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Assessing Green Roof Benefits for Pollinators

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Abstract

Through a partnership with local business Living Roofs Inc, a four-year-old green roof was observed for pollinator use. The primary goal of this project was to study the practical application of urban agriculture and its impact on pollinators. The green roof, which is a plant guild that is similar to a meadow, provides habitat and food support for local wild pollinators through using plants that are native to Western North Carolina, and are favored by a variety of different pollinators, including, but not limited to honey bees, pollinating flies, and butterflies. Plants on the roof that were studied include *Allium schoenoprasum,* commonly known as chives, *Petrorhagia saxifrage,* or petrorhagia, *Asclepias tuberosa,* or butterflyweed, and *Sedum sp.*, or stonecrop. Research was conducted on the current populations of pollinators that visit urban Asheville and were monitored over the course of the project. The green roof was found to be effective habitat for many kinds of pollinators in the Hymenoptera and Diptera orders. The secondary goal of this study was to build on the existing literature surrounding the relationship between vegetated roofs and pollinators, which is slightly lacking.

1. Introduction

1.1 Values of Pollinators

Although they may seem unrelated, the modern global economy relies on pollinators. Pollinators are a keystone species, necessary for the reproduction of approximately 85% of the Earth's flowering plants[1]. Agriculture has a crucial role in the economies for many developing countries[2], and currently, pollinators are relied on by 70% of agricultural plants[3]. In a study done in 2009, researchers found that the estimated economic value of pollinators worldwide at the time was 170.3 billion USD[4]. It is widely accepted that pollinators are an essential element of most ecosystems. However, there are currently over 40 species of pollinators federally listed as endangered or threatened[5]. With the steady increase of development over the course of human history, it was noticed that pollinators have been suffering due to numerous effects caused by urbanization. Factors such as habitat fragmentation, loss of habitat, changes in land use, agricultural techniques, and the use of harmful chemicals are all causing the decline in pollinator populations[6]. The loss of pollinators has major negative implications for our food supply, especially for the persistence of fruits[6]. There are many different types of pollinators. Invertebrates, birds such as hummingbirds, bats, and even large mammals can be pollinators[7]. However, in the study area on the green roof in downtown Asheville, North Carolina, invertebrate pollinators were the only relevant group. Other types of pollinators are either not found in the area or were not targeted by the green roof planning. Invertebrate pollinators are likely to have the most substantial negative impact of all pollinators if their decline continues[6].

Many studies have been completed on the impacts that these obstacles have on pollinators, particularly bees[2,3,7,9,11,12]. These have paved the way for further research by creating different methodologies that can be used when studying pollinators, and compiling data that lends itself to a bigger picture. In a study completed in 2006, researchers compared species incidence and abundance to evaluate the impact of habitat fragmentation on bees in the desert[8]. This study lays the groundwork for further research to be completed. Another study was conducted in San Francisco in 2015 that evaluated the impact of pollination on urban agriculture, specifically tomato plants. This study concluded that pollinators could provide the services that urban plants need to thrive, and that an increase in floral density had a positive correlation with the number of pollinators that visited the garden[9].

All in all, it can be inferred that pollinators are of great importance to the modern world. The rate at which their habitat is being destroyed and they are being lost is alarming, and many researchers are trying to find new ways to support pollinators to mitigate the harm they are experiencing. One of the possible approaches that has not been studied much is urban agriculture. Green roofs specifically have great potential to make a big positive difference in the world of invertebrate pollinators.

1.2 Vegetated Roofs

There are a few different types of urban agriculture that can be created. Front gardens, urban parks, balcony gardens, living walls, and green roofs all fall under this broader category. For the purposes of this study, green roofs specifically were the only type of urban agriculture observed. However, the results found in this study could certainly be applied to the other types with further research. While urban agriculture has been around for approximately 2,000 years, since Mediterranean palaces trained vines to cover their walls, modern urban agriculture for the purpose of improving the environmental impact of development is a relatively new concept, beginning in the 1980s[10]. Since then, many articles have been written on this topic, over 700 by 2008[11]. However, few have studied the direct relationships between green roofs and pollinators. When discussing urban agriculture in general, urban parks and front gardens have received the most attention.

In the review of literature that was done for this study, only one article was found that addressed the ability of living walls to host pollinators. This study was completed by a researcher in Sweden who sent a survey out to different living wall manufacturers that contained questions regarding the types of plants that living walls can host[11]. The results of this study were inconclusive. The literature regarding the ability of living walls to host pollinators is greatly lacking.

Green roofs have had more research done on their impact on pollinators than vertical gardens. In general, green roofs have been found to be incredibly beneficial to urban areas. Studies have shown that the implementation of green roofs can have impacts such as "stormwater management, reduced urban heat island, increased urban plant, wildlife habitat and roof life, enhance the air and water quality and quality of life, decreased the energy consumptions costs of the building, decreased the noise pollution, procreates the recreational activities and increased the green areas and aesthetic value in urban environments."[12] Cities all over the globe have begun to implement green roofs into the skyline. New York City passed a law in 2019 requiring all new buildings to have green roofs[13], and many other cities have done so as well.

