The Pennsylvania State University

The Graduate School

Department of Horticulture

IDENTIFYING "POLLINATOR-FRIENDLY" CULTIVARS FOR GARDENS AND GREENROOFS

A Thesis in

Horticulture

by

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Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

May 2010

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ABSTRACT

Home gardens and greenroofs have the potential to provide foraging resources for native and managed pollinators. The importance of identifying plants that offer adequate forage for pollinators is becoming increasingly important as pollinator populations continue to decline. It has been demonstrated that high nectar secretion rates do not necessarily illicit more pollinator visits; the insect and flower morphology can limit or prevent access to floral rewards. The cultivated novelties of some cultivars occur at the expense of reproductive organs, rendering them useless to pollinators. The Master Gardeners of Pennsylvania have begun providing educational opportunities for consumers to learn about pollinator-friendly garden selections. In an effort to provide them with regionally accurate information, surveys of insect visits to primarily recently introduced garden annual cultivars were conducted at the Penn State Horticulture Trial Gardens located at the Landisville Research Center throughout the summer of 2008. The surveys resulted in a list of 18 pollinator friendly genera that accounted for 96% of all bee visits. In addition, insect surveys of commonly used greenroof plants were conducted to identify and make recommendations for pollinator-friendly greenroof plants. The resulting list consisted of 15 cultivars that accounted for 96% of all bee visits.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I would like to thank Haagen-Dazs for funding this project; a million thanks to my committee for their patience and guidance: Robert Berghage, James Sellmer, and Diana Cox-Foster; Alan Michael, Rajwinder Singh for their expertise and assistance. Particular thanks goes to the crew at Emory Knoll Farms; Ed Snodgrass for your advice, humor, and access to your farm and crew; Carrie for your efforts and interest, and Rich Hoover for collecting data, it was truly appreciated. Last I'd like to thank my family and friends back home in Texas and beyond for your unwavering support and positivity. Last I'd like to dedicate this work to Michael, forever my guiding light.

Chapter 1

Introduction

Increased attention focused on the importance of pollinators and the consequences of the decline in monitored populations has spurred a movement to maintain and support existing pollinator populations worldwide. Little academic research has been conducted linking common ornamental plants and pollinators. There are many sources that offer lists that recommend pollinator-friendly plants to consumers but many are not confirmed as being preferred by the insects themselves. The term “pollinator-friendly” refers to plants that attract pollinators by providing some necessity such as food, nesting materials, or shelter. These lists often have no scientific data cited to back the claims and are therefore seemingly anecdotal. Regional variation in environmental conditions and insect populations inherently imply these plant lists are not universal. Corbet et. al. (2001) demonstrated that high nectar secretion rates don’t necessarily illicit more pollinator visits; the insect and flower morphology can limit or prevent access to floral rewards. The hypothesis for this research centered on the view that certain genera and cultivars will be visited more frequently than others for reasons that could potentially be attributed to the amount and accessibility of foraging resources provided throughout the season.

Greenroofs have become a viable solution to many ills of the modern urban matrix. A greenroof is a building design that incorporates living plants on rooftops. Among the proposed benefits of greenroofs, and one of the least studied is the biodiversity that greenroofs could potentially support. It has been suggested that they can provide habitat and act as stepping-stones for species whose habitats have been lost or disrupted (Dunnett and Kingsbury, 2008). This habitat is limited to highly mobile species such as birds and certain arthropods. Greenroofs have the potential to provide habitat and foraging resources for pollinators. The most commonly used plants are considered to be pollinator-friendly. This survey was conducted in order to quantify the number and types of pollinators that visit standard greenroof plant cultivars so that confirmed pollinator-friendly cultivars can be determined. The majority of the plants surveyed were *Sedum* sp. There is a considerable amount of diversity among the sedums and their bloom times; therefore, differences in the quantity of visits and the time of season visited might be expected. Simultaneously, an additional survey examining new plant introductions and the pollinators that they attract was also conducted so that recommendations could be made for pollinator-friendly gardens in Pennsylvania. The ultimate goal was to provide a list of garden plants and greenroof plants for vegetation management that supports local pollinator populations both native and managed. Cultivars were designated as "pollinator-friendly" according to the quantity and timing of bee visits.

The importance of identifying plants that offer adequate forage is of the utmost importance. Declines in pollinator populations are being observed worldwide (National Research Council et al., 2007). Monitoring of pollinator populations in the United States, unfortunately, is limited mostly to *Apis mellifera* (European honey bee). There is a lack of long term or definitive population studies that can be used as a baseline for native pollinators, and subsequently the noted declines are mostly anecdotal (National Research Council et al., 2007). Several European nations have conducted pollinator surveys and results have shown that native pollinator populations are in decline (National Research Council et al., 2007).

Observations of a wide variety of insects were expected in the surveys conducted for this study. Bees are specialized insects that are the most notable and often the most significant pollinators for many ecosystems, but other insects are pollinators as well. Moths, butterflies, flies, and beetles are also known to pollinate flowers. Since pollinators are often relied upon to perpetuate the next generation of many plants, the maintenance of a healthy and diverse invertebrate population is of the utmost importance to ecosystems. There are 99 *Bombus sp.* found in the United States. In Maryland alone there are 129 species of butterflies (Maryland DNR, 2005). It is also estimated that 17,460 species of flies act as pollinators in North America.

Thus, observed insect specimens in this study were expected to be quite diverse. Among the observed insects, *Apis mellifera* was the only insect reported to the species level. Both survey sites are in rural areas that are in close proximity to developed suburban areas; these areas may prove to support a more diverse fauna than that of the typical urban area in this region.

Chapter 2

Literature Review

The urban areas of the world are growing at an alarming rate. The urban population of the world is expected to reach 50% of the total population by 2008, which is a projected 3.3 billion people. This number is expected to rise to 70% by 2050 (Dept. of International Economic and Social Affairs, 2007). Urban infrastructure often cannot keep up with the demands of population influxes. The transformation of vegetated areas into vast tracts of impervious surfaces such as roads, parking lots, and built structures results in fragmentation of the landscape, which negatively impacts the flora and fauna and the roles that they play in the ecosystem.

Efforts to mitigate some problems associated with urban development have resulted in development and utilization of technologies that mimic natural processes. One of these technologies is greenroofs. Greenroofs are increasingly recognized as a tool in mitigating problems caused by urbanization such as stormwater runoff and loss of wildlife habitat. A greenroof has the necessary components to facilitate plant growth, as opposed to a traditional roof of shingles, concrete, etc. They have successfully been used to provide habitat for otherwise displaced species (Gedge, 2003). Current research is improving the design and function of greenroofs in order to maximize their ecological potential.

Loss of biodiversity has contributed to the disruption and loss of pollinator habitat. Habitat loss results in extirpation and potentially extinction of the inhabiting species. In particular, the loss of insect populations is raising a lot of questions regarding humanity's ability to sustain itself (Kim, 1993). Insects play important roles in ecosystem processes and ecosystems cannot function without the primary driver species, which often are insects and other small organisms (Kim, 1993; Miller, 1993; Odum, 1989; Robinson et al., 1992; Samways, 1993; Wilson, 1987). In particular, the decline of native and managed pollinators has been at the forefront of concern due to their importance in food production. Greenroofs have the potential to provide habitat and foraging resources for pollinators. In this study, this possibility was explored by surveying common greenroof plants as foraging resources for pollinators.

The suburban home is often envisioned when referring to the American dream. The proliferation of suburban areas can be attributed to the advent of the affordable automobile. Suburban areas often involve clearing land to make way for a single housing unit and a grass lawn. Frederick Law Olmsted designed one of the first planned suburban communities in the United States in the late 1860's. He designed it to look as though the residents lived together in a park; a rebellion against the walled gardens of England, and thus the American lawn was born (Pollan, 1991). Grass lawns are often monoculture plantings of often non-native grass species and are not a native landscape of most regions of North America. In North American grasslands, the native grasses are torn out and replaced because they do not resemble the lawns desired by homeowners. This suburban practice has devastating effects on the ecosystem as discussed above. Since grass lawns are often the larger part of a suburban lot these spaces do not provide much in the way of habitat for many native invertebrate and vertebrate animals. What can't survive in lawns finds refuge in remnants of the original habitat or the gardens of the home. These gardens can provide forage and/or habitat for these displaced species. The purpose of a garden most often is to add to the aesthetics of the house. Fortunately, for visual interest a garden often consists of a variety of plants, which can encourage biodiversity.

Often gardens are planned so that plants bloom in succession in order to provide color throughout the growing season. Some ornamental plants do not provide much forage or habitat for local invertebrates because they are often exotic and/or have been continually bred for aesthetic purposes. The floral resources produced by some exotic plants are inaccessible to native insect species. Some native and exotic double cultivars, often very popular in gardens, are bred that way, often at the expense of anthers and carpels (Coats, 1956; Reynold and Tampion, 1983).

This manipulation has rendered some varieties useless to insects due to their reduced or total lack of nectar and pollen production (Corbet et al., 2001). The process involved in sexual reproduction, the lure of pollinators with nectar as a means to vector pollen, is impaired in some way. The nectar production may have been reduced as the flower structure is manipulated or the sexual appendages may have become more difficult or impossible to access. A more pollinator-friendly cultivar may be put it in its place without losing the desired aesthetic effects. For this reason a survey was performed to identify pollinator-friendly varieties for Pennsylvania in an effort to encourage homeowners to support their local pollinators.

2.1 The 'Pollination Crisis'

Decreases in monitored bee populations have been reported throughout the world (National Research Council et al., 2007). Generalist pollinators, such as *Apis mellifera*, and the factors that would result in their decline are being disputed. Some claim this decline is caused by human disruption and could cause a cascade of declines among the species they pollinate; which would lead to an increase in loss of biodiversity (Cox, 1983; Gilbert, 1978; Pauw, 2007). Others argue that there isn't enough evidence to support the theory of the "pollination crisis" and that the ecological significance of pollinators is unknown (Pauw, 2007). Though, studies are consistently showing that certain nicotinoid pesticides appear to be to blame for the population declines (Bonmatin et al., 2005; Bortolotti et al., 2003; Medrzycki et al., 2003; Rortaisa et al., 2005; Thompson, 2003) other factors probably play a role as well.

Allen-Wardell et al. (1998) made the argument that if we don't apply more resources into understanding the impact of pollinators and their interactions with plants and other fauna there could be dire consequences. There are examples where pollination failure of one key plant has drastically impacted the whole ecosystem. Low blueberry yields resulting from pesticide use ultimately negatively affected many organisms all along the food chain including humans in this

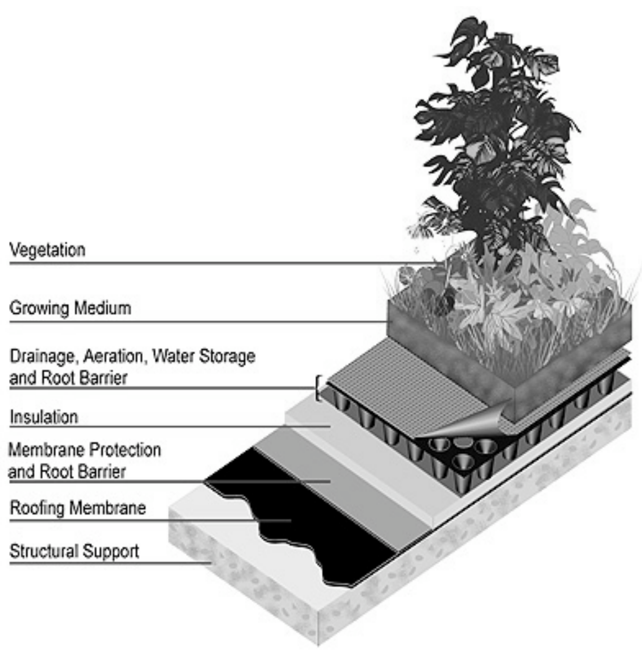
Canadian study (Allen-Wardell et al., 1998; Kevan, 1977). Even though many crops don't require insect pollinators, increased yields have been documented when pollinators are present (Allen-Wardell et al., 1998; Pimental et al., 1992). Also pointed out in this study is the shortage of information regarding the rewards offered by newer cultivars (Allen-Wardell et al., 1998).

Pollinators play a vital role in this world and it is imperative that their populations are maintained and monitored. North American studies are concluding regional declines in pollinator populations. Some native pollinator species have been identified as endangered or possibly even extinct, one example is Franklin's Bumble Bee (*Bombus franklini*). *Bombus franklini* has a small distribution range that spans from southern Oregon to northern California and may now be extinct (Xerces Society, 2007). One long-term study in Illinois has concluded that many native species are indeed in decline with regional extirpations also noted; for some of the investigated species population decline began as early as the 1940's (Grixti et al., 2009). The mounting evidence indicating pollinator decline throughout the country necessitates the need to support the pollinator webs as much as possible for preservation of our national heritage as well as for our survival as a species. To design a greenroof or garden that is pollinator-friendly could be an easy task that would involve very little additional effort by industry and designers. Enhancing biodiversity in these landscape features could be as simple as planting pollinator-friendly species or cultivars in place of other similar plants. Effort could further be extended to the designs recommended by Brenneisen (2004), such as varying depths of substrate, which supports overall biodiversity.

2.2 Introduction to Greenroofs

Greenroofs have been apart of human architecture for many millennia. Perhaps the most famous example is the Hanging Gardens of Babylon, circa 500 B.C., that was rumored to have been built by an ancient king for a home sick queen (Osmundson, 1999). Another example would be that of the Norwegians who have for centuries built sod roofs on their homes to help insulate the interiors from the harsh winters (Osmundson, 1999). A rudimentary greenroof has plants growing in media on a roof. Often older buildings unintentionally support plant life such as mosses, lichens, and sometimes larger vascular plants on their facades (Dunnett and Kingsbury, 2008). There are mainly two types of greenroofs: extensive and intensive. An extensive roof typically consists of a waterproofing/root barrier, drainage system, thin layer of substrate, and plants (Figure 2-1). All of which usually comes to a total depth of 2-15cm (Dunnett and Kingsbury, 2008). Intensive roofs are systems that contain more substrate than an extensive roof, ranging from 15 centimeters to several meters in depth. Intensive roofs are usually used as places of recreation sometimes called rooftop gardens; apart from plants they can also have patios, playgrounds, and water features. There is not always a clear distinction between an extensive and intensive roof, often roofs will share characteristics of both types and are referred to as semi-extensive or semi-intensive (Dunnett and Kingsbury, 2008).

Figure 2-1. Diagram of greenroof components. (Villanova Urban Stormwater Partnership, 2009).



