago nemoralis,* and *Tradescantia ohiensis* (Villagrana, 2010).

The immediate landscape context within 100 m (328 ft) surrounding the Aquascape green roof included a large pond, stream, and a mixture of natural landscapes and small wooded areas. The extended context (beyond 100 m) was that of light commercial buildings, non-densely populated residential, and a small airport field located within 200 m (656 ft) of the roof.

The highest family richness (n_r=65) and second highest total abundance of insects and spiders (n_a=1898) was found on the Aquascape roof (Table 4). This is likely due to the fact that Aquascape exhibited vegetation that closely replicated a native meadow landscape (Figure 16). Of all the insects and spiders collected on the Aquascape roof, those belonging to the order *Orthoptera* were the most abundant (46.5%) followed by *Hemiptera* (20.1%) and *Aranea* (12.4%) (Table 5). Aquascape was the only green roof to have only insects and spiders collected, as opposed to other specimens of invertebrates (ie., centipedes, millipedes, and woodlice), which were found on every other roof.

Ford. The Ford green roof was originally planted with a variety of *Sedum* species. The *Sedum* species included: *Sedum spurium* 'Fulda Glow', *Sedum middendorfianum* 'Diffusum', *Sedum acre*, *Sedum kamtschaticum*, *Sedum ellacombeanum*, *Sedum album*, *Sedum pulchellum*, *Sedum spurium* 'Coccineum', *Sedum sexangulare, Sedum floriferum, Sedum reflexum, Hylotelephium verticillatum*, and *Hylotelephium spectabile* (Longfellow-Jones, 2010).

The immediate landscape context within 100 m (328 ft) surrounding the Ford green roof was dominated by a mixture of impervious surface, small amounts of natural landscapes, and turf on the ground plane. The extended context beyond 100 m included a large (445 ha [1,100 acres]) industrial campus used for automobile manufacturing.

The Ford roof exhibited characteristics of being the largest in total vegetated area, but also the shallowest in media depth. It is perhaps a combination of both these characteristics that resulted in an insect and spider richness and abundance (n_r=50, n_a=753, respectively) in the middle range of the different roofs (Table 4). One would expect the largest roof to display the largest abundance of insects and spiders, and perhaps, diversity, but due to the extremely shallow media profile and subsequent lack of vegetation structural diversity, this was not the case. The shallow media also contributed to the fact that Ford was one of the only roofs where more insects and spiders were collected through sweep net sampling compared to pit fall traps. The shallow media made it difficult to successfully install pitfall traps, and also lent to more rapid evaporation of the liquid within the pitfall traps. The diversity of insects and spiders collected were evenly distributed (E = 0.7208). Of all the insects and spiders collected on the Ford roof, those belonging to the order *Hemiptera* were the most abundant (32.4%) followed by *Coleoptra* (19.1%) and *Diptera* (15.7%) (Table 5).

GRCC. The Grand Rapids Community College (GRCC) green roof was originally planted with a variety of *Sedum* species. The *Sedum* species included: *Sedum album* 'Coral Carpet', *Sedum spurium* 'Bronze Carpet', *Sedum spurium* 'Fuldaglut', *Sedum spurium* 'Red Carpet', *Sedum spurium* 'Voo Doo', *Sedum x* 'Vera Jameson', *Sedum* *acre* 'Aureum', *Sedum album* 'Green Ice', *Sedum ellacombianum, Sedum hybridum* ''Immergrunchen', *Sedum kamtschaticum* 'Takahira Dake'*, Sedum rupestre* 'Angelina'*, Sedum spurium* 'Royal Pink', *Sedum album* 'Athoum', *Sedum album* 'Faro Island', *Sedum floriferum* 'Weihenstephaner Gold', *Sedum* 'Mini Me', *Sedum oreganum*, *Sedum sexangulare, Sedum spurium* 'Green Mantle', and *Sedum takesimense* 'Gold Carpet' (Van Dokkumburg, 2010).

The immediate landscape context within 100 m (328 ft) surrounding the GRCC green roof consisted primarily of residential and mixed-use buildings, small amounts of natural landscape, and turf. The extended context beyond 100 m (328 ft) included neighboring residential homes and a variety of mixed-use facilities.

Despite having a shallow media profile (10.16 cm or 4 in), and being vegetated only with a variety of *Sedum* species, this site was found to have the third highest total insect and spider abundance and richness (n_a=1506, n_r=55 respectively) (Table 4). GRCC also exhibited the second highest ranking among the study sites for the three diversity indices (D, H', E). Of all the insects and spiders collected on the GRCC roof, those belonging to the order *Aranea* were the most abundant (21.3%) followed by *Hemiptera* (17.2%) and *Orthoptera* (17.1%), with the orders *Hymenoptera* and *Coleoptera* close behind (14.5%, 13.4% respectively) (Table 5).

When comparing all the *Sedum* roofs observed in this study, GRCC demonstrated the best representation of *Sedum* plant variety in structure and plant species diversity (Figure 17). Within the roof were multiple types of flowering Sedums, exhibiting bloom periods almost throughout the entire seven month sampling process. It is because of these characteristics, that the author believes GRCC had the highest insect and spider species abundance and diversity among the *Sedum* roofs, and also ranked high when compared to some of the other intensive style green roofs.

Haworth. The Haworth green roof was originally planted with a variety of *Sedum* species. The Sedum species included; *Sedum acre* 'Aureum', *Sedum album* 'Coral Carpet', *Sedum floriferum* 'Weihenstephaner Gold', *Sedum hybridum* 'Immergrunchen', *Sedum reflexum* 'Green Spruce', *Sedum sexangulare*, *Sedum spurium* 'Album Superbum', *Sedum spurium* 'Dragons Blood', *Sedum spurium* 'Green Mantle, *Sedum spurium* 'John Creech', and *Sedum spurium* 'Tricolor' (Tubergen, 2010).

The immediate landscape context within 100 m (328 ft) of the Haworth green roof included impervious roof surface located to one side of the roof, and an even mixture of parking lots, and natural landscape surrounding the other side of the roof. The extended context beyond 100 m (328 ft) consisted mainly of natural landscape (prairie, mature trees, wild flowers), turf grass, a variety of impervious surfaces, and non-densely populated mixed-use facilities.

Of all the vegetated roofs sampled within this study, Haworth demonstrated the highest total abundance for insects and spiders (n_a=2233), but also the lowest ranking for all three diversity indices (D, H’, E) (Table 4). The collection methods on the Haworth roof also were very uneven with pitfall traps collecting 96% of the total specimens during the sampling period. The sweep net was not an effective method of collection due to the roof being vegetated with only varieties of low-growing *Sedum*. The majority of specimens collected within the pitfall traps were crickets in the order *Orthoptera* (75.6%). The bulk of the remaining specimens found in the pitfall traps were in the order *Aranea* (containing 14.7% of the total insects and spiders) (Table 5).

Perhaps an explanation of the vast amount of crickets is the fact that the Haworth green roof slopes down and has a ground-level connection. This connection could have made the roof more accessible to certain populations of insects abiding in the adjacent natural areas; however, no data was collected on insects and spiders occupying the adjacent area, so this statement cannot be confirmed. Another explanation would be that the combination of green roof media and *Sedum* vegetation is favorable habitat for crickets, but this explanation is not supported in the collection data from the other *Sedum* vegetated roofs.

Lurie. The Lurie Garden green roof was originally planted with an immense variety of perennials, grasses, shrubs, and trees. Over 200 different species of plants were initially installed on the green roof: approximately 160 perennials, 20 grasses, 10 shrubs, and 12 tree species. The differing species are spread throughout the garden to display yearlong highlights. A plant list can be found at http://luriegarden.org/plantlife/overview.

The immediate landscape context within 100 m (328 ft) surrounding the Lurie Garden green roof included a mixture of hardscaped recreational areas and natural landscape areas located within Millennium Park, Chicago, IL. The extended context consisted of highly urban development with extremely small pockets of designed landscapes to the west and extensive turf grass areas adjacent to Lake Michigan on the east.

The Lurie Garden within Millennium Park exhibited a unique set of characteristics compared to the other vegetated roofs. The garden exists entirely at ground level (technically a green roof because it sits atop a parking garage); contains the highest diversity of vegetation; receives the most intensive maintenance (ie., weeding, fertilizer, herbicides); entertains the most human interaction, and includes the deepest media profile. With the site demonstrating the deepest media, along with the greatest plant diversity, it would be expected that the garden would prove to have the most insect and spider diversity and abundance compared to other roofs. However this was not the case, perhaps as a result of intensive maintenance and human interaction. Lurie Garden was at the lower end for insect and spider abundance (n_a= 731), but did showcase the second highest richness number (n_r= 58). The Lurie Garden was ranked the highest for all three diversity indices (D, H, E) (Table 4).

The garden was only the second site within the study to have more insects and spiders collected through sweep net compared to pitfall traps; however, this was not the case when including all invertebrates into the total abundance measurement. With close to 2,000 woodlice, centipedes, and millipede specimens being collected in pitfall traps, it ranked among the highest abundance for all invertebrates collected. Of all the insects and spiders collected on the Lurie Garden roof, those belonging to the order *Diptera* were the most abundant (37.6%) followed by *Hymenoptera* (25.7%) and *Coleoptera* (13.1%) (Table 5).

PSS. The Plant and Soil Science Building (PSS) green roof was originally planted with a variety of *Sedum* species. The *Sedum* species included: *Sedum reflexum, Sedum album, Sedum pulchellum, Sedum spurium, Sedum hispanicm, Sedum acre,* and *Sedum kamtschaticum* (Rowe, 2010).

The immediate landscape context within 100 m (328 ft) surrounding the PSS building green roof was dominated by university facilities (buildings and parking lots), natural landscapes, manicured landscapes, and small amounts of impervious surface areas (e.g., sidewalks, sheds, etc). The extended context included transportation infrastructure, university facilities, considerable amounts of formal gardens, and highly mowed turf grass areas.

The PSS building green roof on the Michigan State University (MSU) campus is the smallest in size; it contains a shallow media profile, with little plant structure and diversity. This site had the second lowest abundance and richness numbers (n_a= 589, n_r= 40 respectively) (Table 4). The low abundance and richness numbers also could be associated with the fact that only a portion of the entire roof is vegetated (23%), in essence creating a habitat patch isolated by impervious roof environment. This roof does, however, prove the fact that green roofs of a small square footage will still provide habitat for invertebrates. This roof displayed more ant specimens (n= 273) than any other roof. With a dominate abundance of ants, the order *Hymenoptera* had the highest percent abundance on the roof with (48.9%) followed by *Aranea* (17.3%) with *Hemiptera* (10.9%) and *Diptera* (9.5%) following (Table 5).

Schwab. The Schwab Rehabilitation Hospital green roof was originally planted with a mixture of annuals, perennials, grasses, and small trees. The planted species included: *Iris spp., Campanula, Linum, Hemerocallis, Echinacea, Perovskia atriplicifoli, Buddleia, Latrias, Aster,* and *Rhus*. The garden staff continuously replaces plants (mainly annuals) to maintain the health and beauty of the garden and also to provide hands-on planting experience for the rehabilitation patients (Dettmers, 2010).

The immediate landscape context within 100 m (328 ft) of the Schwab green roof was dominated by large neighboring parks, small amounts of mixed-use facilities, impervious surfaces, and manicured landscapes. The extended context consisted of highly impervious, urban development with small pockets of designed landscapes.

The roof garden atop the Schwab Rehabilitation Hospital is a true intensive green roof. The roof has a deep media profile, a variety of vegetative structure, a lot of human activity, and, unique to all other sites, a stream with a small waterfall (Figure 18). Despite these features, the Schwab roof had the lowest abundance and third lowest richness of insects and spiders (n_a= 370, n_r= 42 respectively) (Table 4). These numbers may reflect the fact that only 42% of the roof is vegetated, and the vegetated areas are narrow (less than 5 m [16 ft] in length for most areas) patches surrounded by impervious surface.

The abundance numbers change significantly when considering all invertebrates, primarily due to the fact that 2,384 specimens of the invertebrate woodlice were collected. The collection of such a significant number of woodlice may have played a role in altering the number of insect and spider specimens collected, due to the fact that the pitfall traps would rapidly fill with woodlice specimens, preventing other specimens from being collected. Since pitfall collection would occur once a month, it is plausible that the pitfall traps could fill with woodlice specimens within the first couple days of installation, and therefore, render the rest of days in the month ineffective in trapping insects and spiders. Of all the insects and spiders collected on the Schwab roof, those belonging to the order *Hymenoptera* were the most abundant (48.7%) followed by *Aranea* (16.0%) and *Diptera* (11.1%) (Table 5).

900. The 900 North Building green roof was originally planted with a variety of *Sedum* and grass species. The original plants consisted of: *Sedum* 'Mini Me', *Sedum* *floriferum* 'Weihenstephaner Gold', *Sedum hybridum* 'Immergrunchen', *Sedum rupestre* 'Angelina', *Sedum spurium* 'Green Mantle', *Calamogrostis* 'Karl Forester', *Calamogrostis brachytricha*, and *Allium* 'Forescate' (Paulsen, 2010).

The immediate landscape context within 100 m (328 ft) surrounding the 900 North green roof was dominated by multiple high-rise mixed-use facilities, large amounts of impervious surfaces (parking lots, roof areas), and small amounts of manicured turf grass. The extended context consisted of high urban development with small pockets of designed landscapes.

The 900 North Building green roof exhibited the lowest richness (n_r= 35) and third lowest abundance (n_a= 647) of spiders and insects collected. These low numbers may be attributed to two factors -- the roof is only 41% vegetated, and/or it is elevated off the ground 20 m (66 ft) higher than any other roof (Figure 19). Just as with previous examples, the total number of invertebrates collected is significantly higher compared to total abundance of insects and spiders. This is largely due to the substantial number (n=3875) of the invertebrate woodlice collected on the roof (Table 9). The high number of woodlice caused this roof to have the greatest abundance of invertebrates compared to other study sites. As was explained with the Schwab roof, the large amount of woodlice may have played a role in preventing other insects and spiders from being collected in pit fall traps. Of all the insects and spiders collected on the 900 roof, those belonging to the order *Diptera* were the most abundant (46.2%) followed by *Coleoptera* (18.9%) and *Orthoptera* (18.9%) (Table 5).

Family Abundance

Of the 13 orders of insects and spiders present on the eight green roof study sites, only 6 orders were found to have high relative abundance--greater than 9%--with the remaining orders having less than 2.5% (Table 8). The most abundant order of insects was *Orthoptera* (34.4%). Within this order, the family *Gryllidae* (ie. crickets) constituted the highest abundance of specimens. The next most abundant orders were *Aranea* (ie. spiders) and *Hymenoptera* (ie. ants, bees, wasps) with both orders having similar relative abundances (13.3% & 13.2% respectively). *Diptera* (ie. flies) (12.9%), *Hemiptera* (ie. true bugs, cicadas, hoppers, aphids) (11.9%), and *Coleoptera* (ie. beetles) (9.5%) all had relative abundances within a similar range. When comparing specific families for percent abundance among the green roof sites, there were only a select few found with significant abundance (>2%). Multiple families were found in the 2-3% relative abundance range including: *Salticidae* and *Thomisidae* (ie. spiders), *Anthomyiidae*, *Chironomidea* and *Muscidae* (ie. flies), and *Phalangiidae* (ie. harvestmen). Species found in the 4-7% relative abundance range were: *Lycosidae* (ie. spiders), *Carabidae* (ie. beetles), *Rhopalidae* (ie. plant bugs), *Formicidae* (ie. ants), and *Acrididae* (ie. grasshoppers). As previously mentioned, *Gryllidae* (ie. crickets) exhibited the highest percent relative abundance (29.4%).