A study done in 2009 in Toronto, Ontario, Canada surveyed green roofs for bee abundance and species diversity and determined that green roofs are an effective way to provide habitat for bees living in urban areas[14]. This study evaluated the 6 different sites: two green roofs, and 4 other green areas. The researchers used species abundance, richness, the Shannon-Weiner diversity index, and the evenness index to interpret their results. It was found that the green roofs were able to host similar bee populations to the other green spaces.

The overarching goal of this project was to explore a relatively untouched method of pollinator conservation, a topic that is becoming more important as pollinator species continue to decline. Many other resources have been created as references on how to support pollinator populations. For example, the Xerces Society has published numerous guides and resources on pollinator conservation on their website, such as a habitat assessment guide[15], which provides a list of characteristics that improve the benefit to pollinators of yards, gardens, and parks. The Xerces Society has also published an article on how to improve nest sites for native nesting bees[16], and a species profile of a wide range of at-risk pollinators[17]. These are just a few of the many resources the Xerces Society has created to inform the conservation of pollinators. A paper was published in 2013 by the University of Georgia that specifically addresses bee conservation in the southeast, and not only provides a list of the most impactful southeastern bees, but also a list of plants that people can plant to support southeastern bee populations[18].

While there is extensive literature on the conservation of pollinators, truly little of that literature applies to green roofs, and almost none of it addresses the conservation of pollinators in the context of living walls. While there is literature regarding urban agriculture, most of it is unrelated to the topic that this study is about. This project provides a perspective that currently does not exist within the scientific community and fills gaps in the existing literature.

2. Methodology

2.1 Green roof observations

A three-year-old green roof was observed during the months of June and July 2020. The green roof, called Garage Apartments, was built by Living Roofs Inc. in 2017 on the roof of a garage/apartment building in the urban area of Asheville, North Carolina. This roof is 7,400 square feet and sits next to a pool deck on the third floor of the Aloft Hotel in downtown Asheville. The roof utilizes perennial plants and grasses that are native to the area and is an imitation of a pollinator meadow[19]. The roof was specifically designed to provide food and habitat for local pollinators. The plants that live on the roof were either planted by Living Roofs Inc. or self-seeded. The green roof is a plant guild consisting of different layers. There is an autumn perennial layer, summer perennial layer, and spring perennial layer, as well as a ground cover layer where the plants are shorter. The taller plants that were planted on the vegetated roof include *Solidago shortii, Rudbeckia fulgida, Monarda fistulosa, Eryngium yuccifolium, Pycnanthemum muticum, Liatris spicata,* and *Asclepias tuberosa.* The ground cover consisted of *Allium schoenoprasum, Deschampsia cespitosa, Deschampsia flexuosa, Eragrostis spectabilis, Sedum sp.,* and *Petrorhagia saxifraga*. The majority of the plants present in the quadrat studied were part of the ground cover species. However, there was one spring perennial layer species present as well. The roof receives weekly maintenance that includes weeding. It has an automatic irrigation system.

A 3-foot x 3-foot plot was observed in this study. The same plot was observed every time. A portable marker and measuring tape were used each day that observations were done to ensure that the exact same 3x3 ft quadrat was observed every time. The research plot was chosen based on its proximity to the observation area, as access to the roof was limited. The plot was on the edge of the meadow. A small gravel area separated the observation area from the meadow, but it was not included in the research plot. Its edge lined up with the edge of the meadow, where plants began. This plot was used to create an accurate representation on a small scale of what would be observed in the entire rooftop garden, due to the fact that it would be impossible to observe the entire roof for this research. The use of plots has been effective for other pollinator studies in the past. For example, it was used by researchers in 2013 to observe the abundance of pollinators in a blueberry field[20].

Pre-observation questions were noted each day, which included the following: the date and time; a description on the weather; an identification of all plants in bloom; how many inflorescences each plant had; and the stage of bloom they were in. Any major changes in landscape, and any newly dead plants, were also recorded. These questions were developed from reviewing other studies that have been done on pollinators[21]. Observations then proceeded for an hour each time. During the observations, the 3x3 ft area of study was watched for visitations from any kind of pollinators. Visitations were defined as any pollinator visiting a plant that it had not been observed on in the last 30 seconds. This definition was created for this study and used because it was impossible to distinguish whether a visitor was new or had been previously observed. Pollinators were identified using local pollinator guides such as the U.S. Forest Service's guide to native southeastern United States pollinators[21], and the guide provided by Bee City USA[22]. Some pollinators were identified specifically, such as carpenter bees, honey bees, and yellow jackets. Other pollinators were too small, too quick, or not distinguished enough to identify to that degree. Those pollinators were identified using broader terms, such as "fly" or "wasp".

Observations were carried out from June 2020 to August 2020, and were conducted multiple times a week during this period, weather permitting. The time of day varied throughout the observation process. While about half of the observations were conducted in the late morning, Living Roofs Inc. was interested in whether different times of day had varied amounts of pollinators. Therefore, half of the observations were conducted in the mid-afternoon.