The substrate depth is often the limiting factor that determines plant selection on greenroofs. The substrates that are most commonly used in North America are high in lightweight aggregate mineral content (80-100%) and have about 10-20% organic content by volume to allow for water storage and drainage (Beattie and Berghage, 2004). These manufactured substrates are often used due to the weight bearing limitations of built structures. Intensive roofs will have different types of media, typically more like a potting soil. Accordingly, the load bearing capabilities of these roofs will be significantly higher due to the increased weight. The depth of the substrate ultimately determines what plants can be grown on the roof. The plants that are grown on extensive roofs are plants that are able to survive the harsh conditions of a rooftop. The plant community on extensive roofs must be able to withstand periods of drought, wind, and extreme temperatures. These plants consist mostly of drought tolerant species that have adaptations suitable for such a habitat. Adaptations such as trichomes, low mat forming or mounding growth habits, succulent leaves, and CAM (Crassulacean Acid Metabolism) photosynthesis are common in these plants (Dunnett and Kingsbury, 2008). Most of the species marketed for extensive greenroofs are Sedum species. The deeper substrates of intensive roofs are able to absorb and store more water allowing the roof to support a more diverse plant selection such as grasses, shrubs, and even trees. Ultimately the design of the greenroof is dependent on its intended function. Roofs that are only going to be seen by maintenance crews won't have elaborate planting designs, whereas a roof that is meant to be a place of recreation and/or serving biodiversity purposes would have a much more involved design scheme.

2.3 Benefits of Greenroofs

There are numerous reasons for building greenroofs in place of conventional roofs. Greenroofs mimic some of the natural systems that are lost due to development, thereby reducing some of the negative effects of development. Some of the benefits that greenroofs offer are habitat for wildlife, storm water mitigation, pollution reduction, decreased ambient temperature, and an extended roof lifespan. Rooftops offer vast areas of empty unused space and to be able to utilize this space to better our cities and reduce their environmental impact would be an investment for the future.

In the hydrologic cycle, water returns to the earth's surface as precipitation. This water can either be absorbed into the ground, transpired by plants, or it can runoff the surface into other bodies of water. The increased amount of impervious surfaces found in urban areas has increased the amount of runoff that occurs. This runoff must be channeled and piped elsewhere and this can be a daunting task for a city, especially when large rain events occur that overload the system. Greenroofs help replace some of the components that are lost to impervious surfaces. The plants on the greenroof replace some of the plant life that was lost to development and so the transpiration phase of the hydrologic cycle is replaced. The substrate catches the precipitation and either slowly releases it into the drainage system or stores the water. This makes it available for the plants so that they ultimately will transpire and return the water to the atmosphere and the rest is evaporated from the substrate. This evaporation and transpiration helps lower the surrounding temperatures by acting as a large evaporative cooler. The delayed runoff from the roof helps ease the load that the storm water infrastructure must deal with during peak flow times. Storm water mitigation is a major driver to adoption of greenroofs in North America.

If greenroofs are largely adopted they are expected to greatly benefit cities that have a combined sewer system (CSS). A CSS uses a single pipe to transport domestic sewage, commercial and industrial wastewater, snowmelt, and rainwater runoff to a treatment facility (EPA, 2007). Heavy rain events can overload the sewage system and treatment facility causing a combined sewer overflow (CSO) (EPA, 1999). A CSO is a release of excess untreated sewage water into a nearby body of water. The excess sewage can consist of untreated human waste and toxic chemicals, among other things. Water pollution due to combined sewage overflows have caused beach closings, fish kills, and are a major concern regarding drinking water quality (EPA, 2007). There are 772 cities in the United States that currently have combined sewer systems (EPA, 2007). The benefits to urban areas that utilize greenroofs are vast. A long term German study found that a 5 cm and a 10 cm soil depth retained 65-70% of the precipitation in the summer and 50% in the winter (Liesecke, 1998; Moran et al., 2004). There have been studies carried out by the City of Portland, Michigan State University, and North Carolina State University that support these findings (Moran et al., 2004). The substrate alone helps with water retention but the addition of plants on the roof increase the retention (Berghage et al., 2007).

As previously stated, evapo-transpiration helps dissipate the retained precipitation, cooling the ambient temperature. A greenroof acts as a thermal mass by shading, insulating, and facilitates evaporative cooling of the roof surface. This proved to lower the energy consumption of a tested building by over 75% in a study performed by the National Research Council of Canada (Liu and Bas, 2003). The shading of the roof by a greenroof system also has the potential to extend the life of the roofing membrane (Liu and Bas, 2003). The substrate and plant material insulate and cover the roof waterproofing. Therefore, the waterproofing is not exposed to extreme temperatures and UV radiation like conventional roofs. The UV radiation from the sun breaks down building materials. The thermal buffering provided by the greenroof prevents the roof membrane from experiencing frequent freeze thaw cycles and extreme temperatures that also degrade a roof. Properly designed and installed greenroofs can extend the life of a roof by 2 to 3 times its normal life. In Germany, there are some greenroofs that are 90 years old and counting (Dunnett and Kingsbury, 2008). A greenroof may cost more initially but in the long run it pays for itself by eliminating the need to replace a roof every 20 yrs or so. The installation of a greenroof can be used towards LEED (Leadership in Energy and Environmental Design) certification. LEED certification is a points based 'award' that indicates the sustainability of a piece of property. A recent study by CoStar Group, a major real estate information company, and Dr. Norm Miller, of the University of San Diego, found that LEED certified buildings had increased occupancy rates, were able to demand higher rental rates, and the sale value per sq. foot was significantly higher than similar non-LEED certified properties (Burr, 2008). The reduced energy consumption by the building, the reduced use of roofing materials, and the carbon sequestration of the plants helps lower a buildings carbon footprint. Another carbon reducing interest that is being pursued is the possibility of producing food on roofs, which could reduce the amount of carbon produced to transport food long distances. There is a Swedish roof being installed with space for vegetable production and space is also being allocated for beehives (Lundberg, 2005).

Biodiversity is another major reason that greenroofs are a good replacement for conventional roofs. Invertebrates and birds have been documented inhabiting greenroofs, demonstrating their potential as a biodiversity tool (Brenneisen, 2003; Bruening and Thuring, 2008; Fitzgerald, 1998; Gedge, 2003; Kadas, 2006). A large portion of the flora and fauna of the United States is at risk of extinction (Stein et al., 2000). Studies that have investigated the biodiversity of urban areas, in general, have shown that they support on average less than half of the diversity found in natural areas. (Johnson and Klemens, 2005). Valuable resources have been negatively affected by the decline in ecosystem function. This has been linked to biodiversity losses in overexploited and degraded ecosystems that have lost dominant species (Grime, 1998; Lecren et al., 1972; Pearson and Rosenberg, 1976; Smith, 1968; Vitousek and Melillo, 1979). Wilcove et. al. (1998) described the 5 major threats to biodiversity to be habitat loss, fragmentation, degradation, invasive species, pollution, over-exploitation, and climate change. Greenroofs can act as an urban oasis that can mitigate some of these threats. Roofs are underutilized and untouched by people in most cases. Since roof surfaces aren't normally accessed by people they are an ideal way to allow highly mobile species to utilize them as stepping stones to other habitats or as a refuge in urban areas.

There seems to be an outdated mentality that development and conservation are conflicting practices. Greenroofs are a prime example of how they can go hand in hand and benefit from each other with the inhabitants of the structure benefiting in many ways from the greenroof while the wildlife benefits as well. Greenroofs have already been utilized as a way to mitigate habitat loss. One such case is the Black Redstart (*Phoenicurus ochruros).* The Black Redstart is a rare bird species in England and it is unique in that it is only found in urban areas. The Black Redstart nests in piles of rubble found on brownfield and abandoned industrial sites. So, when an urban revitalization movement started to redevelop these sites it was noticed that the number of birds were decreasing. To preserve and protect the population of Black Redstarts the United Kingdom declared the Black Redstart as a protected species. This resulted in its nesting sites being protected and prohibited them from being disturbed. In order to continue building on these sites developers had to recreate the brownfield site conditions on the roofs of the new structures so as to provide a nesting place for the birds, resulting in a rooftop habitat. The nesting Black Redstarts in the United Kingdom have brought quite a lot of attention to greenroofs as an ecological tool (Brenneisen, 2003; Gedge, 2003; London Biodiversity Partnership and Redstarts.org.uk, 2008).

Birds aren't the only organisms observed utilizing greenroofs as habitat. There have been several studies in Europe and the United States that have examined the invertebrate wildlife found on greenroofs. A four-year survey of the spider and beetle fauna on roofs in Switzerland revealed that among the greenroof inhabitants were several endangered species listed in the International Union for the Conservation of Nature's Red List of Threatened Species. The International Union for the Conservation of Nature (IUCN) has created and continues to compile the Red List of Threatened Species to provide "taxonomic, conservation status and distribution information on plants and animals that have been globally evaluated" using a system to evaluate the potential risk of extinction and to catalog and bring attention to organisms that are at high risk of extinction (IUCN, 2008). Of the spiders collected 18% were listed in the IUCN Red List of Threatened Species as "faunistically interesting", meaning they were determined to be rare or have a limited distribution, as were 11% of the beetles collected (Brenneisen, 2003; IUCN, 2003; IUCN, 2008; Kadas, 2006). A survey of the insect fauna on the Ford Assembly Plant in Dearborn, MI didn't find as many Coleopteran or Arachnid species as the European surveys, but this could be due to several factors including differences in collection method. The survey did however manage to collect 886 insects over the course of four weeks. The European surveys were taken over a period of several years; which could explain some of the differences in the results. Regardless of the differences these surveys confirm that greenroofs are indeed providing habitat. Brenneisen's extensive work on biodiversity of greenroofs has identified that the substrate surface design is the most important factor influencing the extent of biodiversity. He has shown that varying the depths of substrate, influences the water retention capacities and subsequently allows for varying habitats that can support a range of species (Brenneisen, 2005). When designing greenroofs to encourage habitat, many things must be considered, and it all depends on the extent of effort and the specific desires of the owner of the roof. If a roof is intended to provide habitat or forage for a particular species or group of species then the targeted species' natural habitat should be analyzed to determine the best design. The Black Redstart is a prime example of this (Brenneisen, 2003). Since roofs are underutilized spaces it makes them perfect candidates for use in nature conservation strategies. They are relatively undisturbed which makes it much more feasible to allow for them to be re-established by species that would otherwise live in similar environments at grade (Brenneisen, 2005).

2.4 Biodiversity: Greenroofs vs. Natural Space

Recreating natural landscapes on a roof is not as easy as one may think and it is not necessarily possible or desirable. There is a common desire among people to place native plants on greenroofs to replace and conserve lost plant communities. This is a great idea but it is not always feasible or cost effective. A greenroof is an engineered environment and should be treated as one. A roof is typically subject to much harsher environmental conditions than are typically found at grade. High exposure to wind, extreme temperatures, and a limited substrate depth characterize many greenroofs. Native plants capable of living in a roof environment are not always available. The area may not have environs that are similar to that of a roof. In many cases non-natives, such as many of the sedums currently used on roof plantings, may be more suitable to fulfill site needs or project goals. Even if one or more native species that can survive on the roof are identified they may not provide food or habitat to support the targeted wildlife and thus introduced plants may have higher biodiversity value than the natives (Dunnett and Kingsbury, 2008). The plants found on greenroofs if not meant to mimic the native flora should supplement and support the needs of targeted organisms. There are many exotic plants and animals that have established themselves in urban areas, some of these are considered nuisances but others can be beneficial. There is a current hypothesis that states that species found in urban environments are there because the environment matches their original habitats. The "Urban Cliff Hypothesis" explains that these species are stress tolerant, opportunistic and originated in rocky habitats that are recreated in the built environment (Lundholm, 2005). By studying and recognizing the qualities found in these exotic species we can then try and scout local regions that share this characteristic for native species that may work well on a greenroof, in an attempt to recreate the surrounding natural areas.

Nigel Dunnett and Noel Kingsbury (2008) argue that in order to justify the "call" for more biodiversity on greenroofs further research must be conducted to examine the trade offs of plant composition and roof performance. Greenroofs are often installed purely for functional reasons, and when that is the case the plant community and biodiversity factor often is an afterthought. Until legislation is passed, or design standards are created for regions, roofs as a conservation tool will only be installed by interested parties. There is still a large amount of research needed to understand how greenroofs function as an ecosystem and how we can maximize all the benefits associated with them.

2.5 Biodiversity Components

There are many components of an ecosystem and the ways in which they interact are crucial for supporting life. Greenroofs and urban areas create unique ecosystems that are just beginning to be studied. One of the most crucial components of a terrestrial ecosystem is the soil. Soil is a very active part of an ecosystem; it is constantly evolving and consists of a myriad of different living and nonliving components. Soil is dynamic and understanding how the biotic and abiotic processes work and their functions is a very active area of scientific inquiry.

The media that is used on greenroofs is a manufactured substrate or soil. It is largely mineral with a very small portion of organic material. The substrate is a crucial part of the greenroof infrastructure. It is reasonable to believe that although this substrate is highly inorganic and manufactured it still contains organisms that reside within the organic material. Additional microbial life will be introduced with the plant material and by particles in the atmosphere. However, the absence of biodiversity in the substrate may retard vegetation development and establishment. Meyer (2004) tested commercial organic soil conditioners that contain beneficial soil microorganisms such as mycorrhizal fungi and *Penicillium bilaii* in a greenroof substrate to test its effect on plant growth. Mycorrhizal fungi and *Penicillium bilaii* form symbiotic relationships with plants and aid in delivering nutrients to the roots in exchange for carbohydrates. The results showed that these soil amendments greatly improved the plant's ability to establish in a greenroof media. This ability is crucial in such a harsh environment

(Meyer, 2004). The positive effect of the soil microbes on the total biomass demonstrates that the substrate must maintain the functional components of soil in order for the greenroof to succeed.

The role that plant biodiversity plays on a greenroof is unknown at this time. It is hypothesized that higher plant diversity should lead to less temporal variability in surface temperature. The reduction in variability is attributed to an increase in biomass consistency (Cottingham et al., 2001). So a more stable plant community that has a mixture of annuals and perennials would not only provide consistent plant cover to maximize a greenroofs thermal and storm water benefits throughout the year but also provide habitat and forage for wildlife. A German study demonstrated this by examining several roof communities. The more biodiverse greenroof community, a European Wildflower meadow, could moderate diurnal temperature fluctuations by up to 94%. A lower temperature reduction was seen in the communities with lower biodiversity (Kolb and Schwarz, 1986a). It was speculated that the phenotypic variation of species, especially heights, allowed for greater insulation. They also found that a purely evergreen roof was better at insulating in the winter than the meadow community that dies back (Kolb and Schwarz, 1986b). Plant diversity is a natural phenomenon. It's important to have a diverse plant selection to ensure that a roof succeeds, if one species fails another species that is better equipped for the conditions will survive.

Animals play crucial roles in the plant kingdom. Of all of the flowering plant species, it is estimated that 60-70% are dependent on insects for pollination (Potts et al., 2003; Richards, 1986). Often in fruiting plants, insects will pollinate the flowers and birds will spread the seeds. Among the common plants used on greenroofs many have very attractive flowers. The inflorescences of *Sedum* sp. vary from yellow and white to pink. These flowers can be aesthetically pleasing to humans but they have also been found to be very attractive to different pollinating insects, especially bees. Bees are important beneficial insects. They pollinate a wide variety of plants, including fruits and vegetables. The plants they pollinate provide food for animals, and these animals help spread the seeds thus perpetuating the populations.