State Record for Species

Other studies involving invertebrates and green roofs have found cases of rare or threatened species being present (Jones, 2002; Kadas, 2006). Although finding rare or threatened species was not the original goal of this study, field work revealed that several rare or threatened invertebrate species were present on the green roof study sites. Because resources to properly identify all specimens to species level were not available, only a few specimens were professionally identified to species level by the entomologists who helped with the identification process. Those specimens that caught the eye of the scientists in this part of the study set several state records, because they were species never collected or recorded in the state of Michigan. Although the specimens have been documented in other states within the Mid-west region, no history in Michigan implies that the species would be considered rare in the region. The fact that they were found to be present on multiple different green roofs also has significance linking green roofs and their potential to provide habitat for rare invertebrate species.

The most notable state record belongs to the insect species *Anthidium oblongatum,* a type of Palearctic wool-carder bee. The *Anthidium* species was first recorded in North America in 1994 as being present in the State of New York (Hoebeke & Wheeler, 1999). Documentation of the species in other states shows how this species spread across the United States (Tonietto & Ascher, 2009). The *Anthidium* species collected from the Ford and GRCC sites, located on the east and west sides of the state of Michigan, represent the first documentation and known record for this species in the state of Michigan. A second collected species, *Pagasa fusca,* also was considered a state record for Michigan. This species has not been reported in the literature for the state of Michigan, but it has been recorded in neighboring states to the east and west of Michigan.

Pitfall vs. Sweep Net

The two collection methods utilized in this study were sweep net and pitfall traps. To date, the majority of other green roof studies have taken advantage of only one method per study, with pitfall traps typically being the collection method of choice (MacIvor & Lundholm, 2010; Kadas et al., 2008; Coffman, 2007). It was important in this study to obtain the most complete representation of the insect and spider communities that were present on the green roof study sites. Therefore, it was necessary to collect invertebrates on the ground level with pitfall traps, and more mobile, airborne invertebrates with sweep nets.

Pitfall traps have the advantage of permanence--once installed, they continuously trap specimens until emptied. In this study, the pitfall traps produced greater abundance numbers compared to sweep net. The specimens typically collected in pitfall traps (spiders and beetles) are also considered to be good indicator species of invertebrate communities and overall community health (Gedge & Kadas, 2005; Hellman & Sanders, 2007). This study found that if pitfall traps are not regularly emptied (ie. once per month), certain invertebrate specimens (like pill bugs and centipedes) could fill traps quickly and not allow other specimens to be collected. Pitfall traps also provided difficulty in installation where shallow media profiles were present. The smaller depth (and thus capacity) of the pitfall traps due to shallow media also led to quicker evaporation of the liquid within the traps once installed.

Sweep nets, on the other hand, may not provide an accurate representation of an insect and spider community since, in this example, they were only used one time a month. It is also a difficult task to collect insects and spiders with greater mobility especially since their presence on the green roofs were dictated by several constraints like time of day, time of year, flowering periods, full sun, and wind. Low growing vegetation, as is common with most *Sedum* roofs, also hindered sweep net collection. All of these constraints were found to have an effect on the presence of insects and spiders when collecting with sweep nets.

Overall, pitfall traps were found to be a more effective means of insect and spider collection for species abundance. This was due to the continuous month long collection exhibited by pitfall traps compared to the one time a month collection of the sweep net. There was, however, found to be no significant differences between the two collection methods for measuring insect and spider richness and diversity on a green roof. This suggested that both collection methods are viable means for profiling the diversity of insect and spider populations on a green roof.

Sedum vs. non-Sedum

When comparing extensive sedum green roofs to intensive green roofs with diversified vegetation for insect and spider presence, one would expect more abundance and richness to be found on the intensive green roofs. Green roofs with greater vegetation diversity have been documented to provide a more varied range of habitats and food sources for organisms (Dunnett et al., 2005). This study has shown that may not always be the situation, as was found in the case of the GRCC green roof. The extensive green roof atop GRCC displayed richness, abundance, and diversity numbers towards the upper end of the spectrum when comparing the study sites. This is thought to be caused by the variety of different *Sedum* plants present, which flowered throughout the year and provided different structural regimes through their flowering heads and vegetative morphology.

Sedum roofs are typically selected for their qualities of tolerance to the extremes of temperature and moisture exhibited on rooftops. Within this study, however, even the smallest (PSS) or thinnest substrate (Ford) *Sedum* roofs have proven to be valuable in providing habitat for insects and spiders. Some species of *Sedum* are even known to be host plants for butterfly species such as the Red Admiral, Painted Lady, and Small Apollo (Snodgrass & McIntyre, 2011). Although *Sedum* roofs have displayed some good qualities for attracting insect and spider communities, they should not be considered the single solution for designing roofs specifically for insect and spider habitat. As shown in this study with the Aquascape and Lurie green roof data, (along with other studies--Siemann et al., 1998; Tews et al., 2004) as vegetation diversity and structure increases, so does insect and spider diversity.

Installation Method

A question to consider from this study is whether the type of green roof installation will impact the presence of insects and spiders. Is it possible that a conventional green roof system will have less diversity and abundance of insects and spiders compared to a modular or mat system because of the ground-level vegetation growing period and the consequent transport of insects and spiders to the roof upon installation. Would the location and length of growing period make a difference in insect and spider presence on the modular and mat systems? Perhaps an independent study is required to fully answer these questions, but as a general observation from this study, there seems to be no discernable difference in green roof installation type compared to insect and spider presence. This is shown when comparing insect and spider abundance and diversity among the conventional green roof systems of Lurie and Aquascape with the modular and *Sedum* mat systems of GRCC and Ford, respectively.

Habitat Implications

This study has shown that irrespective of the number of positive or negative characteristics exhibited by a green roof, invertebrates will inhabit green roofs to some extent. Although the ideal situation for wildlife and invertebrate habitat would be to incorporate a palette of native vegetation species and soil characteristics similar to those found at ground-level, the reality of the matter is that most natives will not adapt to the extremes demanded of green roof systems, and at best, habitat can be replicated but not recreated (Snodgrass & McIntyre, 2010). Natural habitat creation on a green roof involves not only vegetation varieties but also structural components that allow the roof to function horizontally and vertically as it does in nature.

One of the most important factors to consider when designing green roofs for habitat conservation is the role of pollinating insects in functioning ecosystems. Pollinators are keystone species because the survival of large numbers of other species is dependent on them (Xerces Society, 2011). Pollinators also serve as important indicator species providing a view to the overall heath of an ecosystem (Xerces Society, 2011). Bees represent one of the most noteworthy classes of pollinators due to their role in pollen collection and dissemination, which puts them in contact with a great variety of flowers. This is in comparison to other pollinators, who only seek the nectar of flowers (Kevan & Baker, 1999). Thriving bee communities were found in this study and several other green roof studies (Colla et al., 2009; Tonietto et al., 2011).

Certain actions need to be implemented in order to craft an ideal environment on green roofs for pollinators and all invertebrates, which in return is the building block to attract other forms of wildlife. The first action, and arguably the most important, is that of incorporating plant diversity and structure to green roofs. Specific diversity levels and ideal plant species in terms of structure will determine the success of a green roof in providing habitat for a diversity of invertebrates and wildlife species. Native plants should be selected when suitable for the green roof environment. Selecting plants with overlapping bloom times and varieties in floral color, height, shape, size, and odor creates a wide array of all-season bloom periods and constant food sources for invertebrates (Kevan & Baker, 1999). Specific host plants should be incorporated when targeting butterflies and other individual pollinators. Grouping plants of the same species has also been found to be beneficial in attracting more pollinators (Xerces Society, 2011).

Integrating shelter is a critical component in green roof design for invertebrates. This is because as shelter opportunities tend to increase, invertebrate numbers tend to increase (Capinera, 2010). This can be accomplished naturally through incorporating objects such as leaf litter, twigs, logs, rocks, small brush piles and other objects into the green roof design. Artificial nesting sites also can be integrated in green roofs through the use of garden hose pieces, bamboo stakes, nest blocks and stem bundles (Gaston et al., 2005).

Another action to improve invertebrate habitat on green roofs is to take a “hands-off approach”. Once a green roof has been installed, let nature take control. In most cases, it is beneficial for invertebrate communities to have “weed” species appear;

likewise if certain plants die back and bare ground is exposed, that also can encourage invertebrate establishment. It is particularly important that the “hands-off approach” be accompanied by public education. This will allow people to better understand that the typical manicured aesthetics of a green roof are not the primary goal; rather, the beauty comes from the invertebrates and wildlife attracted to the site.

Special considerations also should be given to the maintenance schedule of green roofs when invertebrate habitat is in mind. At times mowing is beneficial for green roof vegetation to remove dead material and recycle nutrients, but mowing may also destroy valuable invertebrate habitat and should be done sparingly if at all (Helden & Leather, 2004). Pesticide application can be extremely damaging to a variety of invertebrates, not just the target pest, and should be performed cautiously when necessity requires. Fertilizer also holds the potential for adverse affects on invertebrate communities, and caution should be taken with application. A final maintenance commonly performed on green roofs is weeding, which may deprive invertebrates of beneficial “weed” vegetation.

CONCLUSION

The results presented in this study have added to the body of work previous conducted by others on the potential of green roofs to support invertebrate habitation. This study supports much of the earlier work by demonstrating green roofs provide viable habitat for invertebrates (Brenneisen, 2006; Jones, 2002; Kadas et al., 2008; MacIvor & Lundholm, 2010). Even the smallest vegetated roofs (in terms of area) have shown to provide a source of habitat for invertebrates. Some vegetated roofs provide a more favorable environment for invertebrate establishment than others. The factors for invertebrate establishment are dependent on a number of different elements associated with the roof, such as, vegetation type, roof area, roof height, roof age, media depth, and vegetation coverage.

In this study the amount of vegetative cover present on a roof was a significant determinant of insect and spider abundance and richness. This study has shown that higher richness and abundance numbers will exist on green roofs with higher proportions of vegetation cover. This leads to the conclusion that the impervious surfaces present on a green roof act to isolate and fragment habitat areas. The isolation of insect and spider habitat, therefore, generates another unfavorable habitat element to the already extreme green roof environment.

The size (in area) of vegetated roofs was also found to be a significant factor contributing to insect and spider richness. Abundance numbers, however, were not influenced by the size of a green roof. Between the eight study sites, three were considered to have a large area (over 20,000 m^2) with the other five having a smaller area (under 5,000 m^2). Different from what was expected in hypothesis number three (Ha3) (Appendix 4), only richness increased as the size of the green roof increased. The high richness could be contributed to the fact that two of the three larger roofs exhibited high plant variety -- Aquascape and Lurie – therefore, resulting in increased insect and spider variety.

Other characteristics of green roofs (vegetation type [diversity and structure], media depth, roof height, and roof age) were found to have a much smaller influence on insect and spider presence than was originally hypothesized (Appendix 4). Within this study it is of particular interest that the vegetation cover of green roofs had more of a significant impact on insect and spider abundance and diversity, than vegetation type as was recorded in other studies (Brose, 2003; Murdoch, et al., 1972). This might be attributed to the fact that this study categorized vegetation into the two broad categories of low-growing (less than 0.5m) *Sedum* roofs compared to mixed perennial roofs with more vegetation structure. Perhaps if vegetation data from the study sites were classified into individual species counts, the results would have been different.

Although the age of a roof can prove to be a significant factor when determining insect and spider abundance and diversity, it was found to have no influence within this study. This is due to lack of age difference between the study sites. The oldest green roof was installed in 2003 and the newest was installed in 2008. With a difference in installation dates of only five years among the study sites, small variations existed in the amount of years available for each roof to promote insects and spider establishment.

Media depth and green roof height also were found to have no significant impact on abundance and diversity of insects and spiders between the study sites. Even the extremes of an urban sky scraper (900 North) and severely limited media profile (Ford) were not enough to prevent invertebrates from colonizing green roofs.

The results of this study also may have been affected by the collection methods used. The two methods of sweep net and pitfall traps were effective means of invertebrate collection, but the methods did display shortcomings at particular times. On certain roofs with a low media profile (Ford, PSS), the pitfall traps were difficult to fashion into small enough traps to effectively place in the media. Collection of pitfall traps one time a month also led to an over flow of collected invertebrates on certain sites. Sweep netting was found to be a limited collection method on roofs with low-growing *Sedum* vegetation (Haworth) or during unfavorable weather conditions (ie, high wind, overcast sky, and cold temperatures). Another method of collection, sticky traps, was undertaken with little success. More research is needed to determine if other methods of collection, such as vacuums, beat sheets, or different sticky trap methods could assist in combating the shortcomings found in sweep nets and pitfall traps.

Although certain green roof characteristics were found to influence the presence or absence of insects and spiders, the results cannot be asserted as being conclusive. Several of the green roof characteristics that were analyzed in the study hold the potential to influence each other. For example, if a green roof is large in size, it may be expected to have high amounts of invertebrates present, but the roof also may possess the shallowest media profile and undesirable vegetation, both of which also influence invertebrate habitat. The confounding of these green roof characteristics is important, and caution needs to be taken when interpreting the results.

Table 1. Roof characteristics for each of the study sites.

	AQUASCAPE	FORD	GRCC	HAWORTH	LURIE	PSS	SCHWAB	900 NORTH
Location	St. Charles, IL	Dearborn, MI	Grand Rapids, MI	Holland, MI	Chicago, IL	East Lansing, MI	Chicago, IL	Chicago, IL
Installation	2005	2003	2008	2007	2004	2004	2003	2008
Accessibility	Accessible, Private. Roof entrance by free standing ladder.	Accessible, Private. Veg. access restricted.	Accessible, Public. Patio overlook, veg. access restricted.	Accessible, Private. Veg. access restricted.	Accessible, Public. Veg. access restricted.	Accessible, Private. Entrance on 2nd floor of building.	Accessible, Private. Restricted to Hospital use.	Accessible, Private. Veg. access restricted.
Area (m^2)	23,783	42,178	1,621	4,181	20,234	325	929	1,567
Height (meters)	Sloped: Approx. 9-18	Approx. 15-18	Approx. 9-12	Approx. Ground level-24	Ground Level	Approx. 9-12	Approx. 18-24	Approx. 42-48
Slope	8.33%	1.50%	3%	10%	1-5%	1%	1.50%	1%
Media depth (cm)	10.16 - 15.24 (4-6in)	2.54 - 5.08 (1-2in)	10.16 (4in)	10.16 (4in)	.02-1.22m (8in-4ft)	2.54 - 7.62 (1-3in)	20.32 - 45.72 (8-18in)	10.16 - 15.24 (4-6in)
% Veg. cover	59%	41%	82%	100%	75%	23%	42%	41%
Maintenance	Monthly weeding	Annual fertilization	Mowing, weeding, fertilization	Fertilization, weekly weeding	Weeding, pruning, fertilization	No maintenance	Weeding, pruning, fertilization	Fertilization, weeding
Irrigation	Subsurface, used sparingly	Above surface, used sparingly	No irrigation	Above surface, used sparingly	Above surface, used often	No irrigation	Hand & drip irrigation	Above surface, used often
Green roof type	Semi-Intensive, Conventional system	Extensive, sedum mats	Extensive, modular system	Extensive, modular system	Intensive, built-up retaining walls	Extensive, sedum mats on 1-2 in of media	Intensive, built-up retaining walls	Extensive, modular system

Table 2. Physical and chemical properties of substrate for each of the study sites.