2.3 Statistical Analysis

Once data on the green roof was collected, it was evaluated based on the Madre et al. method, which assessed the potential that urban agriculture has as habitat for spiders and beetles[23]. The frequency of pollinator visits was evaluated by determining the percentage of visits per plant species and the percentage of visits per pollinator orderF. The data was also used to compare variables, such as the frequency of different pollinators relative to other species, the frequency of pollinators relative to the amount of blooms provided by the plants, and the frequency of pollinators compared to the time of day and weather. These variables were evaluated for significance.

3. Results

3.1 Green Roof Visits by Pollinator Category

Throughout the course of observations, a total of 816 pollinator visits were recorded, averaging 102 visits per hour. It is worth noting that this total includes two observation days which were cloudy and had very few pollinator visits. Overall, on the green roof, four different orders of pollinators were identified on the four species of plants within the research quadrat. The most abundant order of pollinator by far was Diptera, commonly known as flies. Diptera comprised 70.7% of the total pollinators observed, while Hymenoptera (bees and wasps) made up 27.2%, the other 2.0% being Coleoptera, or beetles (Figure 1). Only one Lepidoptera individual was observed over the two months. Out of the 16 instances a Coleoptera individual was observed, 15 were ladybug beetles, *Coccinella sp*. The Diptera category contains approximately seven different species of flies, including *Eristalis sp.*, *Chironomidae sp.*, and other syrphid flies, otherwise known as flower flies. The Hymenoptera category contained 2 bee species: *Apis sp.* (honey bees), and *Xylocopa sp.* (carpenter bees), as well as 4 wasp species, including various *Vespula spp.*

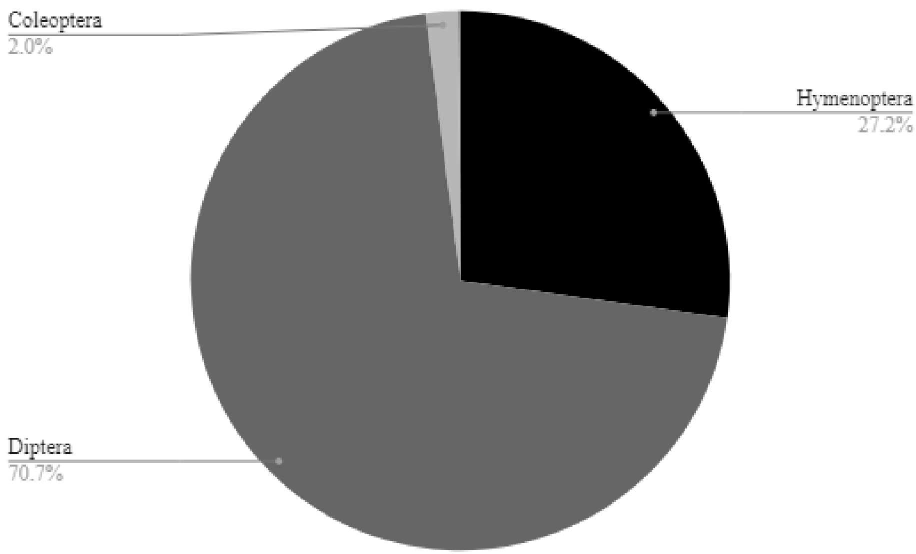

Figure 1. Percentages of total plant visits per pollinator order

3.2 Green Roof Visits by Plant Category

There were four plant species present and flowering in the observation area: *Petrorhagia saxifrage* (or saxifrage pink), *Sedum sp.* (or stonecrop), *Asclepias tuberosa* (or butterfly weed), and *Allium schoenoprasum* (or wild chives). There was a fairly even distribution of visits between all the present flowering species. While *Petrorhagia* was the most frequently visited plant species out of the four (Figure 2), it was rarely visited in the month of June. As the other species began to fall out of season and their blooms disappeared, petrorhagia began to dominate the plot, becoming much more present than the other species.