2.6 Urban Areas as Potential Habitat and Forage Resources for Bees

A Swedish roof, designed with an area for vegetable production and two honeybee hives is in the works. The hives will pollinate the vegetables and produce honey and wax for the residents of the building. The designers consider roofs an optimal site for hives because vandals are unable to gain access (Lundberg, 2005). In addition, the *Sedum* spp. commonly used on greenroofs are believed to be a good source of nectar for bees. Bees are highly mobile and can easily utilize roofs, which make greenroofs an ideal place to support these important insects. The effort to maintain and increase their populations is of the utmost importance at this junction due to the global recognition of their decline. So the question is what do bees need? Bees need suitable nesting areas and an adequate supply of food sources in close proximity. Often these needs vary from species to species but they can generally be met by providing a variety of plant species and nesting sites i.e. substrate, nesting boxes, driftwood, etc. The extent of the accommodations on a greenroof would depend on the targeted species. Bees forage mostly on pollen and nectar; pollen is their major source of protein where as the nectar provides energy and water. An effective attractant will satisfy the insects needs e.g. food, sex, and brood rearing (Cane, 2005; Faegri and Pijl, 1979)**.** Bees are constantly leaving the nest to forage and return to the nest often multiple times throughout the day. They must have all these needs met within a particular distance. Some species can navigate up to 1-2 km from their nest but, typically, most navigate less than 700 m (Cane, 2005). If these needs can't be met then ultimately extirpation will result. It is crucial to have habitat and foraging resources in close proximity to maintain the population. In urban areas green space can be scarce but often patches exist throughout most areas except in some very large highly urbanized cities. Recreational parks are typically the largest areas of green space within a city. Container gardens are often very common in cities along with ornamental street trees and flowering weeds. Space to provide habitat is crucial, but different species require different conditions and that may be an issue in highly urbanized areas. A study looked at the bees found at the common North American desert plant the Creosote Bush (*Larrea tridentata*) in and around Tucson, AZ (Cane et al., 2006). Surprisingly they found that floral generalists and cavity nesting species were prolific in the smaller fragments sampled within the city. The urban matrix is believed, in this case, to supply these types of bees with increased nesting sites as there is a higher abundance of trees and lawn litter found within the urban areas than in the surrounding desert (Cane et al., 2006)**.** Further studies would need to be carried out in order to be sure that this information could be extrapolated to other types of environments.

The evidence that bees can find suitable habitat in urban areas answers a crucial question as far as habitat is concerned. Some texts have raised concerns regarding bees utilizing roofs as habitats. These concerns were based on previous observations that recorded pollinators flying mostly upwind and that they also seem to prefer to fly at the same level above ground (Frankie, 1975; Levin and H.W., 1973). Dispelling the concerns raised by these observations, Mann, a German scientist and industry professional has concluded that the size of the roof is more important in supporting wildlife than its height and exposure. Insect collections and wildlife observations were taken from roofs of varying height, size, age, and location. He was also able to conclude that the depth of the growing media, rooting volume, and the plant variety were crucial in supporting wildlife (Bruening and Thuring, 2008).

Extensive greenroofs with a thin layer of substrate can mostly only offer seasonal habitat. The deeper the substrate and the more diverse the plant community the more likely the roof is able to provide permanent habitat (Bruening and Thuring, 2008). There has also been research done in Switzerland that found that providing deeper mounds and varying substrate types to mimic the natural area would encourage more biodiversity and allow for insects to retreat to deeper areas in adverse conditions (Brenneisen, 2004). The Black Redstart program in the United Kingdom encourages the placement of driftwood for the birds, this litter could potentially provide habitat simultaneously for insects and cavity nesting bees as well (London Biodiversity Partnership and Redstarts.org.uk, 2008).

The plant selection would determine the types of pollinators that visit the greenroof. Many bees are generalist pollinators, meaning they visit many different types of flowers. Some individuals of higher species will show fidelity towards a certain plant species. It may be imposed or may be conditioned. Fidelity is determined by two factors: the abundance and duration of bloom. The longer a flower blooms the more likely a stronger preference is reinforced (Faegri and Pijl, 1979). Though, most bees do not exhibit flower-constancy (exclusively visit one species) they have one species they 'prefer' to visit (i.e. fidelity) and then supplement their foraging with several other species (Faegri and Pijl, 1979). Waddington (1983) has confirmed that flower visitation is conditioned, as his results indicated that flowers are not visited randomly or in proportion to their abundance. The nectar secreted varies throughout the day and across the blooming season. This variation could explain these observations and why very few bees exhibit flower-constancy. Corbet et. al. (2001) in several dawn to dusk studies has shown this variation and has been unable to show species dependent variation. Often flowers must be in the preferable state for visitation by bees; for example honeybees won't collect when flowers are wet with dew (Faegri and Pijl, 1979; Percival, 1947).

“Relative pollen availability (p:n ratio) is important in structuring the size and richness of the bee fauna” (Potts et al., 2003). So, ideally plants that flower in succession throughout the season should be planted to support the pollinators. Nectar is an energy source and may contain trace amounts of other nutritional compounds. Pollen is collected for its protein, vitamins, and minerals (Kevan, 2001). The composition of the compounds provided is dependent on the plant species. Certain insect species may be more dependent on nectar than others, especially bees such as *Apis mellifera* and other fast flying species (Faegri and Pijl, 1979). Presence of solitary bees appear not to be predominately limited by nectar but by other habitat factors (Potts et al., 2003). Proper habitat would need to be supplied in order to support these solitary bees. Honeybee colonies can only be supported by habitats with a large supply of available energy. The presence of honeybees would signal a rewarding community. When supplying food sources for pollinators flower times must be considered but so must the flower form.

Different insects pollinate different types of flowers. The morphology of flowers in reference to their pollination mechanisms are called pollination syndromes; these are the traits of flowers that attract particular types of insects (Faegri and Pijl, 1979). Beetle pollinated flowers are generally easily accessible, dull colors, and often have a strong odor. Flowers pollinated by moths are open at night, usually white, and have a strong odor (Faegri and Pijl, 1979). Many bees are generalist pollinators and visit many different types of flowers. Pollination by bees is referred to as melittophily (Faegri and Pijl, 1979). The pollination syndrome that attracts bumblebees and honey bees to nectar often includes mechanically strong flower parts so as to support the weight of the insect; they are semi-closed, with hidden nectar, lively colors often yellow or blue (Faegri and Pijl, 1979). The bees are limited to what flowers they can access due to the length of their proboscis. Generally bees can access any flower as long as the nectar is not too deeply hidden (Corbet et al., 2001; Faegri and Pijl, 1979). Some bees have longer proboscis' and can visit deep blossomed flowers like peas and labiates (Weiss and Vergara, 2002). The shorter tongued species are limited to more easily-accessible flowers such as umbels and composites (Weiss and Vergara, 2002). It has been seen that some introduced flowers have evolved with a specific insect and when introduced to a different region without a similar insect it will not warrant visits from the local pollinators (Corbet et al., 2001). Fortunately, most of the tried and true species planted on greenroofs are easily accessible flowers that are often stellate and born in clusters of various forms and in numerous numbers (Evans, 1983). If a particular pollinator species is being targeted then plant species suitable for that particular insect could be planted. A study of a Mediterranean bee guild found that the insect diversity was highly correlated with the floral diversity, particularly the annuals (Potts et al., 2003). This is a very positive finding, just as annuals are planted in gardens for seasonal interest often self-sowing annuals are planted on greenroofs for the same reason. This common planting scheme can be a pollinator-friendly practice if nectar and pollen are available from the chosen plants. The continued support of this practice and the identification of pollinator-friendly perennial species would be a big step in advancing the full utilization of greenroof benefits. Flowering periods of plants on a greenroof in Sheffield were compared in a study. The plants monitored were either a Sedum sp. or in the Labiate (mint) family. The Sedum sp. had a very limited blooming period compared to most of the Labiates. They are both considered to be attractive to pollinators and this study concluded that a mix would be best so as to provide constant foraging resources for the wild bee populations (Dunnett et al., 2005). Alternatively, planting a variety of successively blooming Sedum sp. along with a variety of other species such as the Labiates per the Sheffield study could greatly enhance the success of a pollinator-friendly roof while simultaneously providing seasonal interest. Adventitious rooting is a benefit of using sedums. If pollination were inadequate it would not effect reproduction, whereas most angiosperms require insect fertilization to reproduce and would therefore have limited regeneration abilities. The reproductive abilities of plants are a very important trait to consider when choosing plant communities.

Pollinator-friendly greenroofs and gardens are easily adoptable practices that could help to ensure that our cities are healthier and biodiverse areas. This is becoming more and more important with the increase in city sizes and populations and the subsequent problems associated with urban sprawl. These problems include increased temperature, landscape degradation, impervious surfaces, loss of biodiversity, and the decline in bee populations due to habitat loss and degradation. Pollinator-friendly gardens and greenroofs could be a vital tool in saving the dwindling bee populations.

Chapter 3

Garden Cultivar Survey

New cultivars were surveyed over the summer of 2008 to identify which were more pollinator-friendly. The surveys were conducted to compile a list of pollinator-friendly plants. The list was distributed to the Master Gardener Program of Pennsylvania to aid them in their educational efforts. The Master Gardener's are promoting pollinator-friendly gardening practices with demonstration gardens and educational programs. Some of the pollinator-friendly gardening practices being emphasized include: plant diversity, using natives when possible, plant for blooms throughout the season, reduction or discontinued use of pesticides, and group plantings.

It was hypothesized that floral preferences would vary throughout the season as well as among bee types. *Apis mellifera* was expected to appear in higher numbers and to visit a greater range of plants due to high population numbers and its role as a generalist pollinator. Other bee types were expected to appear in lower numbers and have more restricted plant preferences due to their morphological features and the limitations they potentially impose. Regardless of the insect morphology, the unspecialized flower morphology of the Asteraceae family were expected to attract all bee types. Asters are considered unspecialized because their floral rewards are easily accessed and many types of insects are able to access due to the open nature of the bloom as seen in Figure 3-1.

Insect foraging preferences were expected to be different for different species and cultivars surveyed. Some plant genera and cultivars, such as those in the Asteraceae family, were expected to attract more pollinators than others. Visitation differences were expected to reveal plants that were utilized for forage and these visits were expected to vary with changes in nectar and pollen production.

Figure 3-1. *Argyranthemum sp.* An example of the Asteraceae flower morphology.

3.1 Materials and Methods

The Pennsylvania State University has a program that evaluates new plant cultivars from the horticulture industry to ascertain their garden performance in the Pennsylvania climate. The plants surveyed in this study were a selection of the plants grown at the Pennsylvania State University's horticultural trial gardens. The trial gardens are located near Landisville, PA at 40.11770°N, -76.42648°W. The plants were predominantly vegetatively propagated annuals and perennials grown in above ground containers and watered with drip-irrigation. Pollinator surveys were performed in June-September 2008 starting mid-morning and finishing in the early afternoon. Preliminary scouting was performed June 11 and the varieties with the most insect activity were chosen for the subsequent surveys. Scouting consisted of a slow walk through the gardens noting insect activity. There were 74 cultivars in 34 genera that were observed with insect visitors during the scouting survey. Ultimately, 3 cultivars (when available) of 27 genera were chosen for the surveys (Appendix A). The final cultivar list was based on various factors. Some were chosen due to their appearance on pollinator-friendly lists, bloom color, difference in growth habit, in addition to the noted insect activity.

Each cultivar in the trial included three containers with 3 plants in each container. Each cultivar was monitored for three minutes in each survey. The insects observed visiting the flowers of the chosen cultivars were tallied. The insects were classified into the groups: *Bombus* spp. (Bumble bees), *Apis mellifera* (European honeybee), and Apidae (all other bees). Apidae is the family in which *Bombus* spp. and *Apis mellifera* are classified under but for the purpose of this survey Apidae is used to categorize those bees that don't fall into the former categories. The survey was repeated 5 times to evaluate the cultivars over the growing season.

Anecdotally, there are said to be high numbers of *Bombus* spp. on this site. There are also several *Apis mellifera* colonies kept on the farm as well. The farm is an active farm and is the site of many different types of research. The farm is located in an agricultural area where pesticides and herbicides are sure to be in use and the applied chemicals may affect the insect populations in the area. In the region and on the farm the *Popillia japonica* (Japanese Beetle) is a recurring pest and its population is controlled with insecticides in the flower trial plots. The insecticides used include Endeavor (active ingredient: pymetrozine), Orthene (active ingredient: acephate), Conserve (active ingredient: spinosad), and malathion. According to the Institute of Food and Agricultural Sciences Extension, acephate and malathion are highly toxic to honey bees (Stanford, 1993). These insecticides may affect the beneficial insect populations but this can be minimized with proper application.

3.2 Results and Discussion

The observed values of bee types varied across the surveys. The numbers of Apidae and *Bombus* spp. were unexpectedly high compared to *A. mellifera*. There weren't any *Bombus* spp. observed in the first survey however there were *Bombus* spp. present in the gardens on this day, so the observations cannot be attributed to the absence of the bee type.

Table 3-1: Observed bee totals for each survey by bee type.

	Survey					
Cultivar	6/25/08	7/3/08	8/1/08	8/21/08	9/23/08	Total
Apis mellifera	28	55	7	29	125	244
Bombus spp.	0	20	49	128	89	286
Apidae	44	129	28	112	42	355
Total	72	204	84	269	256	885

3.2.1 Shared Preferences

Preferred plants are defined in this study to be the genera that were visited most by bees. Differences were expected between preferred plants and bee types. Although, shared preferences, and visits by multiple bee types to a particular genus were also expected to a lesser extent. Upon closer inspection there were numerous shared preferences between two bee types and shared preferences between all bee types was observed twice (Table 3-2).

Table 3-2: Shared preferences. Frequency indicates the number of surveys each genus was visited by multiple bee types. The genera in bold represents visits by all bee types at one time point.

Genus	Frequency
***Gaillardia* spp.**	**5**
Salvia spp.	5
Lobelia sp.	4
Sutera (Bacopa) sp.	3
Ageratum sp.	2
***Euphorbia* sp.**	**2**
Pentas sp.	2
Scaevola sp.	2
Tecoma sp.	2
Coreopsis sp.	1
Lantana sp.	1
Nemesia sp.	1
Portulaca sp.	1
Xerochrysum sp.	1
Zinnia sp.	1
Total: 15	33

Of the 27 genera surveyed there were two, *Phlox* sp. and *Talinum* sp., that elicited zero visits from any bee type in all of the surveys. Of the 25 genera that received visits, 60% were shared preferences and all three bee types shared two of these. *Gaillardia* sp. and *Euphorbia* sp.

elicited visits by all bee types in one survey each, the *Gaillardia* sp. on 8/1 and the *Euphorbia* sp. on 9/23.