	AQUASCAPE	FORD	GRCC	HAWORTH	LURIE	PSS	SCHWAB	900 NORTH
Sand Classifcation								
>2mm	78.80%	90.40%	58.10%	61.20%	12.80%	61.90%	30.20%	66.20%
VCoS	6.50%	3%	13.30%	16.90%	14.10%	6.60%	29.40%	13.70%
CoS	1.60%	3.20%	10.90%	9.60%	26.60%	11.50%	23.40%	9.80%
MS	4.90%	2.10%	9.20%	6.50%	31.10%	13.10%	12.20%	6.30%
FS	2.80%	0.70%	3.80%	3.10%	7.80%	4.60%	2.60%	2.10%
FSFI	1.50%	0.20%	1.60%	1%	2.70%	1%	0.80%	0.70%
VFS	2.20%	0.30%	2.20%	1.10%	3.20%	0.90%	0.90%	0.90%
Silt + Clay	1.70%	0.10%	0.90%	0.60%	1.70%	0.40%	0.50%	0.30%
Soil pH	7.7	7	7.1	7.2	7.3	7.5	7.2	7.6
%Organic Matter	15.9	*34.1	5.5	5.8	11.4	5.7	19.1	7.6
Phosphorus	76ppm	143ppm	56ppm	72ppm	91ppm	235ppm	78ppm	81ppm
Potassium	49ppm	346ppm	91ppm	163ppm	147ppm	95ppm	131ppm	88ppm
Magnesium	514ppm	362ppm	253ppm	279ppm	464ppm	132ppm	380ppm	286ppm

VCoS = Very Course Sand (1mm)
CoS = Coarse Sand (0.5 mm)
MS = Medium Sand (0.25 mm)
FS = Fine Sand (0.15 mm)
FSFI = Fine Sand – Fine Fraction (0.1 -0.18)
VFS = Very Fine Sand (.05 mm)

Authors Note: (* The high percent of organic matter is likely a result of soil sample contamination with the roofs existing organic matter (moss particles, dead vegetation, etc). This was due to lack of media profile and difficulty in collecting media only samples. Analysis per Michigan State University Soil and Plant Nutrient Laboratory, East Lansing, Michigan.)

Table 3. Vegetation structure on each of the study sites.

	AQUASCAPE	FORD	GRCC	HAWORTH	LURIE	PSS	SCHWAB	900 NORTH
Total Vegetation Profile	0 - 1.5 meters	0 - .5 meters	0 - .5 meters	0 - .5 meters	0 - 10 meters	0 - .5 meters	0 - 10 meters	0 - 1.5 meters
Sedum (0 -.5m)		100%	100%	100%		100%		33%
Grass/Perennial (0 - 1.5m)	100%				78.50%		77%	67%
Grass/Perennial/ Shrub (1.5 - 3m)					13%		12%	
Tree (5 - 10m)					8.50%		11%	

Table 4. Measurements of insect and spider richness, abundance, insects m^2, and diversity indices (Simpson (D), Shannon-Weiner (H'), and Evenness (E)) for each of the study sites.

Measurements	Total Sites	Aquascape	Ford	GRCC	Haworth	Lurie	PSS	Scwhab	900 North
Richness (Total)	110	65	50	55	49	58	40	42	35
(Sweep Net)	87	34	29	29	24	46	18	28	28
(Pitfall Trap)	72	55	33	36	36	26	31	18	13
Abundance (Total # of indiv(s))	8727	1898	753	1506	2233	731	589	370	647
(Sweep Net)	2449	532	413	498	83	425	100	95	303
(Pitfall Trap)	6278	1366	340	1008	2150	306	489	275	344
Simpson's (Total)	0.8898	0.8561	0.8784	0.9196	0.4421	0.9360	0.7563	0.8193	0.8865
(Sweep Net)	0.9272	0.9498	0.6993	0.8405	0.8155	0.8747	0.8036	0.9227	0.7716
(Pitfall Trap)	0.8084	0.7569	0.8884	0.8685	0.3997	0.9099	0.6631	0.6835	0.7945
Shannon-Weiner (Total)	3.0713	2.7980	2.8198	2.9100	1.2386	3.1594	2.1710	2.5695	2.4686
(Sweep Net)	3.2225	3.3192	1.9149	2.2724	2.2698	2.6736	2.1236	2.8652	1.9575
(Pitfall Trap)	2.4756	2.1144	2.7743	2.4452	1.0773	2.6179	1.8240	1.7742	1.8105
Evenness (Total)	0.6534	0.6703	0.7208	0.7262	0.3183	0.7781	0.5885	0.6875	0.6943
(Sweep Net)	0.7216	0.8283	0.5687	0.6748	0.7142	0.6983	0.7347	0.8599	0.5875
(Pitfall Trap)	0.5789	0.5996	0.7935	0.6823	0.3006	0.8035	0.5311	0.6138	0.7059
Insects sq.m. (Total)	0.0920	0.0798	0.0179	0.9291	0.5341	0.0361	1.8123	0.3983	0.4129
(Sweep Net)	0.0258	0.0224	0.0098	0.3072	0.0199	0.0210	0.3077	0.1023	0.1934
(Pitfall Trap)	0.0662	0.0574	0.0081	0.6218	0.5142	0.0151	1.5046	0.2960	0.2195
Richness (Total)*	115	65	52	59	52	61	42	46	38
(Sweep Net)*	87	55	29	29	24	46	18	28	28
(Pitfall Trap)*	77	34	35	40	39	29	33	22	16
Abundance (Total # of indiv(s))*	17352	1898	760	1620	2297	2710	594	2913	4560
(Sweep Net)*	2449	532	413	498	83	425	100	95	303
(Pitfall Trap)*	14903	1366	347	1122	2214	2285	494	2818	4257

Authors Note: (* richness and abundance measurements for all invertebrates within the study sites.)

Table 5. Abundance and percent relative abundance of insect and spider orders within each of the study sites.

Order	Aquascape	Ford	GRCC	Haworth	Lurie	PSS	Schwab	900
Araneae (Spiders)	236	54	321	329	31	102	59	24
Coleoptera (Beetles)	175	144	201	32	96	26	29	122
Dermaptera (Earwigs)	0	0	3	0	1	1	0	0
Diptera (Flies)	96	118	136	104	275	56	41	298
Ephemeroptera (Mayflies)	0	0	1	0	0	0	0	0
Hemiptera (True Bugs, Hoppers, and Allies)	382	244	259	16	35	64	23	11
Hymenoptera (Ants, Bees, Wasps and Sawflies)	169	82	219	18	188	288	180	11
Lepidoptera (Butterflies and Moths)	15	41	74	8	23	5	14	5
Neuroptera (Antlions, Lacewings and Allies)	1	1	0	0	1	0	0	0
Odonata (Dragonflies and Damselflies)	35	2	1	0	2	0	1	2
Opiliones (Harvestmen)	0	0	28	37	37	18	16	50
Orthoptera (Grasshoppers, Crickets, Katydids)	787	67	257	1689	42	29	7	122
Trichoptera (Caddisflies)	2	0	6	0	0	0	0	0
Total	**1898**	**753**	**1506**	**2233**	**731**	**589**	**370**	**645**
	Aquascape	Ford	GRCC	Haworth	Lurie	PSS	Schwab	900
Araneae (Spiders)	12.4%	7.2%	21.3%	14.7%	4.2%	17.3%	15.9%	3.7%
Coleoptera (Beetles)	9.2%	19.1%	13.3%	1.4%	13.1%	4.4%	7.8%	18.9%
Dermaptera (Earwigs)	0.0%	0.0%	0.2%	0.0%	0.1%	0.2%	0.0%	0.0%
Diptera (Flies)	5.1%	15.7%	9.0%	4.7%	37.6%	9.5%	11.1%	46.2%
Ephemeroptera (Mayflies)	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
Hemiptera (True Bugs, Hoppers, and Allies)	20.1%	32.4%	17.2%	0.7%	4.8%	10.9%	6.2%	1.7%
Hymenoptera (Ants, Bees, Wasps and Sawflies)	8.9%	10.9%	14.5%	0.8%	25.7%	48.9%	48.6%	1.7%
Lepidoptera (Butterflies and Moths)	0.8%	5.4%	4.9%	0.4%	3.1%	0.8%	3.8%	0.8%
Neuroptera (Antlions, Lacewings and Allies)	0.1%	0.1%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
Odonata (Dragonflies and Damselflies)	1.8%	0.3%	0.1%	0.0%	0.3%	0.0%	0.3%	0.3%
Opiliones (Harvestmen)	0.0%	0.0%	1.9%	1.7%	5.1%	3.1%	4.3%	7.8%
Orthoptera (Grasshoppers, Crickets, Katydids)	41.5%	8.9%	17.1%	75.6%	5.7%	4.9%	1.9%	18.9%
Trichoptera (Caddisflies)	0.1%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 6. P-values for the effect of green roof characteristics on insect and spider families in terms of richness, abundance, insects per square meter, and diversity indices (H', D, E).

Roof Characteristic	Measurements	Significance (P)
Roof Height	Abundance	0.3739
	Richness	0.1322
	Shannon-Weiner (H')	0.7247
	Simpson (D)	0.4092
	Evenness (E)	0.5989
	Insects/sq.m.	0.7470
Roof Size	Abundance	0.9184
	Richness	0.0396**
	Shannon-Weiner (H')	0.1428
	Simpson (D)	0.3182
	Evenness (E)	0.2849
	Insects/sq.m.	0.0729
Media Depth	Abundance	0.4963
	Richness	0.9557
	Shannon-Weiner (H')	0.5835
	Simpson (D)	0.6160
	Evenness (E)	0.5485
	Insects/sq.m.	0.4468
Vegetation Type	Abundance	0.5093
	Richness	0.7727
	Shannon-Weiner (H')	0.3062
	Simpson (D)	0.3009
	Evenness (E)	0.2721
	Insects/sq.m.	0.1820
Percent Vegetation	Abundance	0.0159**
	Richness	0.0237**
	Shannon-Weiner (H')	0.9676
	Simpson (D)	0.7121
	Evenness (E)	0.6623
	Insects/sq.m.	0.5745

Authors Note: (** Significance was found between roof size and family richness as well as between percent vegetation and family abundance and richness.)

Table 7. ANOVA table comparing the two methods of collection (pitfall and sweep net) against richness, abundance, insects per square meter, and diversity indices (H’, D, E).

Measurements	Num. Degrees of Freedom	Den. Degrees of Freedom	F Value	P Value
Abundance	1	7	7.16	0.0317**
Richness	1	7	0.09	0.7775
Shannon-Weiner (H')	1	7	2.01	0.1992
Simpson (D)	1	7	1.84	0.2168
Evenness (E)	1	7	1.37	0.2800
Insects/sq.m.	1	7	3.50	0.1034

Authors Note: (**The two methods have significant differences in abundance level.)

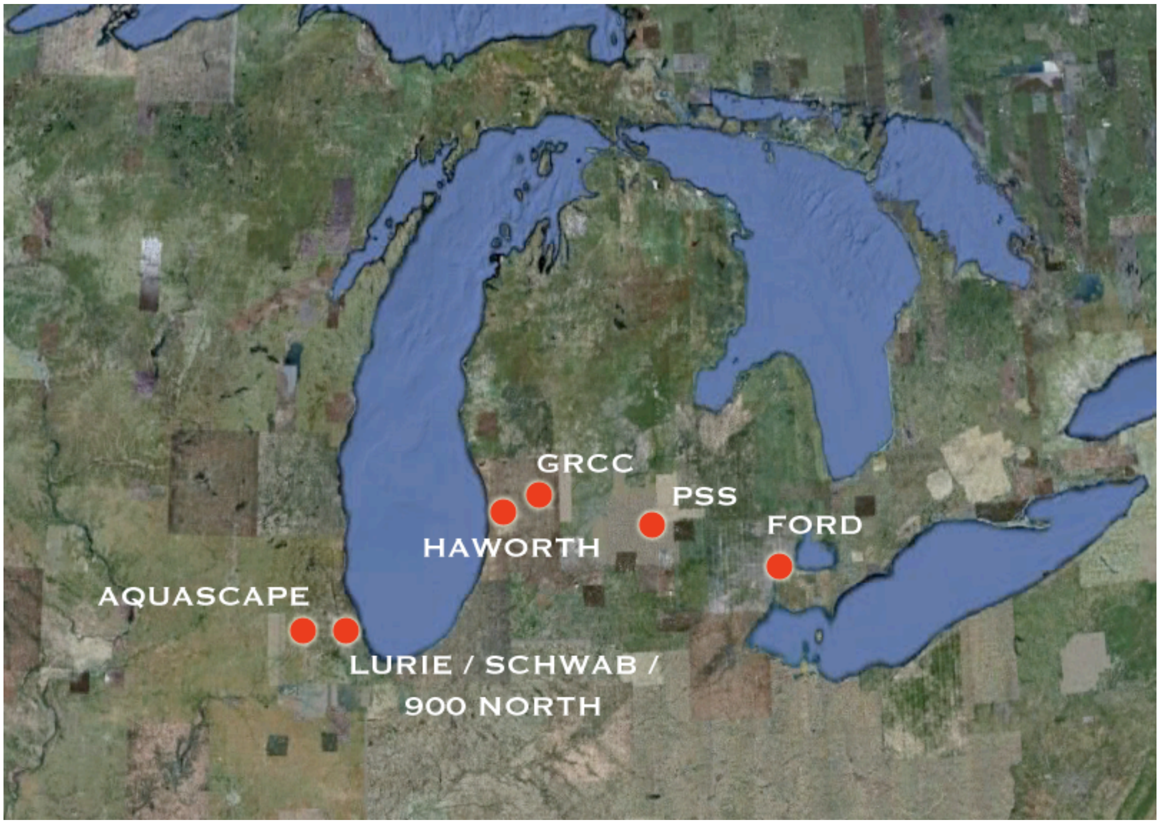

Figure 1. Site locations for the eight different green roofs with four roofs being located in Michigan and four roofs located in Illinois. (For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis). (Photo source: Google Earth 2011).

Figure 2. Sweep net collection technique at Ford Motor Company during the month of August. (Photograph courtesy of J. Monsma).

Figure 3. Pitfall trap installed at Haworth Corporation with cover to prevent rain and irrigation from entering trap. (Photograph courtesy of J. Monsma).

Authors Note: (The sticky traps were removed from all sites due to aesthetics, roof owner concerns, and their inefficiency to randomly collect insects.)

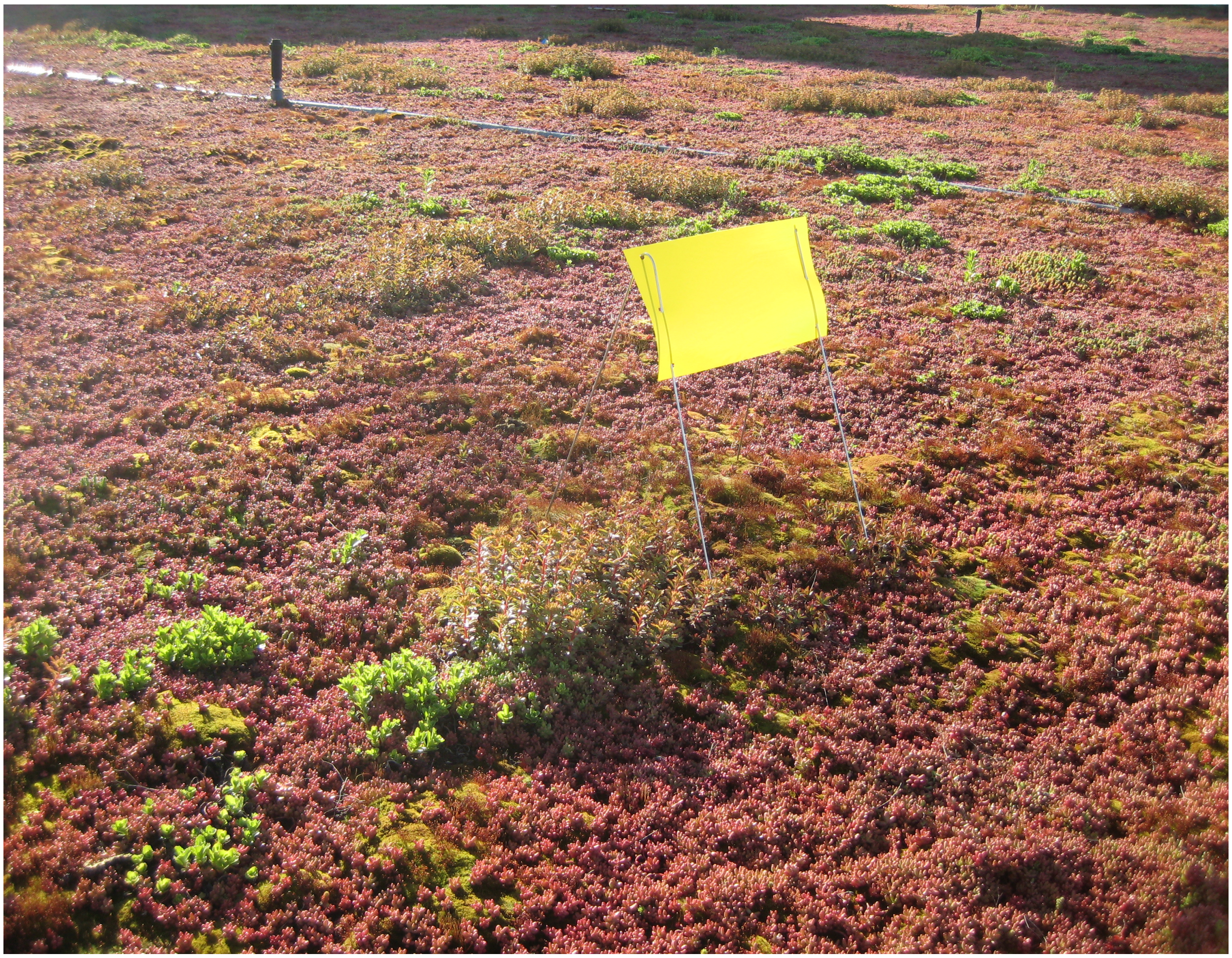

Figure 4. Sticky trap installed on the Ford Motor Company roof. (Photograph courtesy of J. Monsma).