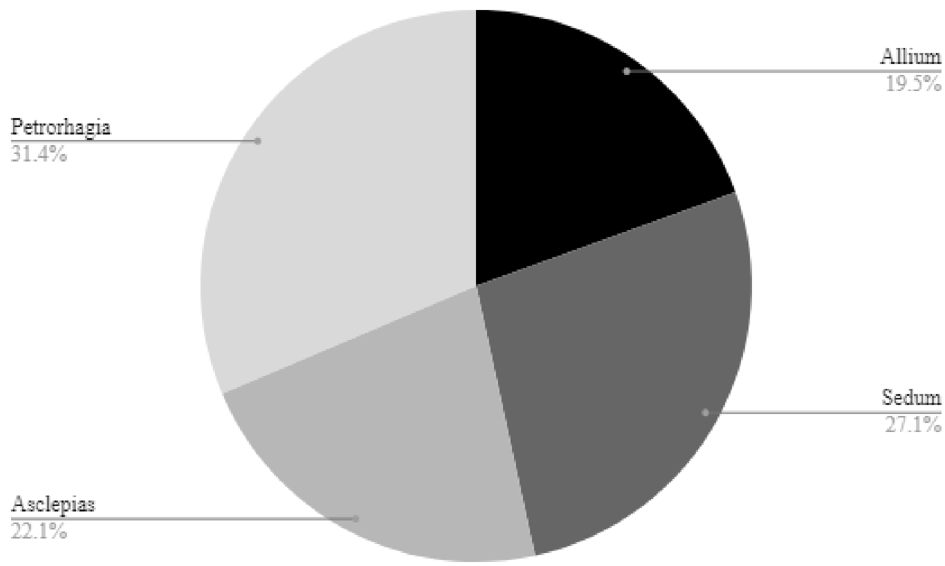

Figure 2. Percentages of total pollinator visits per plant species

Certain plants attract pollinators in different ways. Figure 3 shows which plant was preferred by each pollinator. Hymenoptera were more frequently found on *Allium* than on any other plant, along with Coleoptera. Diptera preferred *Petrorhagia* to any other plant species, and avoided *Allium*.

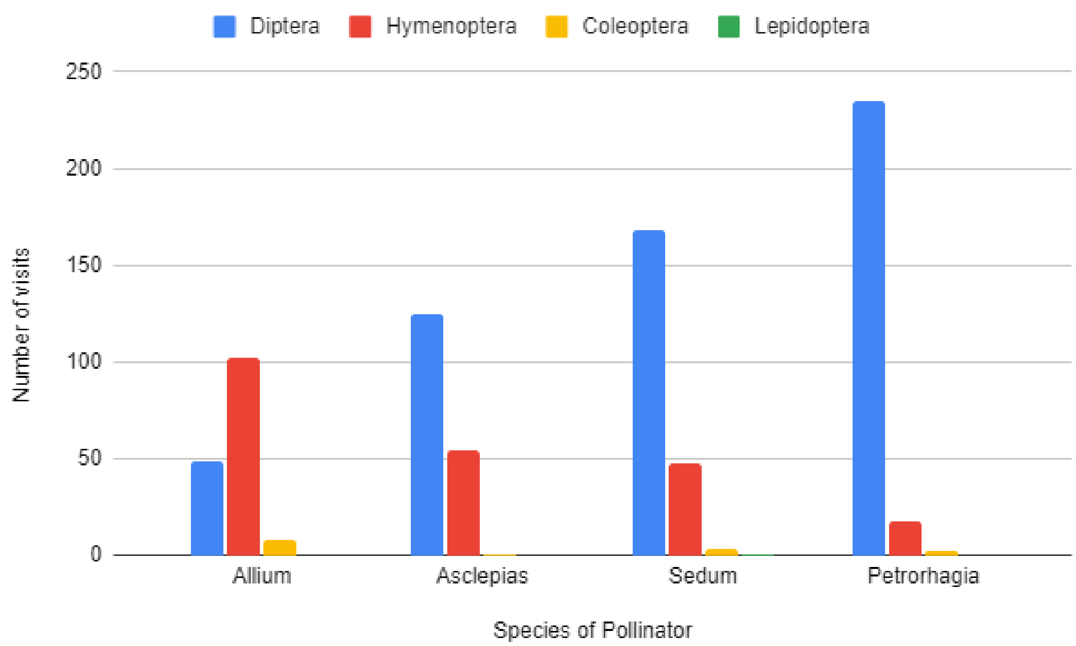

Figure 3. Pollinators' plant preferences.

3.3 Rate of Pollination vs. Number of Blooms (Inflorescences) by Species

There was a suspected correlation between the number of blooms produced by each plant and the frequency at which it was visited. The graphs below compare the two variables, with a trendline and a corresponding r-squared value to help determine correlation. It may also be important to note that all days observed except for two, the weather was warm and sunny. The other two days, which were both cloudy, had the lowest frequency of visits. Figure 4 displays the number of blooms on the x-axis vs the number of visits on the y-axis for *Allium*. The trendline has an r-squared value of 0.301. The p-value for this data was 0.1259, showing that this relationship is not significant.

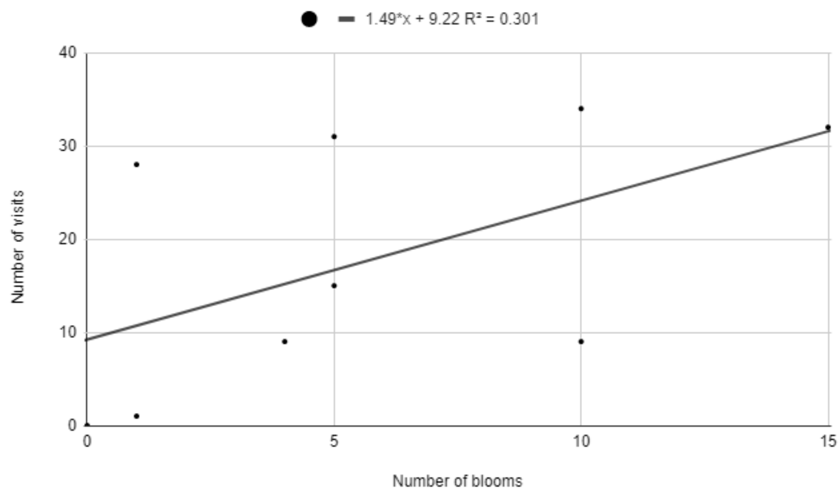

Figure 4. Allium.