3.2.2 Preferred Plants

To further identify the genera that could be considered pollinator-friendly a list of the preferred plants were compiled for each of the surveys to identify the genera that consistently provided forage across the season.

Preferred plants were determined by the percentage of bee visits received. The determining factor was set at 50%. Select cultivars received the majority of visits in each survey, so the percentages were summed until a 50% value was reached and these cultivars were deemed preferred plants. The preferences varied for each bee type. Preferences of *Bombus* spp. amounted to fewer cultivars than the general Apidae; this was not unexpected due to the fact that there is more species diversity included in the Apidae category.

3.2.2a *Bombus* spp.

Of all the surveys *Bombus* spp. were never observed visiting 12 genera of plants, leaving only 15 that were visited (Figure 3-2). Of the 15 that were visited 5 were considered preferred plants (pollinator-friendly) for *Bombus* spp., accounting for 79.37% of all *Bombus* spp. visits (Table 3-3). The *Bombus* spp. appeared to be more selective than the other bee types due to the somewhat concentrated visits to genera for each survey, hence the small list of preferred plants. The *Bombus* spp. did not appear to have a flower form preference. This is evident in Table 3-4 as there were 3 families with different floral morphology represented. The prevalence of Asteraceae as a preference is expected, in part due to its unspecialized pollination syndrome.

There was only one genus that was visited solely by *Bombus* spp. and this was the *Ptilotus* sp. This observation was only seen during one survey and did not constitute a large percentage of the visits; therefore it wasn't deemed a preferred plant and consequently couldn't be considered pollinator-friendly.

Figure 3-2. *Bombus* spp. preferences. Each survey is represented by a different shade with the size indicating quantity of visits. The data has been normalized as percentage of visits per survey. Corresponding data can be found in Appendix B.

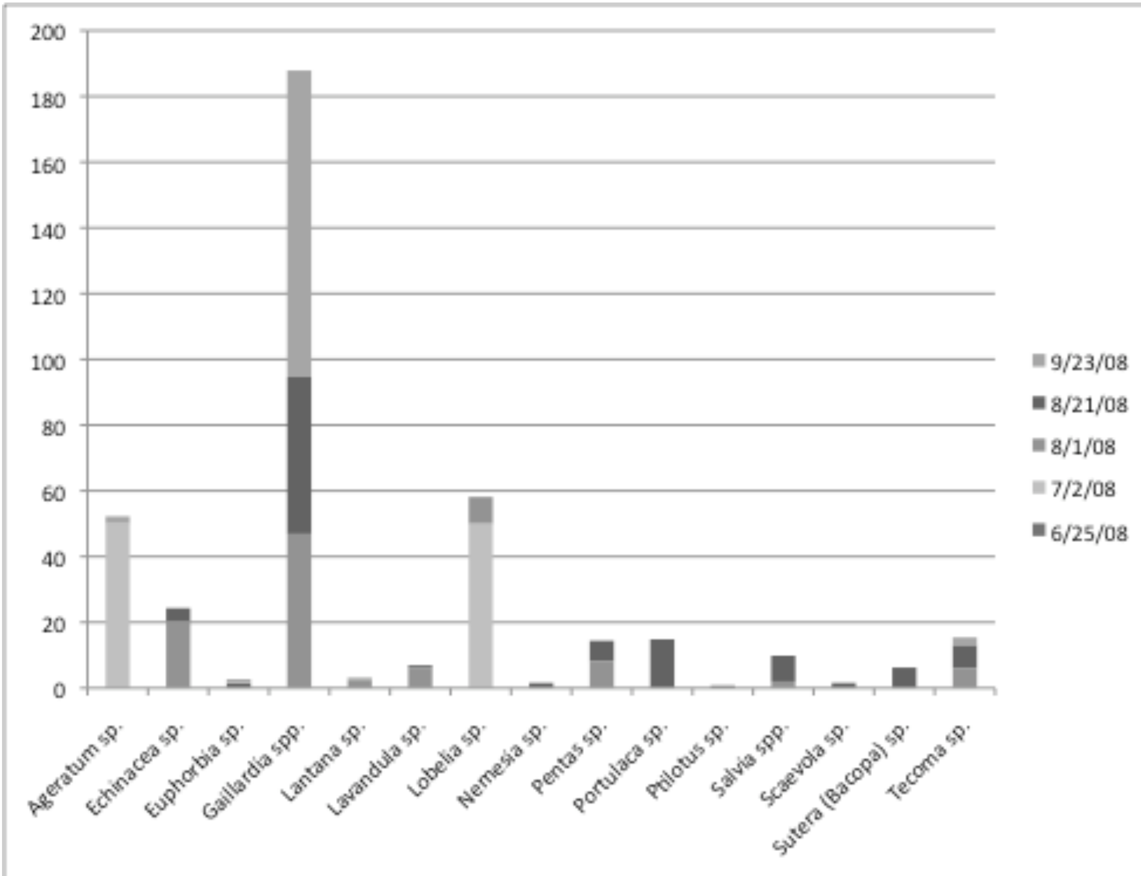


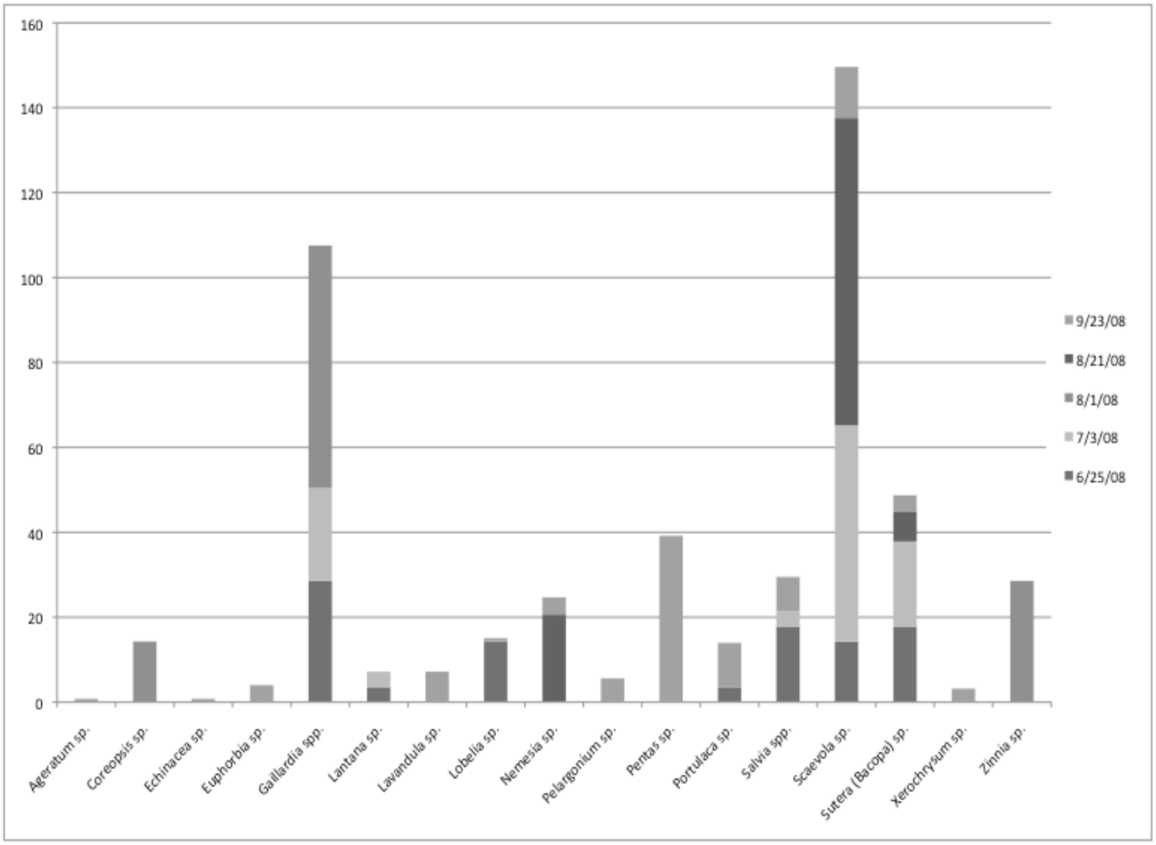
Table 3-3. Preferred Plants: *Bombus* spp. Genera listed in bold typeface are also preferences of other bee types. Total % is the percentage of *Bombus* spp. visits to the genus over all the surveys.

Genus	Frequency	Total %	Family
Gaillardia spp.	3	58.39	Asteraceae
Portulaca sp.	1	6.64	Portulacaceae
Echinacea sp.	1	5.24	Asteraceae
Lobelia sp.	1	4.9	Campanulaceae
Ageratum sp.	1	4.2	Asteraceae
Total: 5	7	79.37	3

3.2.2b *Apis mellifera*

Overall, *A. mellifera* was observed visiting 17 genera (Figure 3-3). This was unexpected due to the reputation of *A. mellifera* as an extreme generalist; this exposed the initial underestimation of the generalist nature of the other bee types, or perhaps the overestimation of *A. mellifera*.

Figure 3-3. *Apis mellifera* preferences. Each survey is represented by a different shade with the size indicating quantity of visits. The data has been normalized as percentage of visits per survey. Corresponding data can be found in Appendix B.



Of the 17 genera visited, 5 were ultimately determined preferred plants specifically for *A. mellifera* (Table 3-4). All of the top performers on the pollinator-friendly list for *A. mellifera* were shared by another bee type as a top performer. One big difference noted was the appearance of more families on the list showing an increased diversity among preferred floral types compared to *Bombus* spp. These 5 preferred plants accounted for 74.19% of all the *A. mellifera* visits.

There was only one genus that was exclusive to *A. mellifera* and that was *Pelargonium* sp. As was seen with the *Ptilotus* sp. and *Bombus* spp., there were few visits to the *Pelargonium* sp. during one survey only, preventing its consideration as an exclusive top performer.

Table 3-4. Preferred Plants: *Apis mellifera*. All of the listed genera are pollinator-friendly for other bee types. Total % is the percentage of *A. mellifera* visits to the genus overall the surveys

Genus	Frequency	Total %	Family
Gaillardia spp.	2	9.84	Asteraceae
Pentas sp.	1	20.08	Rubiaceae
Salvia spp.	1	6.97	Lamiaceae
Scaevola sp.	3	27.87	Goodeniaceae
Sutera (Bacopa) s	1	9.43	Scrophulariaceae
Total: 5	8	74.19	5

3.2.2c Unclassified Apidae

The general unclassified Apidae category, potentially, encompasses a diverse array of bee species excluding the bees accounted for with the other categories. This diversity makes it no surprise that 21 of the 27 surveyed genera were visited (Figure 3-4). Due to the large range of genera visited the visits were much less concentrated resulting in a larger list of preferred plants for the unclassified Apidae category (Table 3-5). More than half of the plant families represented in the surveys appeared on this list with many of the species belonging to Asteraceae. The majority of the genera appearing on this list also appear on the preference lists of the other bee types indicating a significant amount of overlap between preferred plant cultivars. Three of the 4 unshared preferred plants were visited exclusively by the Apidae category these were: *Helenium* sp., *Anagallis* sp., and *Argyranthemum* sp. The *Verbena* sp., *Tagetes* sp., and *Brachyscome* sp. surveyed were also among the genera exclusively visited by the Apidae category but unlike the others they were much like the *Ptilotus* sp. and *Pelargonium* sp.; which received a very low number of visits in a single survey. The preferred plants accounted for the 83.93% of unclassified Apidae visits.

Figure 3-4. Unclassified Apidae preferences. Each survey is represented by a different shade with the size indicating quantity of visits. The data has been normalized as percentage of visits per survey. Corresponding data can be found in Appendix B.

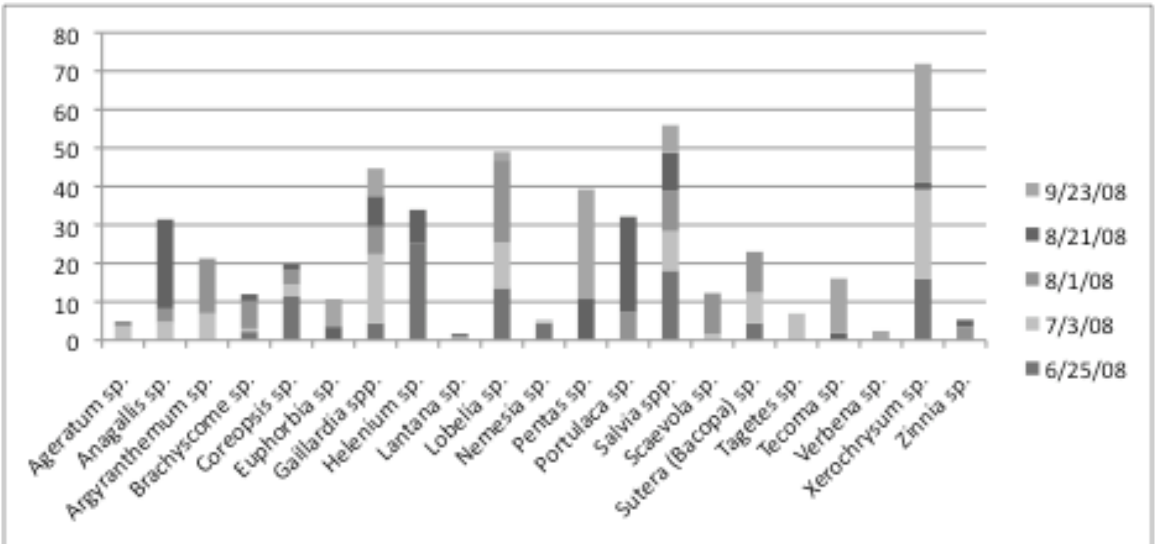


Table 3-5. Preferred Plants: Unclassified Apidae type. Genera listed in bold typeface also are pollinator-friendly for other bee types. Total % is the percentage of unclassified Apidae visits to the genus overall the surveys.