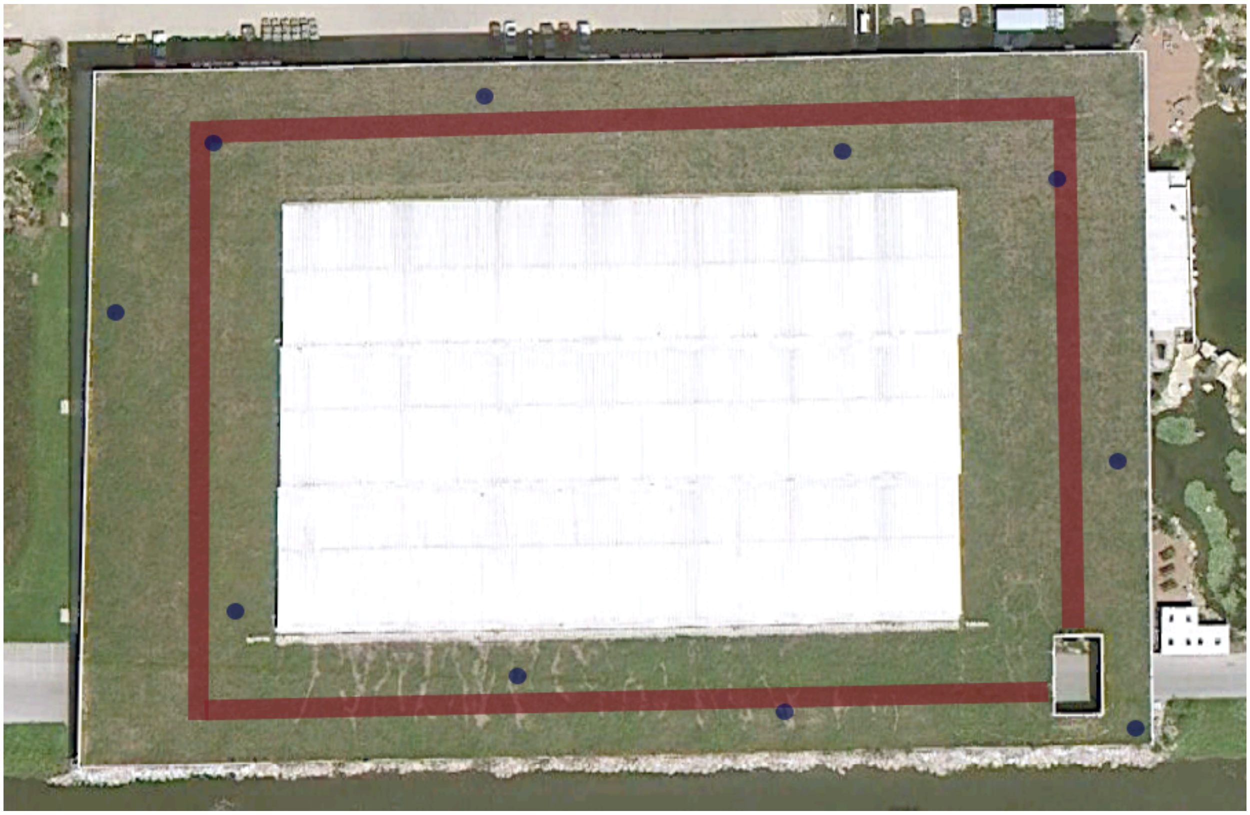

Figure 5. Sweep net transect (red) and pitfall trap (blue) locations for the Aquascape roof. (Photo source: Google Earth 2011).

Figure 6. Sweep net transect (red) and pitfall trap (blue) locations for the Ford Motor Company roof. (Photo source: Google Earth 2011).

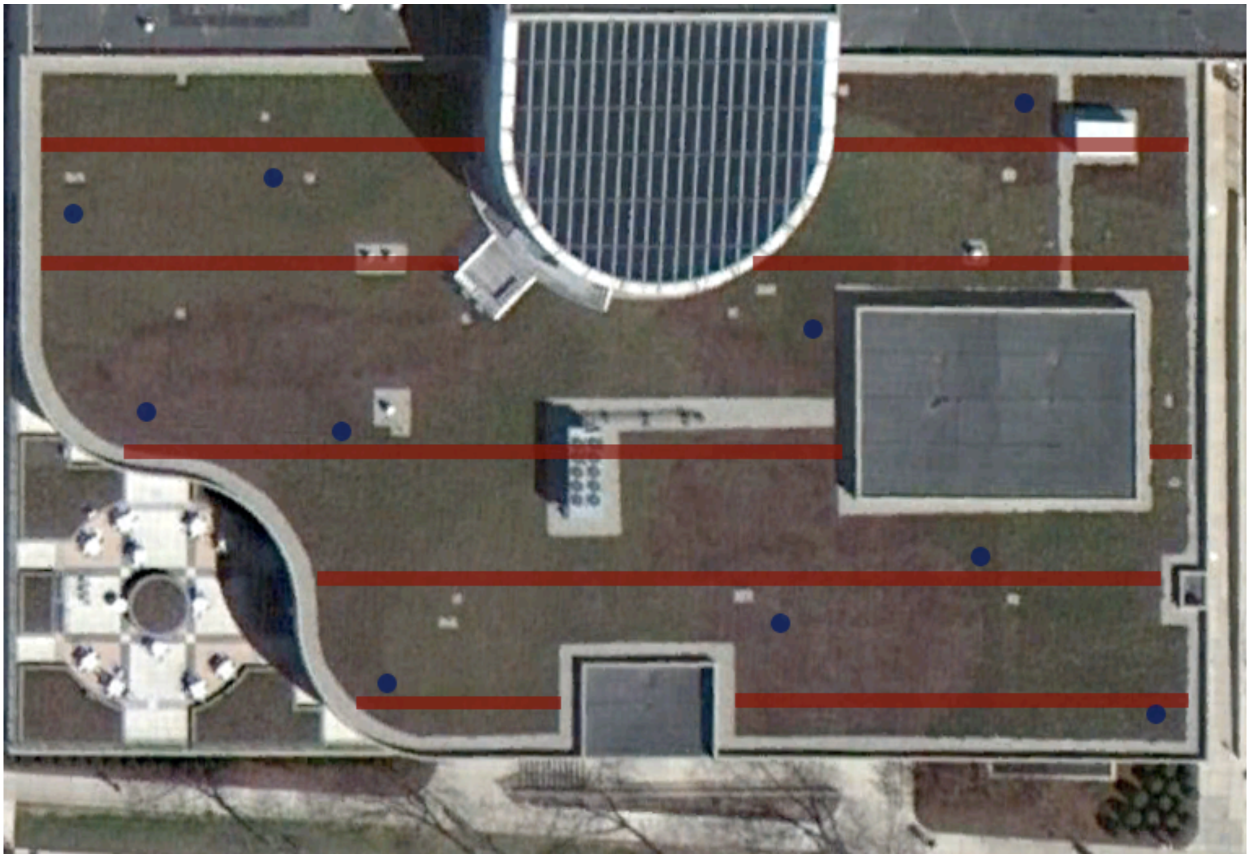

Figure 7. Sweep net transect (red) and pitfall trap (blue) locations for the Grand Rapids Community College roof. (Photo source: Google Earth 2011).

Figure 8. Sweep net transect (red) and pitfall trap (blue) locations for the Haworth Corporation roof. (Photo source: Google Earth 2011).

Figure 9. Sweep net transect (red) and pitfall trap (blue) locations for the Lurie Garden roof. (Photo source: Google Earth 2011).

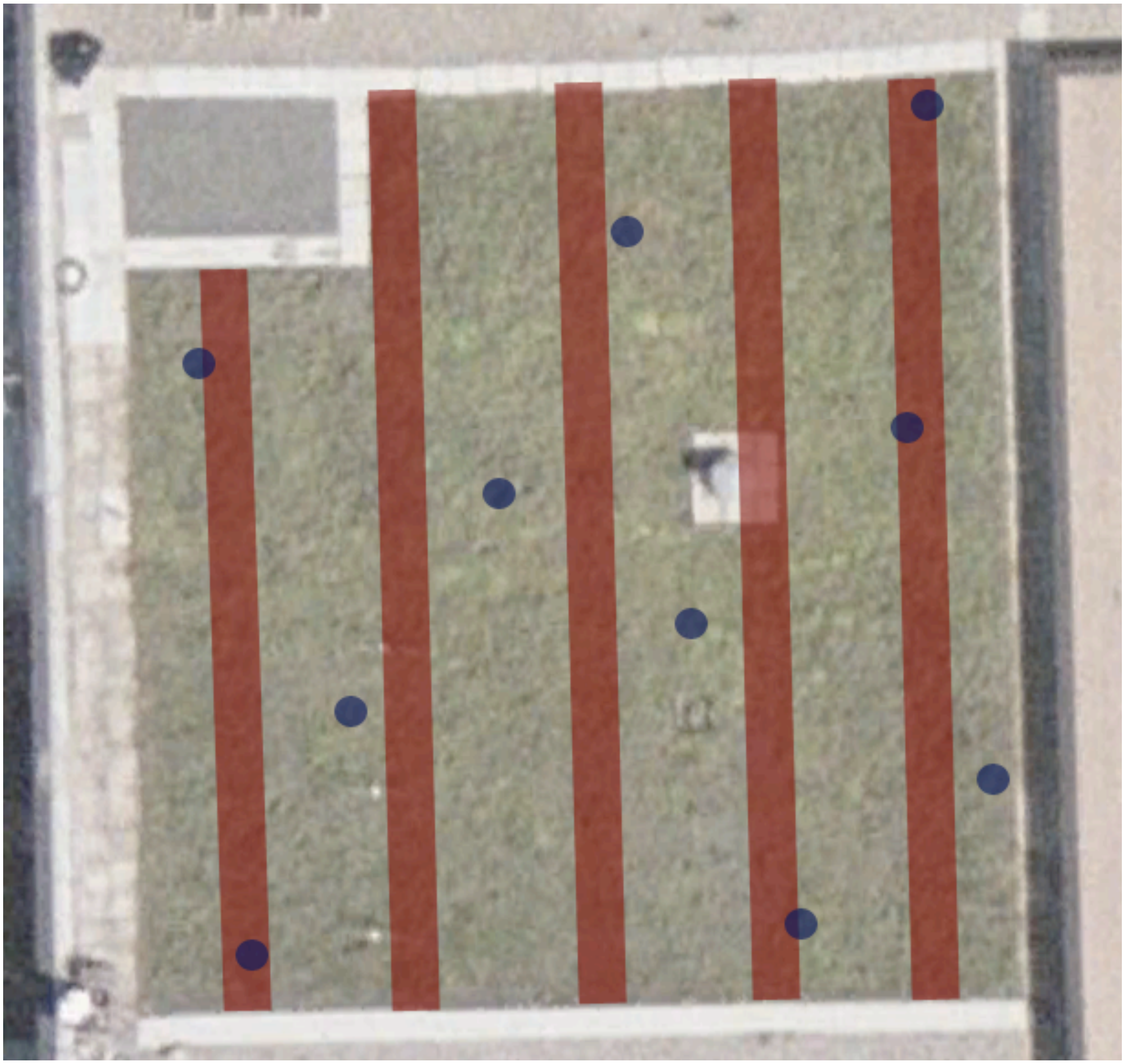

Figure 10. Sweep net transect (red) and pitfall trap (blue) locations for the Plant and Soil Science Building roof. (Photo source: Google Earth 2011).

Figure 11. Sweep net transect (red) and pitfall trap (blue) locations for the Schwab Rehabilitation Hospital roof. (Photo source: Google Earth 2011).

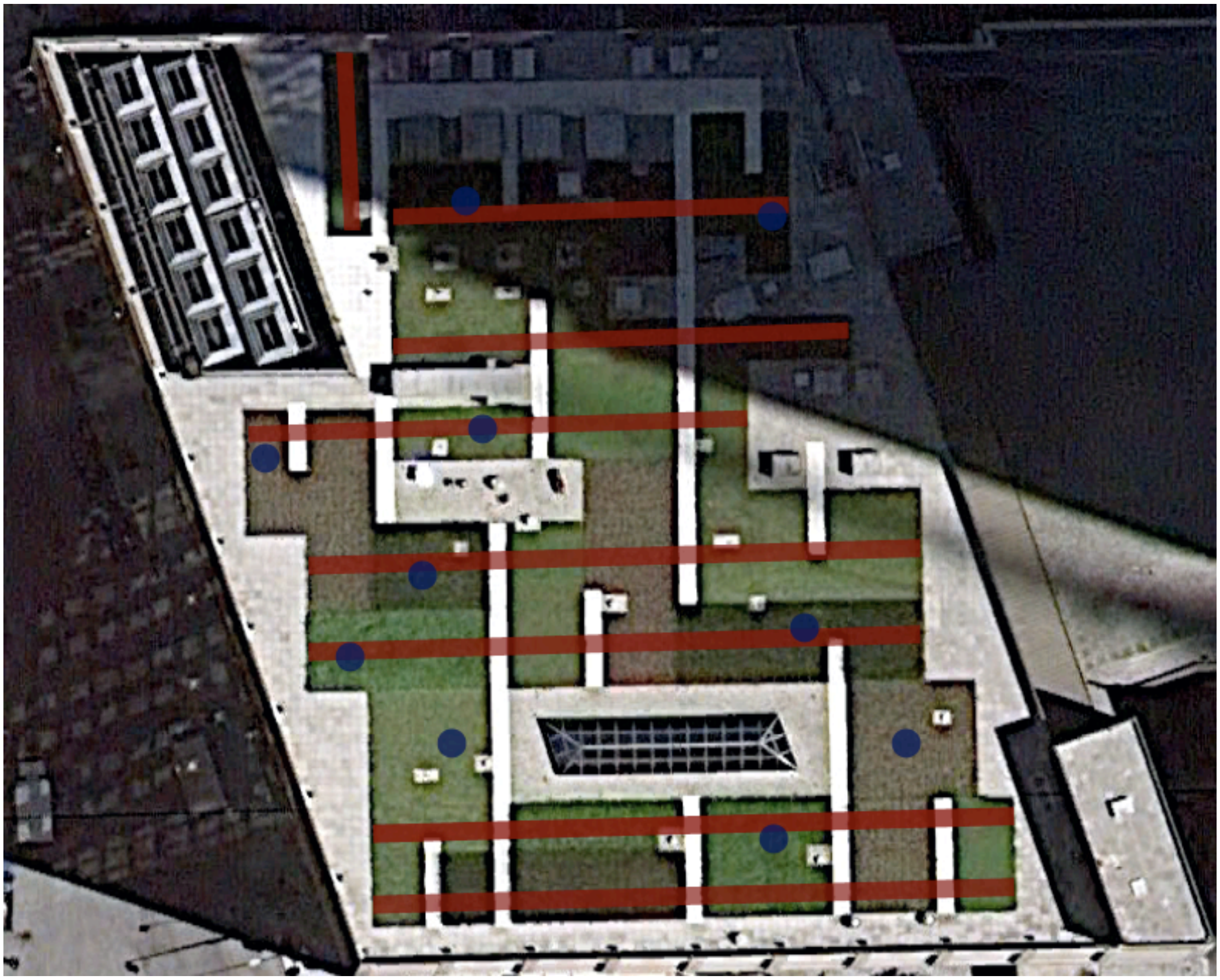

Figure 12. Sweep net transect (red) and pitfall trap (blue) locations for the 900 North Building roof. (Photo source: Google Earth 2011).