The trendline in the observations of *Sedum* has a steeper slope than the *Allium* trendline (Figure 5). The r-squared value for this trendline is 0.755. Most of the data seems to be closely aligned with the trendline, however there were two days where the number of visits was very low, while the number of blooms was average. These data points represent the two cloudy days. The p-value for this data was 0.0023, which means that this relationship is significant.

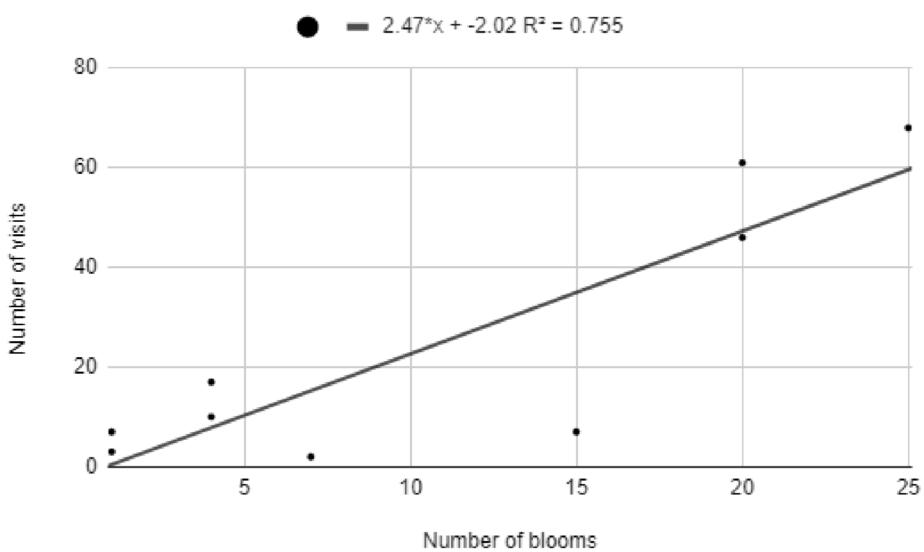

Figure 5. Sedum.

Asclepias has a much less dramatic trendline slope than any other plant species (Figure 6). The r-squared value for the trendline is 0.01, and the p-value for this data was 0.8010. This relationship is not significant.

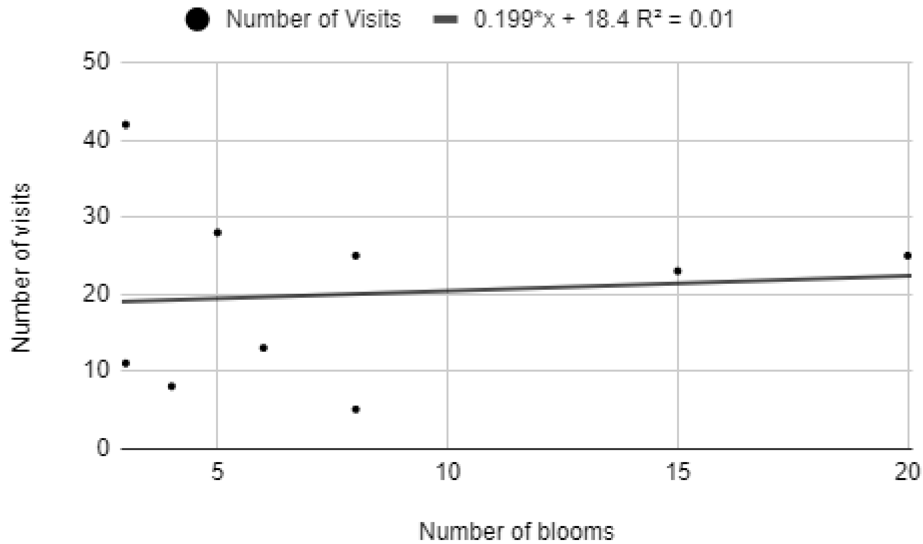

Figure 6. Asclepias.

Petrorhagia shows a slight correlation between the amount of blooms and the number of visits (Figure 7). The number of blooms petrorhagia had were counted as estimates due to the sheer amount of blooms per plant. The flowers are tiny and singular at the terminal end of the stalk. When the plant was in full bloom, a count was taken as accurately as possible, with recognition that it would not be exact. The p-value for this data was 0.16697290. which is also an insignificant relationship.