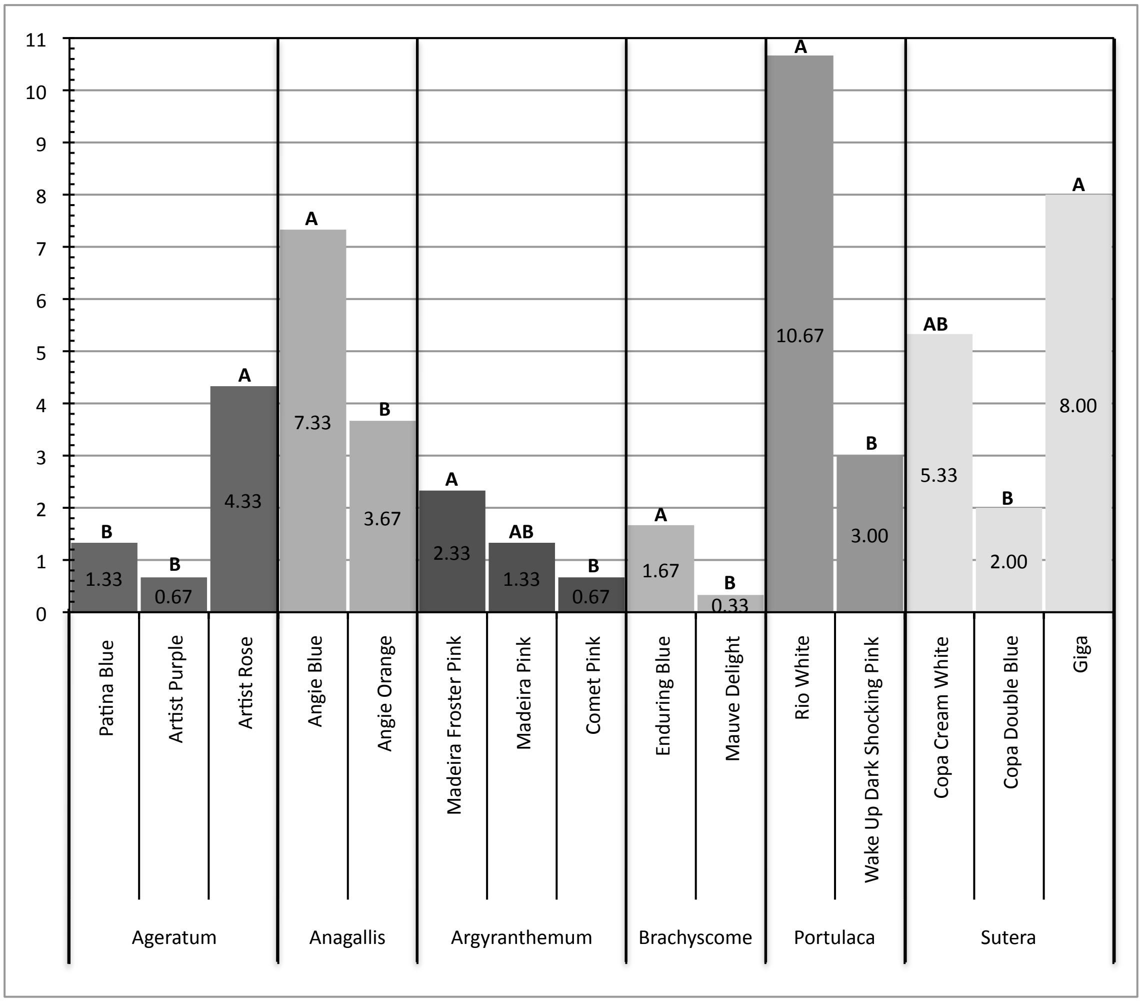
Genus	Frequency	Total %	Family
Xerochrysum sp.	3	14.62	Asteraceae
Gaillardia spp.	1	10.99	Asteraceae
Salvia spp.	2	10.7	Lamiaceae
Anagallis sp.	1	9.3	Myrsinaceae
Portulaca sp.	1	8.45	Portulacaceae
Lobelia sp.	2	7.89	Campanulaceae
Pentas sp.	2	6.76	Rubiaceae
Helenium sp.	1	5.92	Asteraceae
Sutera (Bacopa) sp	1	4.23	Scrophulariaceae
Argyranthemum sp.	1	3.66	Asteraceae
Scaevola sp.	1	1.41	Goodeniaceae
Total: 11	16	83.93	8

3.2.3 Cultivar Variation

Variation of bee visits among cultivars within genera was expected due to the differences in cultivar traits. A one-way analysis of variance was used to identify significant differences within the respective genera for total bee visits. Seven genera were omitted from the analysis due to the availability of only a single cultivar for the survey. Of the remaining genera, six were identified as having significantly different means among the associated cultivars (Figure 3-5). Tukey's HSD test was performed post hoc to identify the significantly different means. Due to insufficient degrees of freedom an appropriate model could not be used to test cultivar effect. In response each genus was analyzed separately.

Inquiry into possible traits or factors influencing bee preferences revealed no consistent trends. Floral color and commercial lines did not appear to have a correlation. Preference of floral color was not consistent. Several cultivars are a part of specific commercially marketed lines and their relation did not predict preference outcome. Despite the fact that some of the cultivars are marketed in the same commercial line, assumptions cannot be made regarding the use of the same parental lineages limiting speculation about the genetic basis for pollinator cultivar preference. With the available information, patterns among the cultivar differences were evident. The significant differences suggest that cultivar did have an effect on bee preferences in this study. Further investigation is required to identify any specific effects of cultivar in eliciting pollinator visits.

Figure 3-5. Cultivar variation of mean bee visits within genera. Genera with significantly different means among cultivars are shown. Means presented are of the overall total bee visits per cultivar. Shared letters indicate means that aren't significantly different from each other within individual genus only (Tukey's HSD P<0.05).



3.3 Conclusions

The surveys ultimately revealed that bees forage with little exclusivity. One of the shared behaviors was the absence of any bees observed on the *Phlox* sp. and *Talinum* sp. The absence of bees at the *Phlox* sp. was somewhat unexpected due to that genus's common appearance on pollinator-friendly lists. The absence of bees could potentially be explained by the fact that the cultivars surveyed were all hybrids. The absence or reduction in nectar production has been noted as an unintended consequence of selective breeding of novel traits in ornamentals (Corbet et al., 2001).

Diurnal bloom rhythms of *Talinum* sp. are controlled by a self-pollination mechanism that is effected by photoperiod length and temperature (Ewusie and Quaye, 1977; Laing and Stephens, 1970). These rhythms could explain the absence of bees; though research has shown that *Portulaca* sp. has a similar mechanism and yet it was a preferred plant in the surveys, potentially an artifact of breeding or the survey protocol (Iwanami and Hoshino, 1963).

There were 8 genera that received visits exclusive to one bee type and five of these received low numbers of visits, failing to conclude exclusivity for those bee types. To further explore the possibility of exclusivity of some kind would involve a more specific classification of the bees and further examination of the cultivars involved. The bee classification used in the surveys was biased due to the unevenness of the species under the bee type categories. The purpose of the surveys was to produce a general pollinator-friendly list not to identify specie specific preferences.

Surprisingly, when bee visits by cultivar were examined there seemed to be no major trend in variation among cultivars within the surveyed genera. There were very few cultivars within a genus with statistically significant differences in pollinator visitation. These findings warrant further investigation of the variability of floral rewards produced between cultivars. Additional study could provide further insight into the physiological effect of certain breeding practices.

Due to the overlap of top performers among the bee types it was concluded that a single list could be compiled. By using the same method for the individual bee types the new list was compiled (Table 3-6). This method left out one of the top performers from the individual bee lists, *Argyranthemum* sp.. To prevent overlooking potential pollinator-friendly plants the overall percentage of bee visits was used to create a threshold at the amount of the lesser of the top-performers (*Argyranthemum* sp.). This method added an additional 5 genera to the top-performers list accounting for 95.93% of total bee visits. From this overall list, most of the preferred plants were shared by more than one bee type as a preferred plant. *Gaillardia* spp. being the only genus shared by all bee types, accounting for 25.99% of all bee visits.

For the individual bee categories, each survey consisted of no more than 5 genera accounting for the top 50% of all visits, indicating the strong preference and utilization of those few genera that subsequently resulted in a list of only 13 genera. Overall, these 13 genera accounted for 87.01% of all observed bee visits. The additional 5 genera that were added elicited more or equal numbers of visits from bees overall than some of the preferred plants for the individual bee types. This outcome confirmed the validity and resulted in the desired generalization of the list. The diversity of floral morphology is represented just as with the individual bee lists. Of the genera that made the final list, several have native species to the Mid-Atlantic region or to other regions of the United States. These results successfully produced a final pollinator-friendly list that could be easily utilized by consumers to implement pollinator-friendly gardening practices. Not only does the list offer a guide to plant selection but it also reinforces the pollinator-friendly gardening practices promoted by the Master Gardener's.

Table 3-6. Preferred Plants: Overall. Genera listed in bold typeface appeared on the individual bee type top performer lists. The common names listed are not a complete list. Total % is the percentage of all bee visits to the genus over all the surveys. Cultivars surveyed can be found in Appendix A.

Genus	Common Name	Total %	Family
Gaillardia spp.	Blanket Flower	*25.99*	Asteraceae
Pentas sp.	Egyptian Starcluster	*9.60*	Rubiaceae
Scaevola sp.	Fan Flower	*8.47*	Goodeniaceae
Salvia spp.	Sage	*7.46*	Lamiaceae
Portulaca sp.	Purslane	*7.12*	Portulacaceae
Xerochrysum sp.	Bracteantha	*6.33*	Asteraceae
Lobelia sp.	Lobelia	*5.31*	Campanulaceae
Sutera (Bacopa) sp.	Bacopa	*5.20*	Scrophulariaceae
Anagallis sp.	Pimpernel	*3.73*	Myrsinaceae
Tecoma sp.	Esperanza	*2.49*	Bignoniaceae
Helenium sp.	Sneezeweed	*2.37*	Asteraceae
Ageratum sp.	Flossflower	*2.15*	Asteraceae
Echinacea sp.	Coneflower	*1.81*	Asteraceae
Nemesia sp.	Nemesia	1.81	Scrophulariaceae
Euphorbia sp.	Euphorbia	1.69	Euphorbiaceae
Argyranthemum sp.	Dill Daisy	1.47	Asteraceae
Coreopsis sp.	Tickseed	1.47	Asteraceae
Lavandula sp.	Lavender	1.47	Lamiaceae
Total: 18		95.93	10

Chapter 4

Greenroof Plant Survey

Proper plant selections can contribute forage and habitat for pollinators both at grade and above. Certain cultivars are expected to attract a greater diversity of pollinators than others. Factors such as plant morphology, origin, temperature, weather, and plant competition can help explain the variation in pollinator preference seen between cultivars. Nectar rewards are known to be temporally variable (Corbet, 2001). The objective of this study was to construct a suggested planting list for greenroofs that would support pollinators. Plant varieties were rated according to the quantity of insects they attract and by bloom characteristics.

4.1 Materials and Methods

The field site was located in Street, MD on Emory Knoll Farms, which is approximately 45 km from Baltimore, MD at 39.64457°N, -76.34114°W. This farm is located in a semi-rural area. The farm produces, almost exclusively, plants for greenroof and living wall installations. The owner of the farm, Ed Snodgrass, is very knowledgeable of the plant material and some varieties suggested by him were used in the surveys. No pesticides have been sprayed on the farm since the early 1970's, and previous scouting visits have shown that there are an abundance of pollinators present on the property. There are also several healthy *Apis mellifera* hives maintained on site.

The surveyed plant materials were found throughout the farm. The survey sites consist of several shade houses, production plots, a living wall, a greenroof, and planting beds. The living wall is made of hollowed 'bricks' that act as planters, these contain some well-established plant material. There are production hoop houses by the living wall and these contained *Delosperma* spp., *Talinum* spp., and *Sempervivum* spp**.** These hoop houses were covered with shade cloth. There was a plant bed displaying several of the *Delosperma* spp. in front of the office. The office was located next to the living wall and the front production hoop houses. Located on the roof of the office is a greenroof that has a variety of 'greenroof' plants. On the other end of the farm are the production plots that are used for cuttings. These plots vary in size from 2.4m x 1.8m to $1.8m^2$. In the vicinity of the production plots are a series of hoop houses that are covered with shade cloth. There are also several prep areas where plant material is being stored outside of the hoop houses on the ground.

There was an initial survey, 6/5/2008, of the available plant material to determine the cultivars to be surveyed. Of the 107 cultivars examined 23 were chosen (See Table 4-1). Cultivars were chosen based on their bloom time, bloom color, growth habit, greenroof performance, professional recommendations, and availability on the farm and hence the marketplace. The survey consisted of randomly placing a $.5m^2$ quadrat within the selected cultivar. The quadrat was monitored for 3 minutes. Each variety had four repetitions when available, stock rotation ultimately prevented consistent repetitions for all varieties. The plant material in the quadrat was determined as percentage filled. The open blossoms were also estimated by percentage of quadrat filled. Following these measurements, bees were surveyed within the quadrat by counting the individuals that visited the flowers. The bees were classified into 3 types i.e. *Bombus* spp., *Apis mellifera,* and unclassified Apidae (all species that didn't fall into the former classifications). The surveys were repeated 4 times throughout the month of July 2008: 7/2, 7/9, 7/18, 7/29.

A diverse number of insect visitors were expected with a high incidence of *A. mellifera.* The plants offering the best rewards were expected to be visited proportionately. Seasonal variation of flower bloom times were expected to elicit changes in bee visitation.

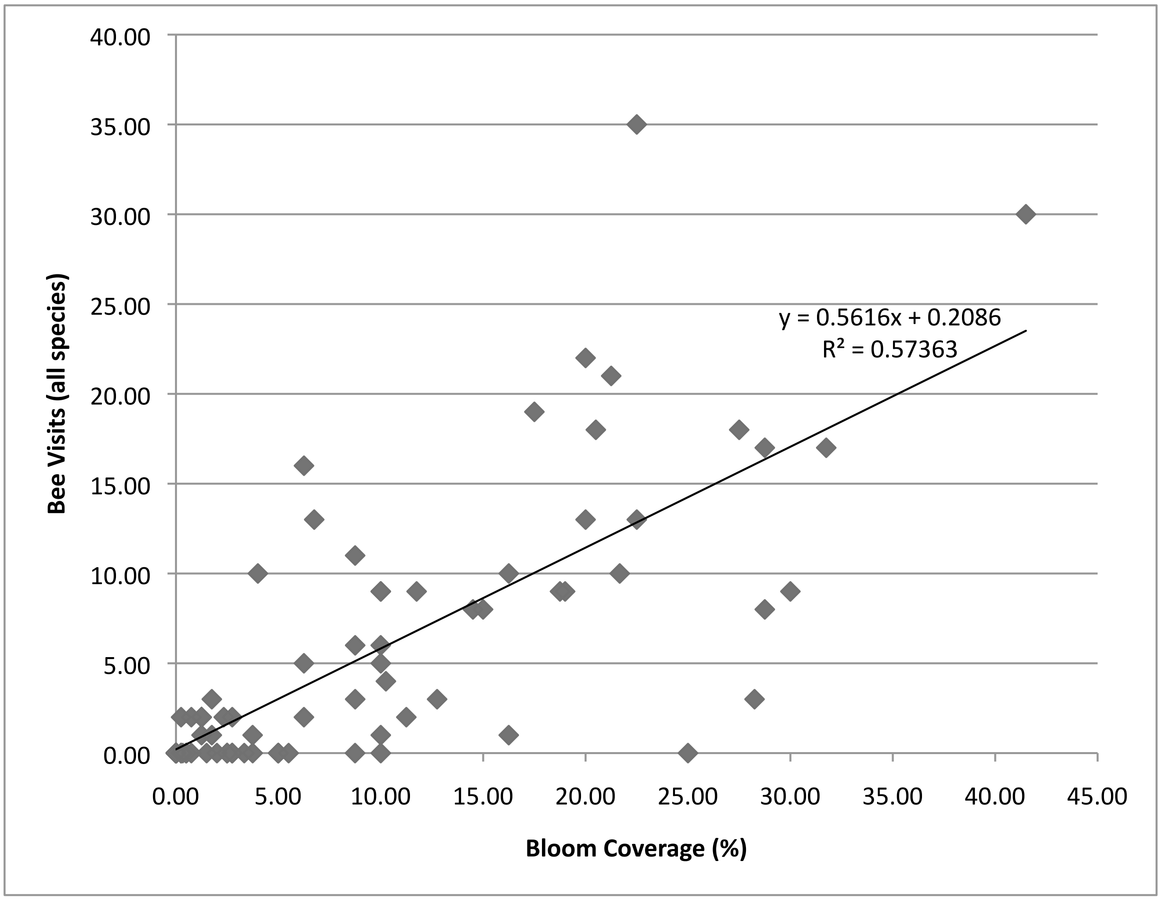
4.2 Results and Discussion

Complications arose due to the nature of the field site, which compromised the experimental design. Due to the fluid nature of the farm inventory there was an inconsistent supply of cultivars available for survey. The maintenance of the plant material often involved cutting back blooms and vegetation skewing the data. The combination of inventory maintenance, turnover, and low repetition numbers resulted in a small and unbalanced data set complicating statistical analysis. This could have been avoided if samples were set-aside solely for the purpose of the survey.