Figure 13. Portion of the Aquascape green roof with its vegetation similar to a native meadow. (Photograph courtesy of J. Monsma).

Authors Note: (GRCC exhibited considerable differences in *Sedum* species structure and diversity with the vegetation displaying flowers throughout the entire collection period.)

Figure 14. Grand Rapids Community College green roof displaying its variety of different *Sedum* species. (Photograph courtesy of J. Monsma).

Figure 15. The intensive green roof atop Schwab Rehabilitation hospital included a water feature. (Photograph courtesy of J. Monsma).

Figure 16. The 900 North green roof sits atop the tallest building compared to the other green roof sites. (Photograph courtesy of J. Monsma).

Authors Note: (Category 1 represents the four roofs with over 58% vegetation coverage. Category 2 represents the four roofs that displayed less than 43% vegetation coverage.)

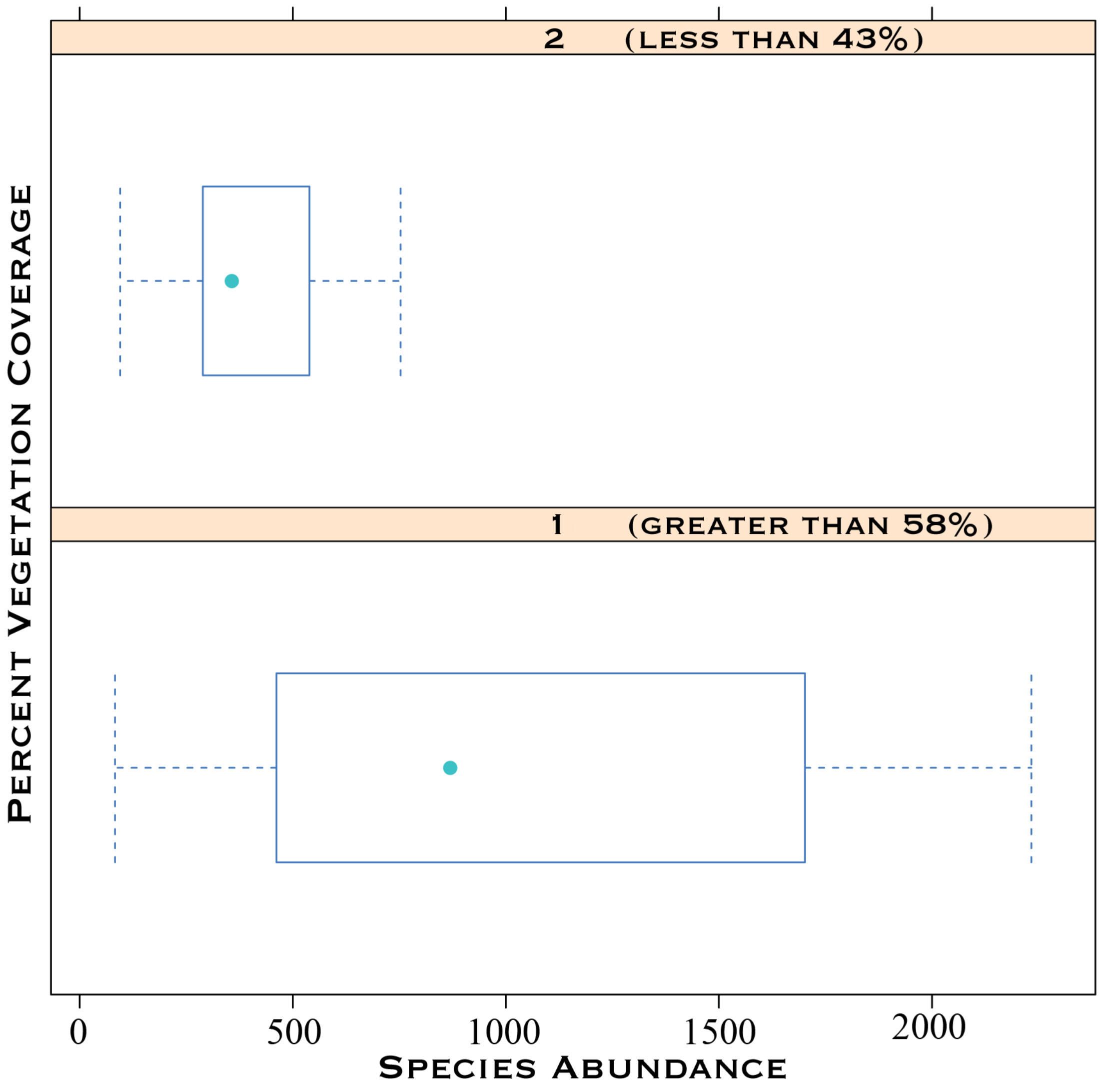

Figure 17. The effect of percent vegetation on family abundance numbers at the various study sites.

Authors Note: (Category 1 represents the four roofs with over 58% vegetation coverage. Category 2 represents the four roofs that displayed less than 43% vegetation coverage.)

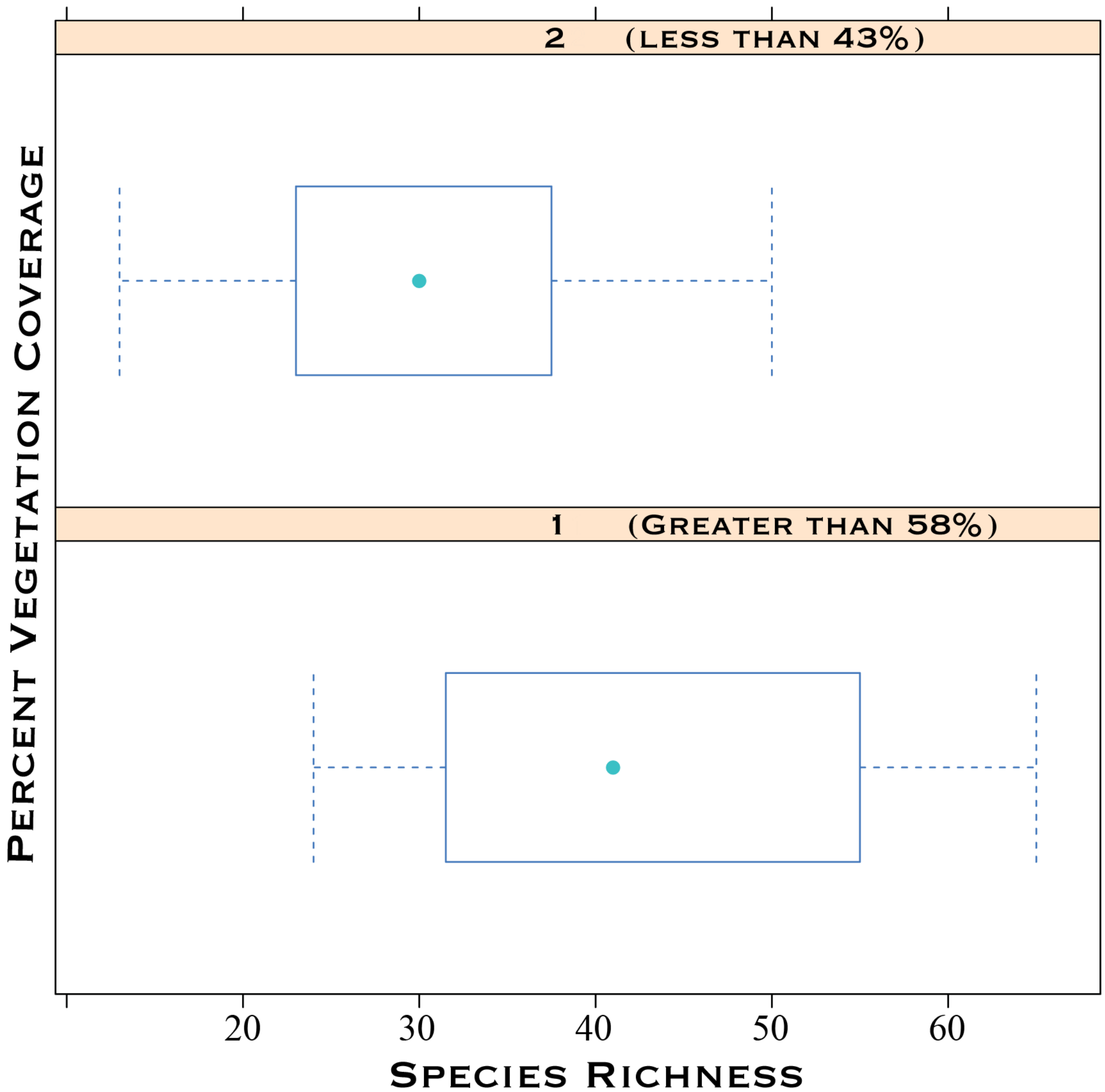

Figure 18. The effect of percent vegetation on family richness numbers at the various study sites.

Authors Note: (The green roofs were placed into two categories, the roofs larger than 20,000 m^2 (green) and the roofs less than 5,000 m^2 (red). Higher average family richness was found in those roofs with larger area.)

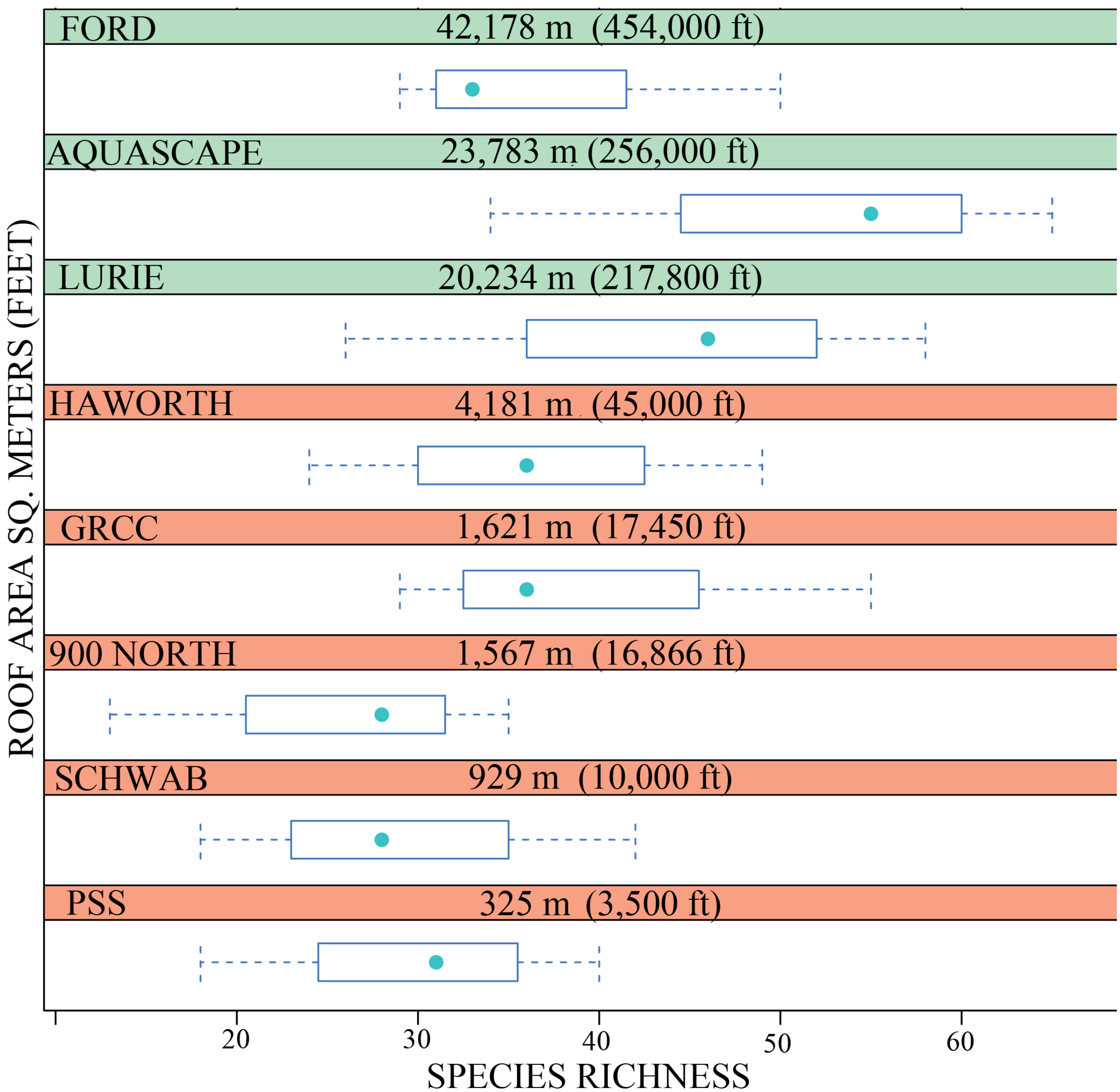

Figure 19. Comparison between family richness and the size (area) of the various study sites.