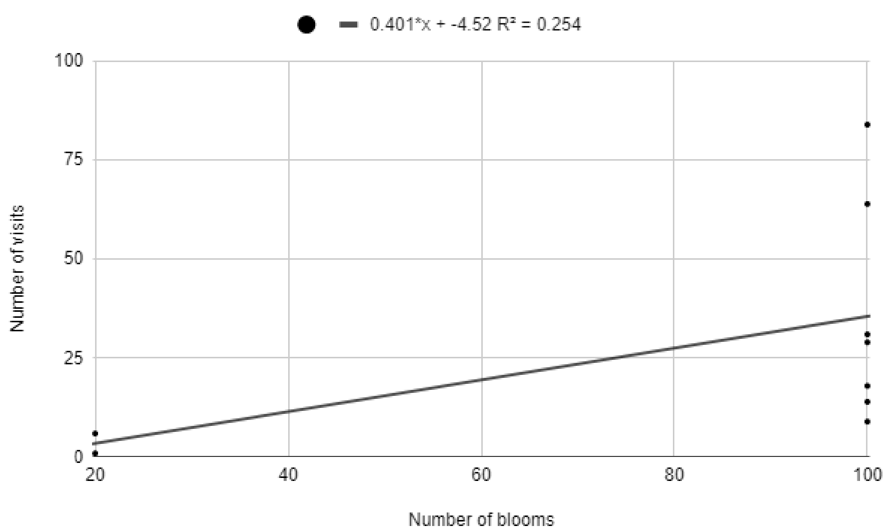

Figure 7. Petrorhagia

3.4 Time of Day vs. Number of Pollinator Visits

Another variable that potentially had additional impact on the number of pollinators observed is the time of day that observations took place. While all observations took place within the same four hour window of 10:00 am to 2:00 pm, it is possible that pollinators are more active at one time of day than they are at another. Therefore, the following figures (Fig. 8 and Fig. 9), compare the time of day the observations took place to the number of pollinators that were observed at those times. It is worth noting that the observations that took place at 10:50 am and 11:37 am were taken on cloudy days.

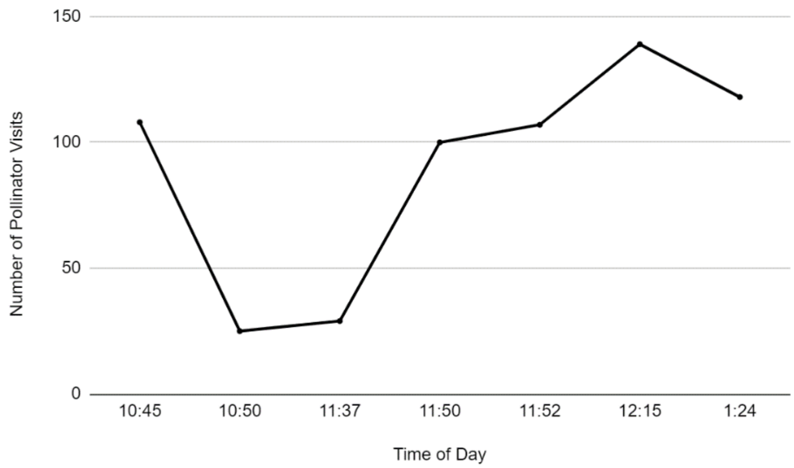

Figure 8. Time of day vs. number of pollinator visits

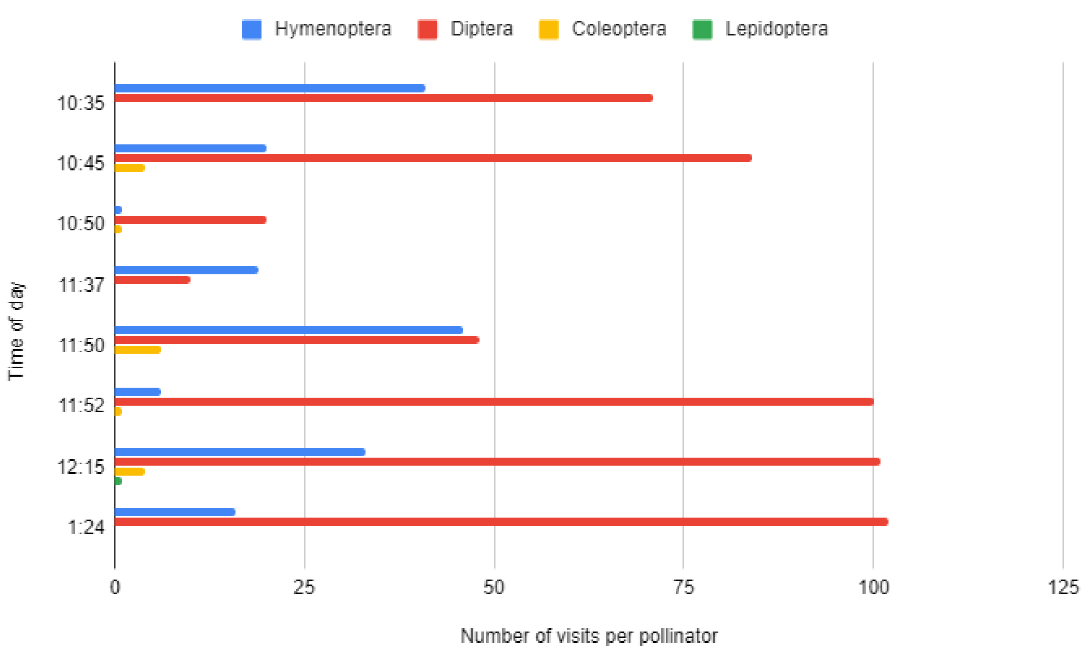

Figure 9. Time of day vs number of visits per pollinator

4. Discussion

4.1 Pollinators present on the green roof.

There are 6 main types of insect pollinators native to Western North Carolina. They are beetles, bees, flies, butterflies, moths, and ants[8]. Out of these 6 categories, during my study period only 4 were present on the green roof. Butterflies and ants were never observed.