Predictably, the overall trend of the data was that bee visits increased as bloom coverage increased, though this was not always the case (Figure 4-1). To mitigate the effects of the survey complications, separate variable analyses were performed for cultivar comparison. Interaction effects could not appropriately be tested statistically so each variable: bloom coverage, bee visits, and their potential interaction were analyzed separately for each survey.

Cultivar comparisons for each variable were performed to identify the 'top performing' cultivars. The Top Performers were ultimately considered pollinator-friendly cultivars. To be considered a Top Performer, cultivars had to outperform the other surveyed cultivars in at least one survey. Each survey was analyzed separately to account for the variability of the cultivars across the duration of the study. Cultivar comparisons were made for the individual surveys using a predetermined threshold. A threshold of 50% was set, meaning the cultivars with the highest proportion of values, when summed accounted for no less than 50% of the total values. Cultivars within this threshold were considered Top Performers. This method can potentially overlook high performing cultivars that don't qualify on an individual survey basis but otherwise performed consistently well. To correct this bias an additional cultivar comparison was made using the gross survey totals. From the overall totals a second threshold was determined. The threshold was set as the lowest value of the Top Performer cultivars determined from the individual survey analyses. Cultivars with overall totals that exceeded the threshold were considered overall Top Performers.

Figure 4.1 Overall Effect of Bloom Coverage on Bee Visitation.



4.2.1 Bloom Coverage

Bloom coverage was recorded to supplement cultivar growth characteristic information. Data analysis was aimed at determining the most prolific and consistently blooming cultivars. An accurate account of the bloom periods could not be documented given the maintenance practices of commercial plant production.

Maintaining and producing plant stock often involves pruning of flowers to promote root formation and vegetative growth of stock beds and inventory. The availability of some cultivars was often limited, so survey of recently pruned material was unavoidable and often hard to detect.

S. ochroleucum is an example of a pruned cultivar that was selected because of prolific bee visits observed during scouting. Just prior to the first survey the blooms were cut back and were not observed in any of the following surveys. Any lasting effects of the initial pruning and speculation regarding the absence of blooms could not be ascertained. *S. ochroleucum* is the only cultivar with both visual and verbal confirmation from the staff regarding pruning; pruning of other cultivars couldn't be verified. Filling orders often resulted in pruning but not necessarily from the entire available stock, as was the case with *S. ochroleucum.* Since the timing and extent of pruning was unavailable the effects on bloom observations are unknown.

Studies have shown that flower abundance isn't the sole determining factor for bee visitation; bloom coverage data was to be used as a guide based on the overall trend seen in Figure 4-1 (Waddington, 1983). The bloom coverage data revealed several of the cultivars were consistent prolific bloomers (Figure 4-2). Overall, in reference to bloom quantity there were 9 Top Performers out of 23 cultivars (Table 4-1). The Top Performers accounted for 72% of all bloom coverage observed. Analysis of the cultivar performance over each survey revealed that most Top Performing cultivars consistently had more blooms in comparison to the other cultivars. Aesthetically, the consistency and quantity observed in the Top Performers is an ideal trait for ornamental plants.

Figure 4-2. Bloom Coverage. Average bloom coverage of each cultivar has been normalized as a percentage of bloom coverage per survey. Each survey is represented by a different shade with the size indicating quantity of visits. Corresponding data can be found in Appendix D.

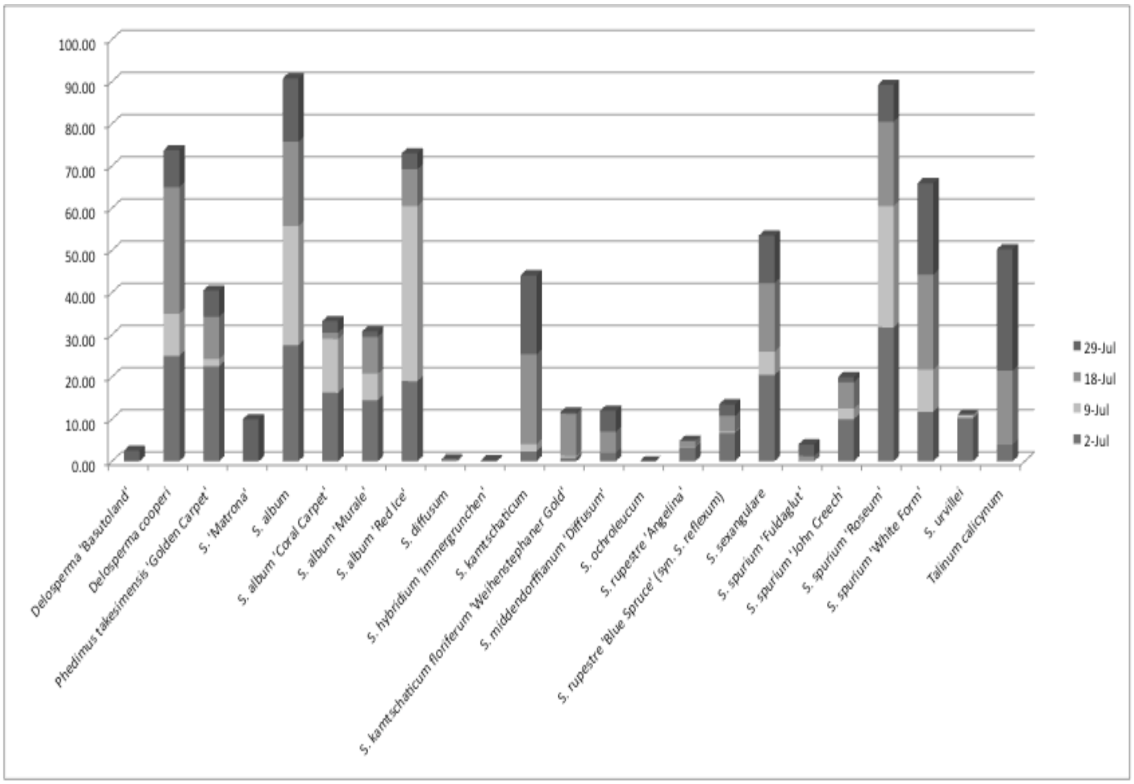


Table 4-1. Top Performers: Bloom Coverage. Cultivars with highest bloom coverage are listed. Frequency is the number of surveys that the cultivar was a Top Performer. Total % indicates the overall percentage of all bloom coverage attributed to cultivar.

Cultivar	Freq.	Total %
S. album	4	12.23
S. spurium 'Roseum'	3	12.03
Delosperma cooperi	2	10.10
S. kamtschaticum	2	6.25
S. spurium 'White Form'	2	8.70
Phedimus takesimensis 'Golden Carpet'	1	5.46
S. album 'Red Ice'	1	9.83
S. sexangulare	1	7.21
Talinum calicynum	1	6.77

4.2.2 Bee Visits

Observed bees were classified into 3 separate categories: *A. mellifera*, *Bombus spp.*, and unclassified Apidae so that differences in foraging behavior could be detected. Ultimately, low numbers of *A. mellifera,* and *Bombus* spp. were observed which made analyzing individual bee type preferences unrealistic (Table 4-2). As a result bee types were combined into a single bee category for cultivar comparisons. Reasons for low bee numbers of the two types are unknown. Weather did not appear to affect the insect activity, as most survey days were moderate. The highest temperatures recorded on survey days was 35° C on July 18 but the highest bee numbers were also recorded on that day.

Table 4-2. Observed Bee Numbers. Observed bee numbers by bee type.

	Bee Type			
Survey	***A. mellifera***	***Bombus* spp.**	**Unclassified Apidae**	**All Bees**
2-Jul	23.00	8.00	111.00	142.00
9-Jul	7.00	0.00	77.00	84.00
18-Jul	28.00	0.00	118.00	146.00
29-Jul	16.00	0.00	44.00	60.00
Total	74.00	8.00	350.00	432.00

Initial cultivar analysis revealed five cultivars: *S. middendorffianum* 'Diffusum', *Delosperma* 'Basutoland', *S. hybridium* 'Immergrunchen', *S. diffusum*, and *S. ochroleucum,* that received zero bee visits in every survey (Appendix D). Each of these cultivars had low bloom coverage ranging from 0-20% and *S. diffusum*, and *S. ochroleucum* were completely absent from the site in 2 surveys.

Trends in bee visits were not consistent (Figure 4-3). The Top Performers attracted the highest numbers overall, but some cultivars were more consistent than others. Three of the 10 Top Performers were Top Performers in multiple surveys and accounted for 87% of all bee visits (Table 4-3). Undoubtedly there is an interaction between flowers and bees and this is highlighted by the almost identical Top Performers list for bloom coverage and bee visits.

Figure 4-3. Cultivar Comparison: Bees. Bee visits to each cultivar have been normalized as a percentage of bee visits per survey. Each survey is represented by a different shade with the size indicating quantity of visits. Corresponding data can be found in Appendix D.

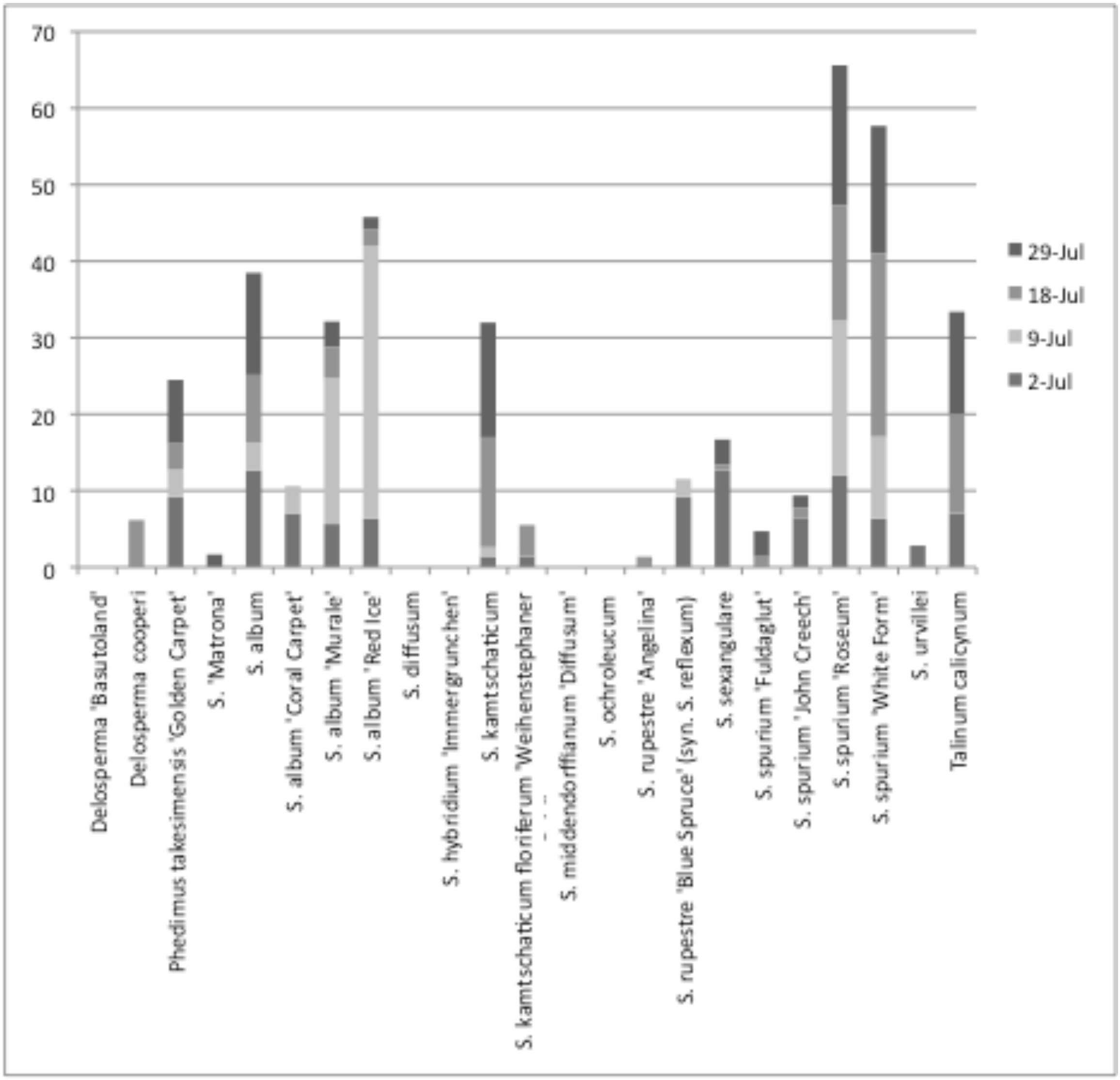


Table 4-3. Top Performers: Bees. Cultivars listed attracted the highest percentage of bee visits. Frequency is the number of surveys that the cultivar was a Top Performer. Overall refers to a cultivar that doesn't meet the threshold for individual surveys but exceeds the threshold to be considered an overall Top Performer.