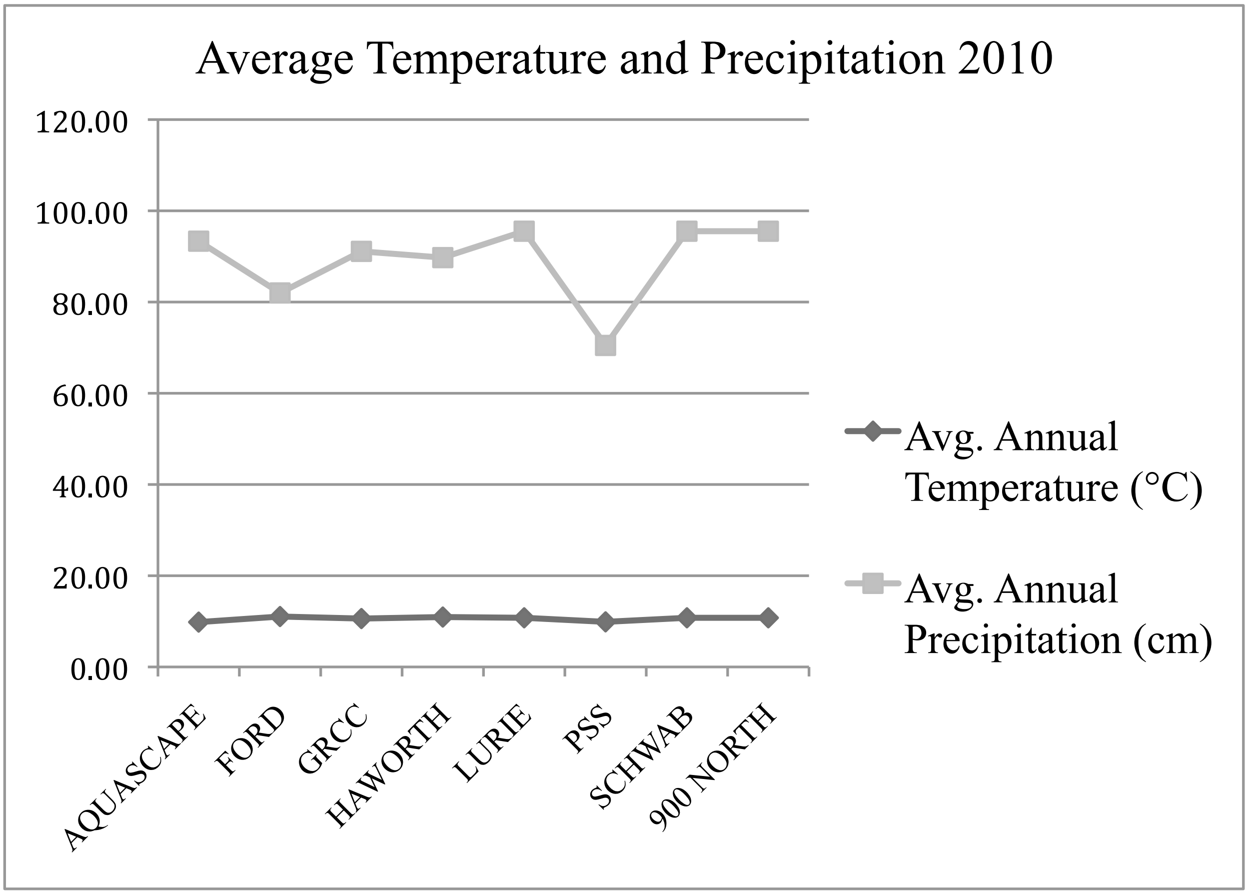

Figure 20. Average temperature and precipitation of the study site locations for the year 2010. Based on the National Oceanic and Atmospheric Administration data (NOAA 2010).

Authors Note: (Ford, the largest roof area, had the least amount of insects and spiders per square meter. PSS, the smallest roof area, had the highest number of insects and spiders per square meter.)

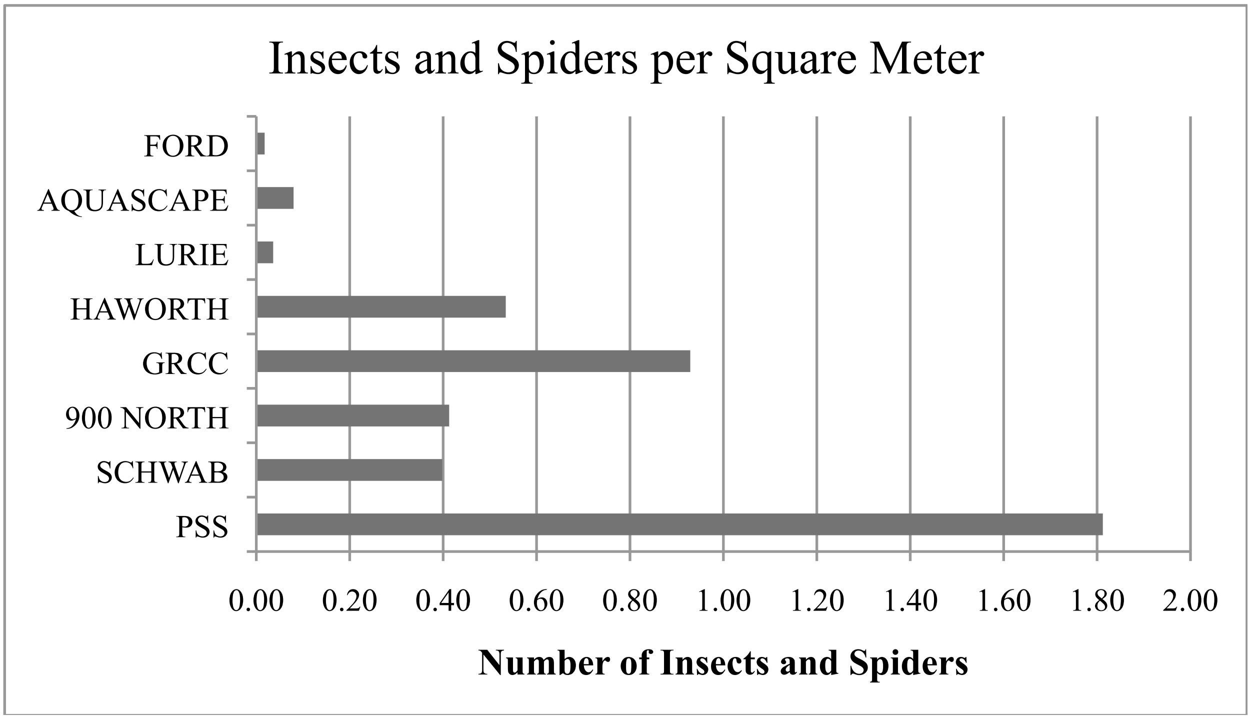

Figure 21. The number of insects and spiders per square meter based on the size of the various study sites.

APPENDICES

Appendix 1. Equations and definitions of diversity indices (D, H’, E). (Source: Pielou, 1966; Whittaker, 1972; Southwood & Henderson, 2001).

Simpson Index (D): Takes into account the number of species (richness) as well as the abundance of each species. This index is represented as 1/D where 1 represents infinite diversity and 0 represents no diversity.

$$(\Sigma(n_i(n_i-1)/(N(N-1))))$$

N_i= number of individuals in the *i*th species
N= total number of individuals in the sample

Shannon Wiener Index (H’): Takes into account the number of species (richness) and the evenness of their abundance. In this index, higher numbers represent more species richness and diversity, and lower numbers less species richness and diversity.

$$-\sum_{i=1}^{s} (p_i \ln p_i)$$

p_i= proportion of individuals of species i

Evenness (E): Measure of the relative abundance of the species making up the richness of an area. In this measure, 1 represents complete evenness, 0 no evenness.

$$H'/\ln(S)$$

H’= Shannon Wiener Index
S = total number of species

Table 8. Abundance, percent abundance, and mean abundance with standard deviation for insect and spider orders and families within the study sites.

ORDER	FAMILY	Abundance	% Abundance	Mean Abundance ±SD
Araneae (Spiders)		1156	13.2462%	
	Araneidae (Orb Weavers)	6	0.0688%	1.2±0.4
	Clubionidae (Sac Spiders)	2	0.0229%	1±0
	Corinnidae (Ground Sac Spiders)	84	0.9625%	14±17.5
	Dysderidae (Dysderids)	37	0.4240%	6.2±8.4
	Gnaphosidae (Ground Spiders)	8	0.0917%	4±4.2
	Lycosidae (Wolf Spiders)	603	6.9096%	16.8±23.8
	Oxyopidae (Lynx Spiders)	2	0.0229%	1±0
	Philodromidae (Running Crab Spiders)	2	0.0229%	1±0
	Pisauridae (Nursery Web Spiders)	4	0.0458%	2±0
	Salticidae (Jumping Spiders)	201	2.3032%	4.5±6.1
	Tetragnathidae (Longjawed Orb Weavers)	23	0.2635%	3.8±3.9
	Thomisidae (Crab Spiders)	184	2.1084%	5.9±7.3
Coleoptera (Beetles)		825	9.4534%	
	Aphodiinae (Aphodiine Dung Beetles)	1	0.0115%	1±0
	Byrrhidae (Pill Beetles)	8	0.0917%	2±2
	Cantharidae (Soldier Beetles)	42	0.4813%	14±21.7
	Carabidae (Ground Beetles)	397	4.5491%	13.7±21.1
	Chrysomelidae (Leaf Beetles)	118	1.3521%	9.1±14.4
	Cleridae (Checkered Beetles)	5	0.0573%	2.5±2.1
	Coccinellidae (Lady Beetles)	5	0.0573%	1.3±0.5
	Curculionidae (Snout and Bark Beetles)	40	0.4583%	2.4±2.1
	Elateridae (Click Beetles)	39	0.4469%	2.1±2.2
	Eucinetidae (Plate-thigh Beetles)	9	0.1031%	2.3±1.9
	Histeridae (Clown Beetles)	1	0.0115%	1±0
	Lampyridae (Fireflies)	2	0.0229%	1±0
	Melyridae (Soft-winged Flower Beetles)	42	0.4813%	3.8±5.2
	Nitidulidae (Sap-feeding Beetles)	10	0.1146%	2.5±0.6
	Phalacridae (Shining Flower Beetles)	1	0.0115%	1±0
	Scarabaeidae (Scarab Beetles)	75	0.8594%	4.7±7.5

Table 8. (cont'd)

Staphylinidae (Rove Beetles)	18	0.2063%	1.5±0.7
Tenebrionidae (Darkling Beetles)	12	0.1375%	2.4±1.3
Dermaptera (Earwigs)	5	0.0573%	
Forficulidae (Earwigs)	5	0.0573%	1.7±1.2
Diptera (Flies)	1124	12.8796%	
Acalyptratae (Acalyptratae Flies)	6	0.0688%	3±1.4
Anthomyiidae (Root-Maggot Flies)	280	3.2084%	7.6±9.1
Asilidae (Robber Flies)	1	0.0115%	1±0
Bombyliidae (Bee Flies)	2	0.0229%	1±0
Calliphoridae (Blow Flies)	71	0.8136%	2.5±2
Chironomidae (Midges)	226	2.5897%	15.1±25.3
Chloropidae (Frit Flies)	5	0.0573%	1.3±0.5
Conopidae (Thick-headed Flies)	2	0.0229%	1±0
Culicidae (Mosquitoes)	2	0.0229%	1±0
Dolichopodidae (Longlegged Flies)	8	0.0917%	1±0
Dryomyzidae (Dryomyzid Flies)	1	0.0115%	1±0
Ephydridae (Shore Flies)	1	0.0115%	1±0
Muscidae (House Flies and kin)	218	2.4980%	12.1±25
Mycetophilidae (Fungus Gnats)	1	0.0115%	1±0
Platystomatidae (Signal Flies)	1	0.0115%	1±0
Sarcophagidae (Flesh Flies)	52	0.5959%	5.2±7.4
Scathophagidae (Dung Flies)	9	0.1031%	1.3±0.5
Sciaridae (Dark-winged Fungus Gnats)	7	0.0802%	2.3±1.5
Sepsidae (Black Scavenger Flies)	16	0.1833%	4±3.8
Simuliidae (Black Flies)	1	0.0115%	1±0
Stratiomyidae (Soldier flies)	12	0.1375%	6±1.4
Syrphidae (Syrphid Flies)	118	1.3521%	4.2±4.8
Tachinidae (Tachinid Flies)	3	0.0344%	1±0
Therevidae (Stiletto Flies)	1	0.0115%	1±0
Tipulidae (Large Crane Flies)	5	0.0573%	1.3±0.5
Ulidiidae (Picture-winged Flies)	75	0.8594%	5.4±5.7
Ephemeroptera (Mayflies)	1	0.0115%	
Heptageniidae (Stream Mayflies)	1	0.0115%	1±0
Hemiptera (True Bugs, Hoppers, and Allies)	1034	11.8483%	
Alydidae (Broad-headed Bugs)	31	0.3552%	10.3±8.4
Aphididae (Aphids)	31	0.3552%	10.3±13.7

Table 8. (cont'd)

Berytidae (Stilt Bugs)	2	0.0229%	1±0
Cercopidae (Spittlebugs)	11	0.1260%	1.2±0.4
Cicadellidae (Leafhoppers)	25	0.2865%	1.9±1.7
Cydnidae (Burrowing Bugs)	113	1.2948%	11.3±15.3
Flatidae (Flatid Planthoppers)	1	0.0115%	1±0
Geocoridae (Big-eyed Bugs)	20	0.2292%	5±2.9
Lygaeidae (Seed Bugs)	157	1.7990%	13.1±19.2
Membracidae (Treehoppers)	1	0.0115%	1±0
Miridae (Plant Bugs)	64	0.7334%	3.4±3.6
Nabidae (Damsel Bugs)	12	0.1375%	1.7±1
Pentatomidae (Stink Bugs)	20	0.2292%	1.7±1
Reduviidae (Assassin Bugs)	1	0.0115%	1±0
Rhopalidae (Scentless Plant Bugs)	494	5.6606%	29.1±38.6
Rhyparochromidae (Dirt-colored Seed Bugs)	34	0.3896%	2.6±3.6
Scutellaridae (Shield-backed Bugs)	17	0.1948%	2.8±2.9
Hymenoptera (Ants, Bees, Wasps and Sawflies)	1155	13.2348%	
Andrenidae (Mining Bees)	3	0.0344%	1.5±0.7
Anthocoridae (Minute Pirate Bugs)	1	0.0115%	1±0
Apidae (Carpenter, Bumble, and Honey Bees)	169	1.9365%	8±11.2
Braconidae (Braconid Wasps)	15	0.1719%	1.4±0.7
Chalcididae (Chalcid Wasps)	5	0.0573%	1.3±0.5
Chrysididae (Cuckoo Wasps)	1	0.0115%	1±0
Colletidae (Plasterer and Yellow-faced Bees)	17	0.1948%	4.3±3.9
Crabronidae (Apoid Wasps)	2	0.0229%	1±0
Diprionidae (Conifer Sawflies)	1	0.0115%	1±0
Formicidae (Ants)	645	7.3909%	16.5±24.8
Halictidae (Sweat Bees)	101	1.1573%	5.3±5.7
Ichneumonidae (Ichneumon Wasps)	20	0.2292%	1.8±1.6
Megachilidae (Leaf-cutter, and Mason Bees)	67	0.7677%	5.6±5.6
Pompilidae (Spider Wasps)	4	0.0458%	1.3±0.6
Sphecidae (Thread-waisted Wasps)	7	0.0802%	1.2±0.4
Tiphiidae (Tiphiid Wasps)	2	0.0229%	1±0
Vespidae (Yellowjackets, Wasps, and Hornets)	95	1.0886%	3.8±4.9

Table 8. (cont'd)

Lepidoptera (Butterflies and Moths)	185	2.1199%	
Erebidae (Owlet Moths)	1	0.0115%	1±0
Hesperiidae (Skippers)	10	0.1146%	1.3±0.5
Noctuidae (Owlet Moths)	8	0.0917%	1.3±0.8
Nymphalidae (Brushfooted Butterflies)	16	0.1833%	2±1.4
Papilionidae (Swallowtails, Parnassians)	2	0.0229%	1±0
Pieridae (Whites, Sulphurs, Yellows)	19	0.2177%	2.1±2.4
Pyralidae (Pyralid Moths)	114	1.3063%	5.7±11.7
Tortricida (Tortricid Moths)	14	0.1604%	2.3±1.2
Yponomeutidae (Ermine Moths)	1	0.0115%	1±0
Neuroptera (Antlions, Lacewings and Allies)	3	0.0344%	
Chrysopidae (Green Lacewings)	3	0.0344%	1±0
Odonata (Dragonflies and Damselflies)	43	0.4927%	
Coenagrionidae (Narrow-winged Damselflies)	37	0.4240%	4.6±5.0
Lestidae (Spreadwings)	1	0.0115%	1±0
Libellulidae (Skimmers)	5	0.0573%	1±0
Opiliones (Harvestmen)	186	2.1313%	
Phalangiidae (Harvestmen)	186	2.1313%	10.3±10.8
Orthoptera (Grasshoppers, Crickets, Katydids)	3000	34.3761%	
Acrididae (Short-horned Grasshoppers)	439	5.0304%	7.7±8.6
Gryllidae (Crickets)	2561	29.3457%	94.9±155.4
Trichoptera (Caddisflies)	10	0.001145869	
Hydropsychidae (Netspinning Caddisflies)	8	0.0917%	1.6±1.1
Phryganeidae (Giant Casemakers)	2	0.0229%	1±0

Table 9. Order and family abundances for all invertebrates collected within the study sites.