The most common order of insects observed was Diptera, or flies. People often picture the common housefly when talking about flies, which means flies are often not expected to be pollinators. There are hundreds of different species of fly, and some make great pollinators. One particular kind of fly, flower flies (family Syrphidae), are bee mimics. They are yellow and black striped, slightly hairy, and have a sponging mouthpart they use to drink nectar[24]. This family of flies, which includes the hoverfly and the drone fly, was the most abundant on the green roof. Other types of flies observed included *Eristalis sp.* and *Chironomidae sp.* Flies can be effective pollinators, especially if they have hairs on their body and are nectar-drinkers. However, flies are limited by only being able to fly short distances[8]. This makes plants with bundles of blooms (infloresences) where multiple flowers are close together better suited for flies.

Also present on the vegetated roof during my study were Hymenoptera, the second most abundant pollinator in my study. This order includes both bees and wasps, as well as ants. The honeybee, *Apis sp.*, the bumble bee, *Apis mellifera*, and the carpenter bee, *Xylocopa sp.* were the only species of bee observed. Bees are generally believed to be the most effective pollinators, especially for plants that target them specifically[25]. Their hairy bodies and the sticky pads on their back legs allow them to collect pollen and spread it to other plants[8]. Honeybees tend to prefer to only pollinate the same species of plant within a short time period, which means the pollen from that plant is more likely getting spread to individuals from the same species[26, 33], which is more efficient than it getting spread to plants that wouldn't have any use for it.

Honeybees were prevalent on the green roof on some days more than others. This could be due to many variables. It is possible that a more valuable resource for food became available during the observation period that drew the honeybees more effectively than the green roof. It is also possible that plants present of the green roof, but not present in the observation plot, attracted the bees away from plants in the observation plot. Carpenter bees stayed a consistent pollinator over the course of the study. Unlike the very social honeybee, carpenter bees are a solitary bee species[23]. This could mean that the distractions the honeybees may have gone for as a group would not have had the same strong impact on the presence of carpenter bees.

The wasps observed on the green roof mostly included *Vespula spp.*, or yellow jackets. There were various species of yellow jackets present. While these insects may not be considered pollinators by most, wasps can be incidental pollinators. Yellow jackets are scavengers, meaning they will eat almost anything that is made available to them, including other insects, honey, nectar, and pollen[27]. They may not specifically and exclusively eat nectar or pollen, but they still do, and in the process can accidentally pollinate[28]. Wasps were only counted if they were clearly landing on flowers.

Beetles, like wasps, are also incidental pollinators. Beetles were evolutionarily the first insect pollinators to exist. They are generalized and are clumsy fliers, sometimes called the "mess-and-soil pollinators"[8]. Those traits, plus their smooth bodies, make them less effective pollinators than bees or flies. Ladybugs, or *Coccinella sp.*, were the most abundant beetle observed. Ladybugs are carnivores, eating aphids. However, like wasps, they can accidentally pollinate while they are eating. Conversely, however, because some beetles eat plant parts needed for reproduction, they can also do more damage than good by chewing away a plant's ovaries[8].

A singular moth was observed over the course of the project, species unknown. While moths are great pollinators, their hairy bodies collecting pollen easily, they are typically nocturnal, so it stands to reason that moths may visit the green roof, but night observations would be necessary to determine that[8]. Butterflies were not observed at all on the green roof, which was a very unexpected outcome of the study. Many plants on the green roof specifically target pollinators in the Lepidoptera order, such as *Aclepias tuberosa*. It may be beneficial to look into ways to attract butterflies to rooftop meadows. It is possible that aspects of green roofs exclude butterflies from being able to pollinate. This could be due to the height of the roof and crosswind, or because the roof is too separated from natural butterfly habitat being in the middle of downtown Asheville. Butterflies are very important pollinators and some species of butterfly, especially the monarch, are suffering from habitat destruction and loss of food sources. Milkweed, another plant species in the *Asclepias* family, is very valuable to monarchs. It would be interesting to see if milkweed could survive on a living roof like the one studied, and if it would attract more butterflies to the roof. Ants were also not present on the roof. While ants can pollinate, they are ineffective at it, and can also be damaging to plants. They are generalists and do not suffer from habitat fragmentation the way other insects might.