Cultivar	Freq.	Total %
S. spurium 'Roseum'	4	15.26
S. spurium 'White Form'	2	15.11
S. album 'Red Ice'	1	9.79
S. album	1	9.57
S. kamtschaticum	2	7.67
Phedimus takesimensis 'Golden Carpet'	1	5.92
S. sexangulare	1	4.78
S. rupestre 'Blue Spruce' (syn. S. reflexum)	1	3.42
Talinum calicynum	(overall)	8.43
S. album 'Murale'	(overall)	7.29

4.2.2a Influence of Bloom Density

A correlation between bloom presence and bee visitation was expected. Deviations from this norm, outliers, would potentially be expected at points of increased reward production most likely occurring around the time of optimal reproductive potential. The complications attributed to the experimental site posed significant statistical obstacles to identifying and evaluating these factors.

To investigate the strength of the potential relationship between bloom quantity and visitation, Pearson's correlation coefficients were used as an initial assessment. Expectedly bloom coverage and bee visitation had a significant correlation coefficient (r^2= .430, p<.0001). Outliers were anticipated to highlight plants with potentially greater reward production. However, there were many zero values present in the data, 39% of bloom and 66% of bee observations. Subsequently correlations were influenced by even the smallest values yielding unreliable correlations.

Since bloom coverage varied, it was necessary to analyze the proportion of bee visits to bloom coverage, referred to as bee density. Bee density would highlight any of the anticipated outliers. A correlation between bloom coverage and bee visits doesn't however imply a cause and effect relationship. Bee density Top Performers closely paralleled the bloom and bee Top Performer lists with a few exceptions highlighted in Table 4-4. Using bee density revealed four cultivars: *S. kamtschaticum floriferum* 'Weihenstephaner Gold', *S. rupestre* 'Angelina', *S. spurium* 'Fuldaglut', *S. spurium* 'John Creech' that would have otherwise been overlooked concentrating on the individual variables.

Table 4-4. Top Performer Comparisons. X denotes presence on Top Performer list for that variable. Listed cultivars are considered pollinator-friendly.

Cultivar	Bees	Bloom Coverage	Bee Density
Delosperma cooperi		X	
Phedimus takesimensis 'Golden Carpet'	X	X	X
S. album	X	X	
S. album 'Murale'	X		X
S. album 'Red Ice'	X	X	
S. kamtschaticum	X	X	
S. kamtschaticum floriferum 'Weihenstephaner Gold'			X
S. rupestre 'Angelina'			X
S. rupestre 'Blue Spruce' (syn. S. reflexum)	X		X
S. sexangulare	X	X	
S. spurium 'Fuldaglut'			X
S. spurium 'John Creech'			X
S. spurium 'Roseum'	X	X	X
S. spurium 'White Form'	X	X	X
Talinum calicynum	X	X	X
Total: 15	9	9	12

4.3 Conclusions

Despite the complications of the experimental design, this study was able to produce a preliminary pollinator-friendly plant list. The combination of the three Top Performer lists (Table 4-4) identified plants that had a high incidence of bee visits paired with the aesthetics of prolifically blooming plants. From 23 surveyed cultivars 15 could be considered pollinator-friendly. The list takes into account the correlation between bloom quantity and bee visits and emphasizes correlation does not necessarily imply cause and effect relationships.

To provide further detailed results and conclusions further study is needed. The future study should be performed at a different scale (both grain and extent) to better ascertain variable interactions. The preliminary list produced from this survey can be used as a baseline from which to work. Cultivars could further be scrutinized by an increase in survey repetition paired with a larger expanse of time. This would provide a more in depth analysis of seasonal variation. A tightly controlled experimental design that also mimics greenroof conditions more closely would be more likely to produce more realistic results. The conditions on a roof are more variable than in a highly managed setting such as production where the plant needs are closely monitored. Ideally surveyed plants would be in different climatic locations and dependent on the natural rainfall and environment to survive.

Chapter 5

Conclusions

Ensuring that pollinators have adequate foraging resources is crucial for maintaining the health of our ecosystems. The goal of these surveys was to produce a list of plants that could be used as guidance when planning a landscape, whether in a front yard or on a roof. Most importantly, the resulting lists consisted of plants that can be easily obtained. The greenroof survey produced a list with 15 cultivars that could be considered pollinator-friendly, these cultivars accounted for 96% of all observed bee visits. The results of the garden annuals survey consisted of 18 genera that also accounted for 96% of all observed bee visits. The results could be used as a preliminary study for further research and for initial guidance for those interested in planting a more pollinator-friendly landscape.

The difficulties that arose from this experimental design prevented a more thorough analysis of the data collected. Regardless of these difficulties the goals of producing pollinator-friendly plant lists were successfully compiled from the existing data. Further investigation is needed to pinpoint more specific results on the effect of color, morphology, and floral rewards in regards to bee preferences. These surveys are by no means comprehensive but they do resemble existing plant lists and confirm claims of some pollinator-friendly gardening practices. The results of the garden annuals survey had 10 plant families represented in the final list, supporting the idea that planting a variety of floral shapes and colors is a pollinator-friendly practice.

Appendix A
Garden Annuals Plant List

Cultivar number refers to accession numbers assigned to the cultivar at the Penn State Trial Gardens in Landisville, PA.

Cultivar	Family	Genus	Cultivar	Common Name
7423	Asteraceae	*Ageratum*	'Patina Blue'	Flossflower
8003	Asteraceae	*Ageratum*	'Artist Purple'	Flossflower
8004	Asteraceae	*Ageratum*	'Artist Rose'	Flossflower
7424	Myrsinaceae	*Anagallis*	'Angie Blue'	Pimpernel
7425	Myrsinaceae	*Anagallis*	'Angie Orange'	Pimpernel
1057	Asteraceae	*Argyranthemum*	'Madeira Froster Pink'	Dill Daisy
1058	Asteraceae	*Argyranthemum*	'Madeira Pink'	Dill Daisy
7002	Asteraceae	*Argyranthemum*	'Comet Pink'	Dill Daisy
2406	Scrophulariaceae	*Sutera*	'Copa Cream White'	Bacopa
2407	Scrophulariaceae	*Sutera*	'Copa Double Blue'	Bacopa
4651	Scrophulariaceae	*Sutera*	'Giga'	Bacopa
1065	Asteraceae	*Brachyscome*	'Enduring Blue'	Swan River Daisy
7023	Asteraceae	*Brachyscome*	'Mauve Delight'	Swan River Daisy
2023	Asteraceae	*Xerochrysum*	'Helica Yellow'	Bracteantha
7024	Asteraceae	*Xerochrysum*	'Wallaby White'	Bracteantha
9814	Asteraceae	*Xerochrysum*	'Mohave Fire'	Bracteantha
7451	Asteraceae	*Coreopsis*	'Corey Yellow'	Tickseed
7417	Asteraceae	*Echinacea*	'Prairie Splender Deep Rose'	Coneflower
8049	Euphorbiaceae	*Euphorbia*	'Diamond Frost'	Euphorbia
9217	Euphorbiaceae	*Euphorbia*	'Silver Fog'	Euphorbia
9218	Euphorbiaceae	*Euphorbia*	'Silver Shadow'	Euphorbia
5215	Asteraceae	*Gaillardia*	'Galileo'	Blanket Flower
7460	Asteraceae	*Gaillardia*	'Aristata Sunburst Scarlet Halo'	Blanket Flower
7461	Asteraceae	*Gaillardia*	'Aristata Sunburst Tangerine'	Blanket Flower
9234	Geraniaceae	*Pelargonium*	'Savannah Pink Sizzle'	Geranium
9240	Geraniaceae	*Pelargonium*	'Savannah White Splash'	Geranium
9242	Geraniaceae	*Pelargonium*	'Pacific Violet'	Garanium
1141	Asteraceae	*Helenium*	'Dakota Gold'	Sneezeweed
1086	Verbenaceae	*Lantana*	'Landmark Rose Glow'	Shrub Verbena

3627	Verbenaceae	*Lantana*	‘White Gold’	Shrub Verbena
7534	Verbenaceae	*Lantana*	‘Bandana Trailing Gold’	Shrub Verbena
7535	Lamiaceae	*Lavandula*	‘Compact Blue’	Lavender
8062	Campanulaceae	*Lobelia*	‘Laguna Heavenly Lilac’	Lobelia
9843	Campanulaceae	*Lobelia*	‘Magadi Light Blue’	Lobelia
1097a	Campanulaceae	*Lobelia*	‘Waterfall Azure Mist’	Lobelia
7407	Asteraceae	*Tagetes*	‘Moonstruck Orange’	Marigold
7408	Asteraceae	*Tagetes*	‘Moonstruck Yellow’	Marigold
7548	Scrophulariaceae	*Nemesia*	‘Confection White’	Nemesia
8067	Scrophulariaceae	*Nemesia*	‘Opal Innocence’	Nemesia
9847	Scrophulariaceae	*Nemesia*	‘Serengeti Upright White’	Nemesia
3630	Rubiaceae	*Pentas*	‘Athena Petite White’	Egyptian Starcluster
3633	Rubiaceae	*Pentas*	‘Ruby Red’	Egyptian Starcluster
7092	Rubiaceae	*Pentas*	‘Bahama Lavender’	Egyptian Starcluster
8108	Polemoniaceae	*Phlox*	‘Intensia Lavender Glow Pink’	Phlox
9628	Polemoniaceae	*Phlox*	‘Astoria Cherry Blossom’	Phlox
9629	Polemoniaceae	*Phlox*	‘Astoria Lavender ‘	Phlox
9631	Polemoniaceae	*Phlox*	‘Astoria Pink’	Phlox
4683	Amaranthaceae	*Ptilotus*	Exaltatus 'Joey'	Mulla Mulla
1113	Portulacaceae	*Portulaca*	‘Rio White’	Purslane
4813a	Portulacaceae	*Portulaca*	‘Wake Up Dark Shocking Pink’	Purslane
4813b	Portulacaceae	*Portulaca*	‘Wake Up Dark Shocking Pink’	Purslane
2125	Lamiaceae	*Salvia*	‘Sallynia Red’	Sage
3635	Lamiaceae	*Salvia*	‘Greggii Hot Lips’	Sage
2124	Lamiaceae	*Salvia*	‘Sallyfun White’	Sage
7600	Goodeniaceae	*Scaevola*	‘Bombay Pink’	Fan Flower
9637	Goodeniaceae	*Scaevola*	‘Surdiva Light Blue’	Fan Flower
9849	Goodeniaceae	*Scaevola*	‘Fairy White’	Fan Flower

1179	Portulacaceae	*Talinum*	‘Limon’	Fame Flower
1180	Bignoniaceae	*Tecoma*	‘Mayan Gold’	Esperanza
2138	Verbenaceae	*Verbena*	‘Veralena blueberry’	Vervain
5238	Verbenaceae	*Verbena*	‘Veralena dark pink’	Vervain
7607	Verbenaceae	*Verbena*	‘Escapade pink’	Vervain
1186	Asteraceae	*Zinnia*	‘Zahara Coral Rose’	Zinnia
1187	Asteraceae	*Zinnia*	‘Zahara Scarlet’	Zinnia
1188	Asteraceae	*Zinnia*	‘Zahara White’	Zinnia

Appendix B
Garden Survey Data

The following tables contain the data presented in Chapter 3: Garden Annuals Survey.

Apis mellifera visit data. Data presented is percentage of visits per survey and in parentheses is raw data. Bold figures are the preferred genera.

Genus	6/25/08	7/3/08	8/1/08	8/21/08	9/23/08	Total
Ageratum sp.	0	0	0	0	0.80(1)	0.41(1)
Anagallis sp.	0	0	0	0	0	0
Argyranthemum sp.	0	0	0	0	0	0
Brachyscome sp.	0	0	0	0	0	0
Coreopsis sp.	0	0	14.29(1)	0	0	0.41(1)
Echinacea sp.			0	0	0.80(1)	0.41(1)
Euphorbia sp.	0	0	0	0	4.00(5)	2.05(5)
Gaillardia spp.	**28.57(8)**	21.82(12)	**57.14(4)**	0	0	**9.84(24)**
Helenium sp.	0	0	0	0	0	0
Lantana sp.	3.57(1)	3.64(2)	0	0	0	1.23(3)
Lavandula sp.	0	0	0	0	7.20(9)	3.69(9)
Lobelia sp.	14.29(4)	0	0	0	0.80(1)	2.05(5)
Nemesia sp.	0	0	0	20.69(6)	4.00(5)	4.51(11)
Pelargonium sp.	0	0	0	0	5.60(7)	2.87(7)
Pentas sp.	0	0	0	0	**39.20(49)**	**20.08(49)**
Phlox sp.	0	0	0	0	0	0
Portulaca sp.	3.57(1)	0	0	0	10.40(13)	5.74(14)
Ptilotus sp.	0	0	0	0	0	0
Salvia spp.	**17.86(5)**	3.64(2)	0	0	8.00(10)	6.97(17)
Scaevola sp.	14.29(4)	**50.91(28)**	0	**72.41(21)**	**12.00(15)**	**27.87(68)**
Sutera (Bacopa) sp.	**17.86(5)**	20.00(11)	0	6.90(2)	4.00(5)	9.43(23)
Tagetes sp.	0	0	0	0	0	0
Talinum sp.	0	0	0	0	0	0
Tecoma sp.	0	0	0	0	0	0
Verbena sp.	0	0	0	0	0	0
Xerochrysum sp.	0	0	0	0	3.2(4)	1.64(4)
Zinnia sp.	0	0	28.57(2)	0	0	0.82(2)

Bombus spp. visit data. Data presented is percentage of visits per survey and in parentheses is raw data. Bold figures are the preferred genera.

Genus	6/25/08	7/3/08	8/1/08	8/21/08	9/23/08	Total
Ageratum sp.	0	**50.00(10)**	0	0	2.25(2)	4.20(12)
Anagallis sp.	0	0	0	0	0	0
Argyranthemum sp.	0	0	0	0	0	0
Brachyscome sp.	0	0	0	0	0	0
Coreopsis sp.	0	0	0	0	0	0
Echinacea sp.	0	0	**20.41(10)**	3.91(5)	0	5.24(15)
Euphorbia sp.	0	0	0	1.56(2)	1.12(1)	1.05(3)
Gaillardia spp.	0	0	**46.94(23)**	**47.66(61)**	**93.26(83)**	**58.39(167)**
Helenium sp.	0	0	0	0	0	0
Lantana sp.	0	0	2.04(1)	0	1.12(1)	0.70(2)
Lavandula sp.	0	0	6.12(3)	0.78(1)	0	1.40(4)
Lobelia sp.	0	**50.00(10)**	8.16(4)	0	0	4.90(14)
Nemesia sp.	0	0	0	1.56(2)	0	0.70(2)
Pelargonium sp.	0	0	0	0	0	0
Pentas sp.	0	0	8.16(4)	6.25(8)	0	4.20(12)
Phlox sp.	0	0	0	0	0	0
Portulaca sp.	0	0	0	**14.84(19)**	0	6.64(19)
Ptilotus sp.	0	0	0	0.78(1)	0	0.35(1)
Salvia spp.	0	0	2.04(1)	7.81(10)	0	3.85(11)
Scaevola sp.	0	0	0	1.56(2)	0	0.70(2)
Sutera (Bacopa) sp.	0	0	0	6.25(8)	0	2.80(8)
Tagetes sp.	0	0	0	0	0	0
Talinum sp.	0	0	0	0	0	0
Tecoma sp.	0	0	6.12(3)	7.03(9)	2.25(2)	4.90(14)
Verbena sp.	0	0	0	0	0	0
Xerochrysum sp.	0	0	0	0	0	0
Zinnia sp.			0	0	0	0

Unclassified Apidae visit data. Data presented is percentage of visits per survey and in parentheses is raw data. Bold figures are the preferred genera.