	Aqua	Ford	GRCC	Haworth	Lurie	PSS	Schwab	900
Araneae (Spiders)	**236**	**54**	**321**	**329**	**31**	**102**	**59**	**24**
Araneidae (Orb Weavers)	3	1	1	0	0	0	0	1
Clubionidae (Sac Spiders)	0	0	0	1	0	1	0	0
Corinnidae (Antmimics and Ground Sac Spiders)	0	5	10	69	0	0	0	0
Dysderidae (Dysderids)	0	0	0	0	0	0	37	0
Gnaphosidae (Ground Spiders)	0	0	0	8	0	0	0	0
Lycosidae (Wolf Spiders)	96	4	254	193	14	15	13	14
Oxyopidae (Lynx Spiders)	0	0	0	0	0	1	0	1
Philodromidae (Running Crab Spiders)	2	0	0	0	0	0	0	0
Pisauridae (Nursery Web Spiders)	0	4	0	0	0	0	0	0
Salticidae (Jumping Spiders)	43	28	7	35	4	73	5	6
Tetragnathidae (Longjawed Orb Weavers)	12	0	1	0	9	0	0	1
Thomisidae (Crab Spiders)	80	12	48	23	4	12	4	1
Coleoptera (Beetles)	**175**	**144**	**201**	**32**	**96**	**26**	**29**	**122**
Aphodiinae (Aphodiine Dung Beetles)	1	0	0	0	0	0	0	0
Byrrhidae (Pill Beetles)	1	6	0	0	0	1	0	0
Cantharidae (Soldier Beetles)	41	1	0	0	0	0	0	0
Carabidae (Ground Beetles)	44	13	181	9	21	10	3	116
Chrysomelidae (Leaf Beetles)	4	97	2	2	7	1	0	5
Cleridae (Checkered Beetles)	5	0	0	0	0	0	0	0
Coccinellidae (Lady Beetles)	3	0	0	0	1	1	0	0
Curculionidae (Snout and Bark Beetles)	12	2	0	10	14	0	2	0
Elateridae (Click Beetles)	20	3	5	5	4	0	1	1
Eucinetidae (Plate-thigh Beetles)	0	3	5	1	0	0	0	0
Histeridae (Clown Beetles)	0	0	0	0	0	0	1	0
Lampyridae (Fireflies)	2	0	0	0	0	0	0	0
Melyridae (Soft-winged Flower Beetles)	35	6	0	1	0	0	0	0
Nitidulidae (Sap-feeding Beetles)	2	5	0	0	0	3	0	0
Phalacridae (Shining Flower Beetles)	0	0	0	0	0	0	1	0
Scarabaeidae (Scarab Beetles)	3	2	7	1	48	0	14	0
Staphylinidae (Rove Beetles)	2	5	1	2	1	0	7	0

Table 9. (cont'd)

Tenebrionidae (Darkling Beetles)	0	1	0	1	0	10	0	0
Dermaptera (Earwigs)	**0**	**0**	**3**	**0**	**1**	**1**	**0**	**0**
Forficulidae (Earwigs)	0	0	3	0	1	1	0	0
Diptera (Flies)	**96**	**118**	**136**	**104**	**275**	**56**	**41**	**298**
Acalyptratae	0	0	2	4	0	0	0	0
Anthomyiidae (Root-Maggot Flies)	19	60	26	56	51	24	7	37
Asilidae (Robber Flies)	0	0	0	0	0	1	0	0
Bombyliidae (Bee Flies)	1	0	0	1	0	0	0	0
Calliphoridae (Blow Flies)	14	5	7	17	18	2	6	2
Chironomidae (Midges)	21	4	52	0	13	1	21	114
Chloropidae (Frit Flies)	0	0	3	0	1	0	0	1
Conopidae (Thick-headed Flies)	1	0	0	0	0	0	1	0
Culicidae (Mosquitoes)	0	0	0	1	0	0	1	0
Dolichopodidae (Longlegged Flies)	2	0	1	1	2	1	0	1
Dryomyzidae (Dryomyzid Flies)	0	0	0	0	1	0	0	0
Ephydridae (Shore Flies)	0	0	0	0	1	0	0	0
Muscidae (House Flies and kin)	9	18	2	4	90	16	1	78
Mycetophilidae (Fungus Gnats)	0	0	1	0	0	0	0	0
Platystomatidae (Signal Flies)	0	0	0	0	1	0	0	0
Sarcophagidae (Flesh Flies)	2	0	32	11	4	3	0	0
Scathophagidae (Dung Flies)	0	2	1	2	0	4	0	0
Sciaridae (Dark-winged Fungus Gnats)	2	4	1	0	0	0	0	0
Sepsidae (Black Scavenger Flies)	0	0	0	0	15	0	1	0
Simuliidae (Black Flies)	0	0	1	0	0	0	0	0
Stratiomyidae (Soldier flies)	0	12	0	0	0	0	0	0
Syrphidae (Syrphid Flies)	23	13	6	6	50	3	3	14
Tachinidae (Tachinid Flies)	0	0	0	1	1	1	0	0
Therevidae (Stiletto Flies)	0	0	1	0	0	0	0	0
Tipulidae (Large Crane Flies)	2	0	0	0	1	0	0	2
Ulidiidae (Picture-winged Flies)	0	0	0	0	26	0	0	49
Entomobryomorpha (Elongate-bodied Springtails)	**0**	**0**	**10**	**0**	**0**	**0**	**0**	**0**
Isotomidae (Elongate-bodied Springtails)	0	0	10	0	0	0	0	0

Table 9. (cont'd)

Ephemeroptera (Mayflies)	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**
Heptageniidae (Stream Mayflies)	0	0	1	0	0	0	0	0
Hemiptera (True Bugs, Cicadas, Hoppers, Aphids and Allies)	**382**	**244**	**259**	**16**	**35**	**64**	**23**	**11**
Alydidae (Broad-headed Bugs)	31	0	0	0	0	0	0	0
Aphididae (Aphids)	27	0	0	0	0	0	0	4
Berytidae (Stilt Bugs)	0	0	0	0	1	0	1	0
Cercopidae (Spittlebugs)	5	3	0	1	0	0	2	0
Cicadellidae (Leafhoppers)	11	0	1	1	7	0	2	3
Cydnidae (Burrowing Bugs)	105	0	0	0	2	0	6	0
Flatidae (Flatid Planthoppers)	1	0	0	0	0	0	0	0
Geocoridae (Big-eyed Bugs)	0	0	13	5	0	2	0	0
Lygaeidae (Seed Bugs)	68	6	72	2	0	5	4	0
Membracidae (Treehoppers)	1	0	0	0	0	0	0	0
Miridae (Plant Bugs)	32	10	3	1	12	0	6	0
Nabidae (Damsel Bugs)	2	0	4	1	0	4	0	1
Pentatomidae (Stink Bugs)	10	1	0	0	5	1	0	3
Reduviidae (Assassin Bugs)	0	0	0	0	1	0	0	0
Rhopalidae (Scentless Plant Bugs)	44	223	166	4	7	49	1	0
Rhyparochromidae (Dirt-colored Seed Bugs)	28	1	0	1	0	3	1	0
Scutellaridae (Shield-backed Bugs)	17	0	0	0	0	0	0	0
Hymenoptera (Ants, Bees, Wasps and Sawflies)	**169**	**82**	**219**	**18**	**188**	**288**	**180**	**11**
Andrenidae (Mining Bees)	0	2	0	1	0	0	0	0
Anthocoridae (Minute Pirate Bugs)	0	0	0	0	0	0	1	0
Apidae (Cuckoo, Carpenter, Digger, Bumble, and Honey Bees)	8	1	39	1	108	0	12	0
Braconidae (Braconid Wasps)	1	8	1	4	1	0	0	0
Chalcididae (Chalcid Wasps)	1	2	0	0	1	0	0	1
Chrysididae (Cuckoo Wasps)	0	0	0	0	0	0	1	0
Colletidae (Plasterer Bees, Masked or Yellow-faced Bees)	0	0	16	0	1	0	0	0
Crabronidae (Apoid Wasps)	0	0	0	0	2	0	0	0
Diprionidae (Conifer Sawflies)	0	0	0	0	0	1	0	0
Formicidae (Ants)	135	18	24	8	32	273	148	7
Halictidae (Sweat Bees)	5	19	34	2	33	6	2	0

Table 9. (cont'd)

Ichneumonidae (Ichneumon Wasps)	1	13	1	0	1	1	2	1
Megachilidae (Leaf-cutter Bees, Mason Bees, and allies)	0	11	44	0	4	4	4	0
Pompilidae (Spider Wasps)	0	0	2	1	1	0	0	0
Sphecidae (Thread-waisted Wasps)	1	0	2	0	3	0	0	1
Tiphiidae (Tiphiid Wasps)	0	0	1	0	0	1	0	0
Vespidae (Yellowjackets, Paper Wasps, Hornets, and Pollen Wasps)	17	8	55	1	1	2	10	1
Isopoda (Isopods)	**0**	**0**	**75**	**43**	**1587**	**4**	**2348**	**3875**
Oniscidea (Woodlice)	0	0	75	43	1587	4	2348	3875
Lepidoptera (Butterflies and Moths)	**15**	**41**	**74**	**8**	**23**	**5**	**14**	**5**
Erebidae (Owlet Moths)	0	0	0	0	1	0	0	0
Hesperiidae (Skippers)	2	0	1	0	3	1	3	0
Noctuidae (Owlet Moths)	1	2	3	1	0	1	0	0
Nymphalidae (Brushfooted Butterflies)	2	1	1	0	4	0	8	0
Papilionidae (Swallowtails, Parnassians)	0	0	0	1	0	0	1	0
Pieridae (Whites, Sulphurs, Yellows)	0	1	5	1	10	0	2	0
Pyralidae (Pyralid Moths)	4	37	64	3	1	3	0	2
Tortricida (Tortricid Moths)	6	0	0	2	3	0	0	3
Yponomeutidae (Ermine Moths)	0	0	0	0	1	0	0	0
Lithobiomorpha (Stone Centipedes)	**0**	**6**	**8**	**10**	**29**	**1**	**57**	**9**
Lithobiidae (Stone Centipedes)	0	6	8	10	29	1	57	9
Neuroptera (Antlions, Lacewings and Allies)	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**0**
Chrysopidae (Green Lacewings)	1	1	0	0	1	0	0	0
Odonata (Dragonflies and Damselflies)	**35**	**2**	**1**	**0**	**2**	**0**	**1**	**2**
Coenagrionidae (Narrow-winged Damselflies)	32	1	0	0	2	0	1	1
Lestidae (Spreadwings)	1	0	0	0	0	0	0	0
Libellulidae (Skimmers)	2	1	1	0	0	0	0	1
Opiliones (Harvestmen)	**0**	**0**	**28**	**37**	**37**	**18**	**16**	**50**
Phalangiidae (Harvestmen)	0	0	28	37	37	18	16	50

Table 9. (cont'd)

Orthoptera (Grasshoppers, Crickets, Katydids)	**787**	**67**	**257**	**1689**	**42**	**29**	**7**	**122**
Acrididae (Short-horned Grasshoppers)	125	32	125	36	6	29	0	86
Gryllidae (Crickets)	662	35	132	1653	36	0	7	36
Polydesmida (Millipedes)	**0**	**1**	**21**	**11**	**363**	**0**	**137**	**29**
Polydesmida (Millipedes)	0	1	21	11	363	0	137	29
Scutigeromorpha (House Centipedes)	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**
Scutigeridae (House Centipedes)	0	0	0	0	0	0	1	0
Trichoptera (Caddisflies)	**2**	**0**	**6**	**0**	**0**	**0**	**0**	**2**
Hydropsychidae (Netspinning Caddisflies)	2	0	6	0	0	0	0	0
Phryganeidae (Giant Casemakers)	0	0	0	0	0	0	0	2

Appendix 4. Original hypotheses expected to be found from the results of the study.

Ho1: There will be no difference between insect and spider family composition (abundance and diversity) and the plant composition (vegetation structure and diversity) of the various green roof study sites.

Ha1: Insect and spider family abundance and diversity will increase on green roof study sites with greater amounts of vegetation structure and diversity.

Ho2: There will be no difference between insect and spider family composition (abundance and diversity) and the age of the various green roof study sites.

Ha2: There will be greater insect and spider family abundance and diversity on older green roof study sites.

Ho3: There will be no difference between insect and spider family composition (abundance and diversity) and the size (in area) of the various green roof study sites.

Ha3: Insect and spider family abundance and diversity will increase on green roof study sites with larger size (in area).

Ho4: There will be no difference between insect and spider family composition (abundance and diversity) and the height of the various green roof study sites.

Ha4: insect and spider family abundance and diversity will increase on green roof study sites with closer proximity to ground level.

Ho5: There will be no difference between insect and spider family composition (abundance and diversity) and the media profile of the various green roof study sites.

Ha5: insect and spider family abundance and diversity will increase on green roof study sites with increased media depth.

Ho6: There will be no difference between insect and spider family composition (abundance and diversity) and the percent vegetation cover of the various green roof study sites.

Ha6: insect and spider family abundance and diversity will increase on green roof study sites with higher proportions of vegetation cover.

LITERATURE CITED

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Baumann, N. (2006). Ground-nesting birds on green roofs in Switzerland: preliminary observations. *Urban Habitats* 4(1): 37-50.

Berndtsson, J. (2010). Green roof performance towards management of runoff water quantity and quality: a review. *Ecological Engineering* 36: 351-360.

Bliss, D.J., R.D. Neufeld, & R.J. Ries (2009). Storm water runoff mitigation using a green roof. *Environmental Engineering Science 26*(2): 407-417.

Borror, D.J. & R.E. White (1970). *Peterson Field Guides: Insects*. New York, NY: Houghton Mifflin Company.

Borror, D.J., C.A. Triplehorn, & N.F. Johnson (1989). *An Introduction to the Study of Insects*. Philadelphia, PA: Saunders College Publishing.

Brenneisen, S. (2005). Green roofs: recapturing urban space for wildlife - a challenge for urban planning and environmental education. *In: Proc. of 3rd North American Green Roof Conference: Greening Rooftops for Sustainable Communities,* Washington, DC. Toronto, Ontario: The Cardinal Group.

Brenneisen, S. (2006). Wildlife: designing green roofs as habitats in Switzerland. *Urban Habitats* 4(1): 27-36.

Brose, U. (2003) Bottom-up control of carabid beetle communities in early successional wetlands mediated: by vegetation structure or plant diversity? *Oecologia* 135: 407–413.

Cantor, S. (2008). *Green Roofs in Sustainable Landscape Design.* New York, New York: W. W. Norton & Company, Inc.

Capinera, J.L. (2010). *Insects and Wildlife: Arthropods and Their Relationship with Wild Vertebrate Animals.* West Sussex, UK: John Wiley & Sons Ltd.

Carter, T., & C.A. Butler (2008a). Ecological impacts of replacing traditional roofs with green roofs in two urban areas. *Cities and Environment 1*(2): 1-17.

Carter, T. & A. Keeler (2008b). Life-cycle cost-benefit analysis of extensive vegetated roof systems. *Journal of Environmental Management 87*: 350-363.

Clark, C., P. Adriaens, & F. B. Talbot (2008). Green Roof Valuation: A Probabilistic Economic Analysis of Environmental Benefits. *Environmental Science and Technology* 42: 2155–2161.