4.2 Plants Species Popularity with Pollinators

All present flower species had similar rates of visits total. *Petrorhagia* was visited the most often, 4.3% more than *Sedum*, and 11.9% more than *Allium*, the plant with the least visits. Plants have individual "pollination syndromes", which are evolutionary adaptations to target specific pollinators and discourage unwanted pollinators[29]. Many factors go into what plants pollinators prefer, and different pollinators have different needs. One big factor is flower shape. A tubular flower, such as *Asclepias tuberosa*, will attract insects with proboscis, as their long mouthpart allows them access to the nectar reward the plant provides for pollination. An irregular flower with a large bottom petal may act as a landing pad for larger, clumsier beetles[8].

Another attractor for pollinators is scent. Plants produce sweet scents to alert nearby pollinators that they have nectar. Some plants even produce a rotten meat smell to trick carrion flies into pollinating them[8]. When an insect's chemoreceptors pick up the scent of a flower, they can determine whether that plant will be a good food source. If the answer is yes, the insect will land on it and the plant will be pollinated. Color also helps insects find food. Some flowers will have markings called nectar guides that the insect can follow to find the jackpot. Additionally, things like hairy stems and chemical defenses can deter unwanted pollinators. All these factors make up the pollination syndrome that determines whether a plant will be attractive to pollinators.

Flies were seen most frequently on *Petrorhagia* in my study. *Petrorhagia* is a tiny, light pink regular flower that grows terminally on the stem. It does not have an odor. The flower is so small that it would make pollination difficult for larger insects such as bees and butterflies. It is possible that this plant is so popular among flies due to the lack of competition from other insects. It can be a reliable easy food source in an area that would otherwise be highly competitive. It is also worth noting that *Petrorhagia* was not as popular in early June when other plants were thriving. However, as the season got later, it became the most available food source when other flowers started to wither.

Allium was the most popular plant among the Hymenopteras. The *Allium* has an inflorescence of flowers at the terminal end of the stem, with 30-50 bell-shaped flowers occurring so close together that at a glance it looks like one large flower[30]. The stem of the *Allium* is thicker than *Petrorhagia*. It is possible that due to the larger landing area and the thicker stem, bees and wasps preferred Allium because it was easier to land on. Additionally, bees can lap up nectar with a tongue-like mouthpart. This may have been easier to fit into the tiny openings of the allium flowers than other insect's mouthparts. Bees also visited *Asclepias* and *Sedum* on the green roof. *Asclepias* and *Sedum* flowers also grow in an inflorescence, although it is flatter than the spherical *Allium* inflorescence. The tubular shape of *Asclepias* is also conducive to the lapping mouthparts of bees. *Allium* was also preferred by beetles. This is likely because of the large flower being easier to land on, and it is possible that there were more aphids on the *Allium* plant.

4.3 Number of Blooms Impact on Number of Visits

It was suspected that the number of blooms a plant had at a particular time impacted the number of visits it received. When the data was analyzed for each plant to see whether there was a correlation between these variables, there were mixed results. *Sedum* had a very high level of correlation, with an p value of 0.0024, which means that the number of pollinators increases significantly with the number of blooms. *Asclepias*, *Allium*, and *Petrorhagia* had no correlation. When a plant is not flowering, it is impossible to pollinate. Pollen is the male reproductive structure of a plant, and when it is not in season for reproduction, it will not produce pollen. When it is being pollinated, there are many other factors that will have an impact on number of visits from pollinators, such as weather, the types of pollinators that are in the area, and what plants it is competing with. These variables can change daily. While the number of blooms certainly has an impact on whether a plant is pollinated, it is inconclusive what scale these variables affect each other.

4.4 Constraints of the Study

Due to the nature of the study, the data could benefit greatly from further research. The observations had to be done on the margin of the green roof, because the observer did not have access to the meadow itself. This meant that the observation plot did not include all the plants present on the green roof, such as *Monarda sp.* and common mullein. This also made identifications of the pollinators more difficult. Pollinators were not able to be collected to determine their exact identification and whether they were actually transporting pollen between the plants. Additionally, time constrains limited the amount of observations that could be done. A more extended observation period starting earlier in the year would provide more insight into the pollinator usage of the green roof. No evaluation was done of the surrounding area proximal to the green roof, so that could have unseen impacts on the pollinators and their behaviors.

5. Conclusion

This study gives some important insight into whether green roofs provide a sustainable habitat to pollinators. Throughout the observations on the green roof, a total of 816 pollinators were recorded, which indicates that using urban spaces agriculturally can have a positive impact on pollinator populations. Urban areas can fragment the habitats of organisms, disallowing them to access all the resources needed to survive. Green roofs have a great potential that is underappreciated currently. If all the roofs that could sustain pollinator habitat were used for that purpose, it would have a huge impact on pollinators' ability to thrive in a constantly developing world. The green roof that was observed throughout this study was four years old. Minimal upkeep has been done on the roof over that time, with only minor weeding and aiding plants to spread as needed[31], and it provides added benefits to the building such as rainwater retention and cooling. Creating a strip of urban agriculture through a concrete jungle can provide these pollinators with the resources needed to not just survive, but thrive.

6. References

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