Genus	6/25/08	7/3/08	8/1/08	8/21/08	9/23/08	Total
Ageratum sp.	0	3.88(5)	0	0.89(1)	0	1.69(6)
Anagallis sp.	0	4.65(6)	3.57(1)	**23.21(26)**	0	**9.30(33)**
Argyranthemum sp.	0	6.98(9)	**14.29(4)**	0	0	3.66(13)
Brachyscome sp.	2.27(1)	0.78(1)	7.14(2)	1.79(2)	0	1.69(6)
Coreopsis sp.	11.36(5)	3.10(4)	3.57(1)	1.79(2)	0	3.38(12)
Echinacea sp.			0	0	0	0
Euphorbia sp.	0	0	0	3.57(4)	7.14(3)	1.97(7)
Gaillardia spp.	4.55(2)	**17.83(23)**	7.14(2)	8.04(9)	7.14(3)	**10.99(39)**
Helenium sp.	**25.00(11)**	0	0	8.93(10)	0	5.92(21)
Lantana sp.	0	0.78(1)	0	0.89(1)	0	0.56(2)
Lavandula sp.	0	0	0	0	0	0
Lobelia sp.	13.64(6)	**11.63(15)**	**21.43(6)**	0	2.38(1)	7.89(28)
Nemesia sp.	4.55(2)	0.78(1)	0	0	0	0.85(3)
Pelargonium sp.	0	0	0	0	0	0
Pentas sp.	0	0	0	**10.71(12)**	**28.57(12)**	6.76(24)
Phlox sp.	0	0	0	0	0	0
Portulaca sp.	0	0	7.14(2)	**25.00(28)**	0	**8.45(30)**
Ptilotus sp.	0	0	0	0	0	0
Salvia spp.	**18.18(8)**	10.08(13)	**10.71(3)**	9.82(11)	7.14(3)	**10.70(38)**
Scaevola sp.	0	1.55(2)	**10.71(3)**	0	0	1.41(5)
Sutera (Bacopa) sp.	4.55(2)	7.75(10)	**10.71(3)**	0	0	4.23(15)
Tagetes sp.	0	6.98(9)	0	0	0	2.54(9)
Talinum sp.	0	0	0	0	0	0
Tecoma sp.	0	0	0	1.79(2)	14.29(6)	2.25(8)
Verbena sp.	0	0	0	0	2.38(1)	0.28(1)
Xerochrysum sp.	**15.91(7)**	**23.26(30)**	0	1.78(2)	**30.95(13)**	**14.65(52)**
Zinnia sp.	0	0	3.57(1)	1.79(2)	0	0.85(3)

Appendix C
Educational Materials

Pollinator-friendly Gardening: Practices and Plant Selection

Many plants have developed mutually beneficial relationships with animal pollinators. The pollinators receive food in the form of nectar and pollen and in return they pollinate the flowers, thus enabling reproduction. So without pollinators many plants would be unable to reproduce and would eventually become extinct. Much of the food we eat is dependent on pollinators in some way. There are many different types of pollinators, most are insects but some birds and mammals also act as pollinators. Unfortunately, many of the world's pollinators, particularly bees, are disappearing. Thorough investigations into the population declines are ongoing and many scientists believe that there is more than one cause. A few of the widely accepted causes include pesticide use, habitat loss, and climate change. There are many different ways to help support your local pollinators, such as altering your landscape maintenance practices, garden design, and/or plant selection.

Insect pollinators have similar needs as animals; they need water, food, and shelter to survive. The recommended gardening practices help fill these needs by providing safe nesting places and flowering plants for forage. A pollinator-friendly landscape can be simple, fun, and involves as little or as much effort as desired. Chances are some of the following pollinator-friendly features are already a part of your landscape.

Pollinator-friendly Practices

- **Eliminate or reduce pesticide and chemical use in and around your landscaping.** If application is necessary be sure to follow the directions on the label to minimize any possible exposure and potential danger to your self, family, and pollinators.

- **Replace areas of grass lawn with flowerbeds or flowering ground covers.** Careful plant selection can reduce lawn maintenance by reducing frequency and time spent mowing, and also potentially reduce fertilizer use by allowing nitrogen-fixing plants such as clover to grow among the grass.

- **Provide a water source**, such as a birdbath or fountain.

- **Protect ground-nesting sites**. Unlike the exotic honeybee that lives in large colonies, many native bees make small burrows in the ground where they live alone or in small colonies.

- **Provide overwintering sites**. Delaying garden clean up until the next spring allows overwintering pollinators to nest undisturbed in the soil or plant debris.

Plant Selection and Garden Design

The diversity of pollinators translates into a wide array of preferred plants, which are often referred to as 'pollinator-friendly'. Planting a wide array of plant types not only adds visual interest and depth to a landscape it also provides habitat for pollinators. There are a few important things to keep in mind when making plant selections.

- **Design for the whole season**. Select plants that bloom in succession so that there is always something in bloom.

- **Plant in clusters or groups** to create foraging hotspots.

- **Provide a variety of floral shapes** to accommodate different types of pollinators.

- **Avoid using double cultivars.** Excess petals often deter or prevent access to floral rewards by physically blocking or producing less nectar. Composite flowers such as daisies are generally ok.

- **Plant larval host plants**. The larvae of some pollinators, particularly butterflies and moths, feed on specific plants, including these ensures the presence of adults.

- **Choose native plants** over exotics when possible. Native plants and pollinators have evolved together so it takes the guesswork out of plant selection.

- **Avoid planting invasive species**. They can escape into the wild displacing native species.

- **Select plants that are preferred by pollinators**. Plant lists are readily available; some are general and others more regionally specific or focused on a particular pollinator type.

Pollinator-friendly Plants

This list provides a few pollinator-friendly plants (genus is followed by common name) that are readily available commercially. Some of the genera listed include species native to North America, Pennsylvania and the surrounding Mid-Atlantic region, and can be found commercially.

- ***Gaillardia*- Blanket Flower**
- ***Portulaca*- Purslane**
- ***Anagallis*- Pimpernel**
- ***Coreopsis*- Tickseed**
- ***Helenium*- Sneezeweed**
- ***Sutera*- Bacopa**
- ***Scaevola*- Fan Flower**
- ***Argyranthemum*- Dill Daisy**
- ***Euphorbia***
- ***Lobelia***
- ***Salvia*- Sage**
- ***Xerochrysum*- Bracteantha**
- ***Echinacea*- Coneflower**
- ***Pentas*- Egyptian Starcluster**
- ***Ageratum*- Flossflower**
- ***Tecoma*- Esperanza**
- ***Nemesia***
- ***Lavendula*- Lavendar**

Pictured above from left to right: Lobelia, Echinacea, Salvia

Targeting Specific Pollinators

Some pollinators prefer specific floral traits due to the limitations of their physical attributes, the result of co-evolution. Honeybees and many other bees are generalist pollinators meaning they are able to utilize a wide variety of flower types. Native pollinators, including some bees, tend to be more specialized. Targeting specific pollinators can ensure their presence in your garden.

Hummingbird feeders are one common way to lure hummingbirds to your landscape. Similar actions can be done to attract other types of pollinators. Bees are fascinating insects; they are fun to watch and are a great way to educate children about nature. Bees will not sting unless provoked and some can't sting at all. Like birdhouses, bee nests can be made or are available for purchase. Additional information and supplies are readily available online and through various special interest organizations.

Additional Information

More information including suppliers, organizations, and local events pertaining to the status of your local pollinators and ways to help can be obtained from the links provided and your local Master Gardener Program. To locate your local chapter contact your regional Penn State Cooperative Extension Office.

- Find your local and regional Penn State Cooperative Extension Office: http://extension.psu.edu/extmap.html.

Additional Resources:

- National Sustainable Agriculture Information Service (ATTRA): Alternative Pollinators: Native Bees - http://www.attra.org/attra-pub/nativebee.html
- U.S. Fish and Wildlife Service:
  Pollinators- http://www.fws.gov/pollinators/Index.html
- The Xerces Society:
  Pollinator Conservation- http://www.xerces.org/pollinator-conservation/
- USDA Natural Resources Conservation Service:
  PLANTS Database- http://plants.usda.gov/
- Pennsylvania Native Plant Society:
  http://www.pawildflower.org/index.htm
- Lady Bird Johnson Wildflower Center:
  http://www.wildflower.org/

Appendix D
Greenroof Survey Data

The following tables contain the data presented in Chapter 4: Greenroof Plant Survey.

Bee Visit data.

	Survey						
Cultivar	**2-Jul**	**9-Jul**	**18-Jul**	**29-Jul**	**Total**	**Average**	**St. Dev.**
Delosperma 'Basutoland'	0	0	0	0	0	0.00	0.00
Delosperma cooperi	0	0	9	0	9	2.25	4.50
Phedimus takesimensis 'Golden Carpet'	**13**	3	5	5	26	6.50	4.43
S. 'Matrona'	0		0	1	1	0.33	0.58
S. album	**18**	3	13	8	42	10.50	6.45
S. album 'Coral Carpet'	10	3	0	0	13	3.25	4.72
S. album 'Murale'	8	16	6	2	**32**	8.00	5.89
S. album 'Red Ice'	9	**30**	3	1	43	10.75	13.28
S. diffusum			0	0	0	0.00	0.00
S. hybridium 'Immergrunchen'	0	0	0	0	0	0.00	0.00
S. kamtschaticum	2	1	21	9	33	8.25	9.22
S. kamtschaticum floriferum 'Weihenstephaner Gold'	2	0	**6**	**0**	8	2.00	2.83
S. middendorffianum 'Diffusum'	0	0	0	0	0	0.00	0.00
S. ochroleucum			0	0	0	0.00	0.00
S. rupestre 'Angelina'	0	0	2	0	2	0.50	1.00
S. rupestre 'Blue Spruce' (syn. S. reflexum)	**13**	2	0	0	15	3.75	6.24
S. sexangulare	**18**	0	1	2	21	5.25	8.54
S. spurium 'Fuldaglut'	0	0	2	2	4	1.00	1.15
S. spurium 'John Creech'	9	0	2	1	12	3.00	4.08
S. spurium 'Roseum'	**17**	**17**	**22**	**11**	67	16.75	4.50
S. spurium 'White Form'	9	9	**35**	**10**	63	15.75	12.84
S. urvillei	4	0	0	0	4	1.00	2.00
Talinum calicynum	10	0	19	8	**37**	9.25	7.80

Bloom coverage data..

	Survey						
Cultivar	**2-Jul**	**9-Jul**	**18-Jul**	**29-Jul**	**Total**	**Average**	**St. Dev.**
Delosperma 'Basutoland'	0.00	0.00	0.00	2.50	0.38	0.62	1.248
Delosperma cooperi	**25.00**	10.00	**30.00**	8.75	10.10	18.44	10.675
Phedimus takesimensis 'Golden Carpet'	**22.50**	1.75	10.00	6.25	5.46	10.12	8.913
S. 'Matrona'	0.00		0.00	10.00	1.80	3.33	5.774
S. album	**27.50**	**28.25**	**20.00**	**15.00**	12.23	22.69	6.338
S. album 'Coral Carpet'	16.25	12.75	1.50	2.74	4.48	8.31	7.307
S. album 'Murale'	14.50	6.25	8.75	1.25	4.14	7.69	5.510
S. album 'Red Ice'	19.00	**41.50**	8.75	3.74	9.83	18.25	16.752
S. diffusum			0.50	0.00	0.22	0.25	0.354
S. hybridium 'Immergrunchen'	0.00	0.00	0.00	0.25	0.03	0.06	0.124
S. kamtschaticum	2.33	1.75	**21.25**	**18.75**	6.25	11.02	10.421
S. kamtschaticum floriferum 'Weihenstephaner Gold'	0.75	0.50	10.00	0.33	1.65	2.89	4.739
S. middendorffianum 'Diffusum'	2.00	0.00	5.00	4.99	1.62	3.00	2.447
S. ochroleucum			0.00	0.00	0.00	0.00	0.000
S. rupestre 'Angelina'	3.33	0.25	1.25	0.00	0.57	1.21	1.516
S. rupestre 'Blue Spruce' (syn. S. reflexum)	6.75	0.25	3.75	2.75	1.82	3.37	2.689
S. sexangulare	**20.50**	5.50	16.25	11.25	7.21	13.37	6.469
S. spurium 'Fuldaglut'	0.00	0.00	1.25	2.75	0.54	1.00	1.306
S. spurium 'John Creech'	10.00	2.50	6.25	1.25	2.69	5.00	3.953
S. spurium 'Roseum'	**31.75**	**28.75**	**20.00**	8.75	12.03	22.31	10.326
S. spurium 'White Form'	11.75	10.00	**22.50**	**21.67**	8.70	16.48	6.519
S. urvillei	10.25	0.75	0.00	0.00	1.48	2.75	5.012
Talinum calicynum	4.00	0.00	17.50	**28.75**	6.77	12.56	13.135

Bee Density

	Survey			
Cultivar	**2-Jul**	**9-Jul**	**18-Jul**	**29-Jul**
Delosperma 'Basutoland'				0
Delosperma cooperi	0	0	0.3	0
Phedimus takesimensis 'Golden Carpet'	0.5778	1.71429	0.5	**0.8**
S. 'Matrona'				0.1
S. album	0.6545	0.10619	0.65	0.5335
S. album 'Coral Carpet'	0.6154	0.23529	0	0
S. album 'Murale'	0.5517	2.56	0.6857	**1.603**
S. album 'Red Ice'	0.4737	0.72289	0.3429	0.2672
S. diffusum			0	
S. hybridium 'Immergrunchen'				0
S. kamtschaticum	0.8571	0.57143	0.9882	0.48
S. kamtschaticum floriferum 'Weihenstephaner Gold'	**2.667**	0	0.6002	0
S. middendorffianum 'Diffusum'	0		0	0
S. ochroleucum				
S. rupestre 'Angelina'	0	0	**1.603**	
S. rupestre 'Blue Spruce' (syn. S. reflexum)	**1.926**	**8**	0	0
S. sexangulare	0.878	0	0.0615	0.1778
S. spurium 'Fuldaglut'			**1.6**	0.7279
S. spurium 'John Creech'	**0.9**	0	0.3201	**0.802**
S. spurium 'Roseum'	0.5354	0.5913	**1.1**	**1.258**
S. spurium 'White Form'	0.766	0.9	**1.556**	0.4615
S. urvillei	0.3902	0		
Talinum calicynum	**2.5**		1.0857	0.2783

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