Coffman, R.R., & G. Davis (2005). Insect and avian fauna presence on the ford assembly plant ecoroof. In: Proc*. of 3rd North American Green Roof Conference: Greening Rooftops for Sustainable Communities,* Washington, DC. Toronto, Ontario: The Cardinal Group.

Coffman, R.R. (2007). Comparing wildlife habitat and biodiversity across green roof type. In: Proc. of 5th North American Green Roof Conference: *Greening Rooftops for Sustainable Communities,* Minneapolis, MN. Toronto, Ontario: The Cardinal Group.

Colla, S. R., E. Willis, & L. Packer (2009). Can green roofs provide habitat for urban bees (Hymenoptera: Apidae)? *Cities and Environment* 2(1): 12, Article 4.

Daniels, J.C. (2005). *Butterflies of Michigan Field Guide*. Cambridge, MA: Adventure Publications Inc.

Dettmers, L. (2010). Vegetation description of Schwab Rehabilitation Hospital green roof. Personal Communication. Chicago, IL: Schwab Rehabilitation Hospital.

Dunnett, N. & N. Kingsbury (2008). *Planting Green Roofs and Living Walls*. Portland, Oregon: Timber Press, Inc.

Dunnett, N., A. Nagase, R. Booth, & P. Grime (2005). Vegetation composition and structure significantly influence green roof performance. In Proc. of 3rd North American Green Roof Conference: *Greening Rooftops for Sustainable Communities*, Washington, DC. Toronto, Ontario: The Cardinal Group.

Durhman, A.K., D.B. Rowe, & C.L. Rugh (2006). Effect of watering regimen on chlorophyll fluorescence and growth of selected green roof plant taxa. *HortScience* 41(7): 1623-1628.

Evans, A.V. (2008). *Field Guide to Insects and Spiders of North America*. New York, NY: Sterling Publishing Co.

Gaston, K.J., R.M. Smith, K. Thompson, & P.H. Warren (2005). Urban domestic gardens (II): experimental tests of methods for increasing biodiversity. *Biodiversity and Conservation* 14: 395-413.

Gedge, D. & G. Kadas (2005). Green roofs and biodiversity. *Biologist 52*(3): 161-169.

Getter, K.L., D. B. Rowe, J.A. Andresen, & I.S. Wichman (2011). Seasonal heat flux properties of an extensive green roof in a Midwestern U.S. climate. *Energy and Buildings* 43: 3548-3557.

Getter, K.L., D.B. Rowe, G.P. Robertson, B.M. Cregg, & J.A. Andresen (2009a). Carbon sequestration potential of extensive green roofs. *Environmental Science and Technology* 43(19): 7564-7570.

Getter, K.L. & D.B. Rowe (2009). Substrate depth influences sedum plant community on a green roof. *HortScience* 44(2): 401-407.

Getter, K.L., D.B. Rowe, & B.M. Cregg (2009b). Solar radiation intensity influences extensive green roof plant communities. *Urban Forestry and Urban Greening* 8(4): 269-281.

Getter, K.L., D.B. Rowe, & J.A. Andresen (2007). Quantifying the effect of slope on extensive green roof stormwater retention. *Ecological Engineering* 31: 225-231.

Gobster, P.H., J.I. Nassauer, T.C. Daniel, & G. Fry (2007). The shared landscape: what does aesthetics have to do with ecology? *Landscape Ecology 22*: 959-972.

Grant G., L. Engleback & B. Nicholson (2003). Green roofs: their existing status and potential for conserving biodiversity in urban areas. In: Proc. of *English Nature Research Report No. 498.* 1-61. London, UK: Ecoschemes Ltd.

Greenroofs.com (2010). Nueva School, Hillside Learning Complex. *The greenroof project database. http://www.greenroofs.com/projects/pview.php?id=727. (Last accessed 16 August 2011.)*

Greenroofs.com (2010). *The greenroof project database.* http://www.greenroofs.com/projects/. *(Last accessed 26 November 2011.)*

Greenroofs.org (2011). Annual green roof industry survey. *Green Roofs for Health Cities.* http://www.greenroofs.org/resources/2011_GRHC_Survey_Report.pdf. (Last accessed14 December 2011.)

Greenstone, M.H. (1984). Determinants of web spider species diversity: vegetation structural diversity vs. prey availability. *Oecologia 62*: 299-304.

Heisler, G.M. & A.J. Brazel (2010). The urban physical environment: temperature and urban heat islands. Chapter 2. In: Aitkenhead-Peterson, J., and A. Volder, [eds.] Urban Ecosystem Ecology. Agronomy Monograph 55. Madison, WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America. p. 29-56.

Helden, A.J. & S.R. Leather (2004). Biodiversity on urban roundabouts-Hemiptera, management and the species-area relationship. *Basic and Applied Ecology* 5(4): 367-377.

Hellmann, J.J. & N.J. Sanders (2007). The extent and future of global insect diversity. *Environmental Science and Technology 25*: 33-55.

Hoebeke, E.R. & A.G. Wheeler, Jr. (1999). *Anthidium oblongatum* (Illiger): An Old World bee (Hymenoptera: Megachilidae) new to North America, and new North American records for another adventive species, *A. manicatum* (L.). In: G.W. Byers, R.H. Hagen and R.W. Brooks, eds. Entomological Contributions in Memory of Byron A. Alexander, University of Kansas Natural History Museum Special Publ. 24.

Hunter, M.R. & M.D. Hunter (2008). Designing for conservation of insects in the built environment. *Insect Conservation and Diversity* 1: 189-196.

Jones, R. A. (2002). Tecticolous invertebrates; a preliminary investigation of the invertebrate fauna on ecoroofs in urban London. In: Proc. of *English Nature Research Report:* 1-36. London, UK: Ecoschemes Ltd.

Jones, T.S., E. Allan, S.A. Harri, J. Krauss, C.B. Muller, & F.J. Frank Van Veen (2011). Effects of genetic diversity of grass on insect species diversity at higher trophic levels are not due to cascading diversity effects. *Oikos* 120: 1031-1036.

Kadas, G.J. (2006). Rare invertebrates colonizing green roofs in London. *Urban Habitats* 4(1): 66-86.

Kadas, G.J., D. Gedge, & A.C. Gange (2008). Can green roofs provide invertebrate habitat in the urban environment. In Proc. of 6th North American Green Roof Conference: *Greening Rooftops for Sustainable Communities*, London, UK. Toronto, Ontario: The Cardinal Group.

Kats, G. (2010). Greening Our Built World: Costs, Benefits, and Strategies. Washington, DC: Island Press.

Kevan, P.G., H.G. Baker (1999). Insects on flowers. Chapter 17. In: Ecological Entomology. New York, NY: John Wiley & Sons, Inc. p. 313-353.

Köhler, M., M. Schmidt, F.W. Grimme, M. Laar, V.L. De Assuncao Paiva & S. Tavares (2002). Green roofs in temperate climates and in the hot-humid tropics. *Environmental and Health* 13(4): 382-391

Kosareo, L. & R.D. Ries (2007). Comparative environmental life cycle assessment of green roofs. *Building and Environment 42*: 2606-2613.

Lawton, J.H. (1983). Plant architecture and the diversity of phytophagous insects. *Entomology* 28: 23-39.

Lomolino, M.V. & M.D. Weiser (2001). Towards a more general species–area relationship: Diversity on all islands, great and small, *Journal of Biogeography* 28: 431–445.

Longfellow-Jones, M. (2010). Vegetation description of Ford green roof. Personal Communication. Dearborn, MI: Ford Dearborn Truck Plant.

Lovejoy, T.E. (1997). Biodiversity: What is it. Chapter 2. In: Reaka-Kudla, M.L., D.E. Wilson, & E.O. Wilson, [eds] Biodiversity II Understanding and Protecting our Biological Resources. Washington, DC: Joseph Henry Press. p. 7-14

Lundholm, J.T. (2006). Green roofs and facades: a habitat template approach. *Urban Habitats* 4(1): 87-101.

MacIvor, J.S. & J.I. Lundholm (2010). Insect species composition and diversity on intensive green roofs and adjacent level-ground habitats. *Urban Ecosystems* 14(2): 225-241.

Millennium Ecosystem Assessment (2005). *Ecosystems and Human Well-being: Biodiversity Synthesis*. Washington, DC: World Resources Institute.

Monterusso, M.A., D.B. Rowe, C.L. Rugh, & D.K. Russell (2004). Runoff water quantity and quality from green roof systems. *Acta Hort* 639: 369-376.

Murdoch, W.W., F.C. Evans, & C.H. Peterson (1972). Diversity and pattern in plants and insects. *Ecology 53*(5): 819-829.

National Oceanic and Atmospheric Administration (NOAA) (2010). *NOAA online weather data.* Available at http://www.sercc.com/nowdata.html. (Last accessed 05 April 2011.)

Oberndorfer, E., J. Lundholm, B. Bass, R.R. Coffman, H. Doshi, N. Dunnett, S. Gaffin, M. Kohler, K.Y. Liu, & B. Rowe (2007). Green roofs as urban ecosystems: ecological structures, functions, and services. *BioScience* 57(10): 823-833.

Oliver, I. & A.J. Beattie (1996). Invertebrate morphospecies as surrogates for species: a case study. *Conservation Biology* 10: 99–109.

Paulsen, T. (2010). Vegetation description of 900 North building green roof. Personal Communication. Chicago IL: JMB Financial Advisors, LLC.

Paulson, G. (2005). *Handbook to the Construction and Use of Insect Collection and Rearing Devices*. Dordrecht, The Netherlands: Springer Publishing.

Pielou, E.C. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology* 13: 131-144.

Rowe, D.B. (2011). Green roofs as a means of pollution abatement. *Environmental Pollution* 159(8-9): 2100-2110.

Rowe, D.B. (2010). Vegetation description of Plant and Soil Science Building green roof. Personal Communication. East Lansing, MI: Michigan State University.

Rowe, D.B., M.A. Monterusso, & C.L. Rugh (2006). Assessment of heat-expanded slate and fertility requirements in green roof substrates. *HortTechnology* 16(3): 471-477.

Samways, M.J. (2005). *Insect diversity conservation*. Cambridge, UK: Cambridge University Press.

Santosa, S.J. (2010). Urban Air Quality. Chapter 3. In: Aitkenhead-Peterson, J. and A. Volder, [eds.] Urban Ecosystem Ecology. Agronomy Monograph 55. Madison, WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America. p. 57-74.

Schindler, B.Y., A.B. Griffith, & K.N. Jones (2011). Factors influencing arthropod diversity on green roofs. *Cities and the Environment* 4(1): 20, Article 5.

Schrader, S. & M. Boning (2006). Soil formation on green roofs and its contribution to urban biodiversity with emphasis on collembolans. *Pedobiologia 50*(4): 347-356.

Siemann, E., D. Tilman, J. Haarstad, & M. Ritchie (1998). Experimental tests of the dependence of arthropod diversity on plant diversity. *The American Naturalist* 152:738–750.

Snodgrass, E.C. & L. McIntyre (2010). *The Green Roof Manual A Professional Guide to Design, Installation, and Maintenance.* Portland, Oregon: Timber Press, Inc.

Snodgrass, E.C. & L.L. Snodgrass (2006). *Green Roof Plants: a Resource and Planting Guide*. Portland, Oregon: Timber Press, Inc.

Southwood, T.R.E. & P.A. Henderson (2000). Ecological Methods. London, UK: Blackwell Science Ltd.

Susca, T., S.R. Gaffin, & G.R. Dell'Osso (2011). Positive effects of vegetation: Urban heat island and green roofs. *Environmental Pollution* 159: 2119-2126.

Tallamy, D.W. (2009). *Bringing Nature Home How You Can Sustain Wildlife with Native Plants.* Portland, Oregon: Timber Press, Inc.

Tews, J., U. Brose, V. Grimm, K. Tielborger, M. C. Wichmann, M. Schwager & F. Jeltsch (2004). Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. *Journal of Biogeography* 31:79-92.

Theobald, D.M., S.J. Goetz, J.B. Norman, & P. Jantz (2009). Watersheds at risk to increased impervious surface cover in the conterminous United States. *Journal of Hydrologic Engineering* 14(4): 362-368.

Tonietto, R., & J. Ascher. (2009). Occurrence of the Old World bee species *Hylaeus hyalinatus*, *Anthidium manicatum*, *A. oblongatum*, and *Megachile sculpturalis*, and the native species *Coelioxys banksi*, *Lasioglossum michiganense*, and *L. zophops* in Illinois (Hymenoptera: Apoidea: Colletidae, Halictidae, Megachilidae). *The Great Lakes Entomologist*. 41(1&2): 200-203.

Tonietto, R., J. Fant, J. Ascher, K. Ellis, & D. Larkin (2011). A comparison of bee communities of Chicago green roofs, parks and prairies. *Landscape and Urban Planning* 103(1): 102-108.

Tubergen, C. (2010). Vegetation description of Haworth green roof. Personal Communication. Holland, MI: Haworth Inc. Headquarters.

United Nations Population Division (2008). An overview of urbanization, internal migration, population distribution and development in the world. Available at http://www.un.org/esa/population/meetings/EGM_PopDist/P01_UNPopDiv.pdf (Last accessed 27 October 2011.)

U.S. Department of Energy, Energy Information Administration (2011). *Annual energy outlook 2011: with projections to 2035*. Report DOE/EIA-0383. Available at http://www.eia.gov/forecasts/aeo/pdf/0383(2011).pdf (Last accessed 15 September 2011.)

U.S. Environmental Protection Agency (EPA) (2004). *Report to Congress on Impacts and Control of Combined Sewer Overflows and Sanitary Sewer Overflows.* EPA 833-R-04-001. Available at http://cfpub.epa.gov/npdes/cso/cpolicy_report2004.cfm (Last accessed 15 September 2011.)

Van Dokkumburg, J. (2010). Vegetation description of Grand Rapid Community College green roof. Personal Communication. Grand Rapids, MI: Grand Rapids Community College.

Van Renterghem, T., & D. Botteldooren (2008). Numerical evaluation of sound propagating over green roofs. *Journal of Sound and Vibration* 317: 781–799.

Van Renterghem, T., & D. Botteldooren (2009). Reducing the acoustical façade from road traffic with green roofs. *Building and Environment* 44: 1081-1087.

VanWoert, N.D., D.B. Rowe, J.A. Andresen, C.L. Rugh, R.T. Fernandez, & L. Xiao (2005). Green roof stormwater retention: effects of roof surface, slope, and media depth. *Journal of Environmental Quality* 34(3): 1036-1044.

Villagrana, J. (2010). Vegetation description of Aquascape green roof. Personal Communication. St. Charles IL: Aquascape Inc.

Waldbauer, W. (2003). *What Good Are Bugs?* Cambridge, MA: Harvard University Press.

Weiler, S & K. Scholz-Barth (2009). *Green Roof Systems: a Guide to the Planning, Design, and Construction of Landscapes Over Structure*. Hoboken, NJ: John Wiley & Sons Inc.

Wellington, W.G., D.L. Johnson, & D.J. Lactin (1999). Weather and Insects. Chapter 10. In: Ecological Entomology. New York, NY: John Wiley & Sons, Inc. p. 313-353.

Whittaker R. H. (1972). Evolution and Measurement of Species Diversity. *International Association for Plant Taxonomy* 21: 213-251.

Whittinghill, L.J. & D.B. Rowe (2011). The role of green roof technology in urban agriculture. *Renewable Agriculture and Food Systems* (In press) (http://dx.doi.org/10.1017/S174217051100038X).

Wilson, E.O. (1987). The little things that run the world (the importance and conservation of Invertebrates). *Conservation Biology* 1(4): 344-346.

Xerces Society Guide (2011). *Attracting Native Pollinator: Protecting North America's Bees and Butterflies.* North Adams, Massachusetts: Storey Publishing.

Yang, J., Q. Yu, & P. Gong (2008). Quantifying air pollution removal by green roofs in Chicago. *Atmospheric Environment 42*(31): 7266-7273.