Pollinator Habitat on the University of Richmond Campus:

Assessing the Success of Pollinator Meadows in the Gambles Mill Eco-Corridor

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Abstract:

Globally, many insect pollinator populations are declining in response to anthropogenic harms including habitat loss due to land-use change and urbanization, climate change, increasing pesticide use, invasive species introductions, and increased pathogen transmission. In order to protect these insects, and the benefits they provide through pollination, habitat must be protected. Much of the effort to protect insect pollinator habitat is occurring in urban areas, where pollinators may struggle to find the resources they need to survive. The purpose of this study was to assess the success of three pollinator meadows created within the Gambles Mill Eco-Corridor (Eco-Corridor) on the University of Richmond (UR) campus in Richmond, VA. These meadows were designed to provide habitat to insect pollinators as part of UR's recertification process as a Bee City USA certified Bee Campus. In order to assess the quality of habitat provided by these meadows, they were compared to three other sites on campus containing managed flower beds. At each site, five 1x1 meter quadrats were laid and the percent ground cover, individual number of plants, number of plant species, and presence of pollinators within each quadrat were recorded. Each presumed plant species was photographed and later identified, and its nativity to the area was noted. Results of these surveys suggest that the pollinator meadows do provide better habitat for insect pollinators than managed flower beds on campus. This information may be used to suggest to the campus Landscape Services Department ways to improve managed flower beds in terms of pollinator habitat. However, this study also revealed flaws within the pollinator meadows, and indicates a need for further planting projects to improve habitat on campus.

Introduction:

Pollination is the ecological process by which pollen is transferred between the reproductive organs of plants, thus enabling fertilization and sexual reproduction (Perkins, 2014). Pollination can occur via abiotic forces, such as wind, but can also occur as zoophily, the process in which animals are responsible for pollination (Ollerton, 2017). Globally an estimated 78% of plants in temperate communities rely on zoophily for pollination, and an estimated 94% in tropical communities (Ollerton et al., 2011). The majority of animal pollinators are insects, with butterflies, moths, and bees receiving much more attention in research on pollination than beetles or flies, which can also act as pollinators (Ollerton, 2017). From an ecocentric perspective, pollination is essential to successful plant reproduction, which provides the basis for all trophic pyramids. Pollinators and plants have mutually dependent relationships, so there is a positive relationship between plant diversity and pollinator diversity and abundance (Weiner et al., 2014). Specifically, reduced pollinator availability can lead to reduced plant diversity and abundance by reducing community-wide seedling diversity, which is important to plant population persistence (Lundgren et al., 2016). Without insect pollination, there would be fewer plants, and therefore fewer resources to support the animals which together make up global ecosystems. Additionally, close plant-pollinator relationships can lead to diversification of species through coevolution (Ollerton, 2017). More species of plants and insects are able to support more species which feed on them, thus maintaining healthy ecological communities.

From an anthropocentric perspective, pollination is also extremely valuable. The ecosystems which pollination helps to support can serve as homes, recreational sites, and physical resources to human communities. Though additional studies are necessary to determine exact relationships, evidence suggests that as biodiversity decreases, as is currently the case with pollinators and the plants which rely on them, the processes which support vital ecosystem services, such as crop, wood, and fodder production, resistance to invasion by exotic plants and plant pathogens, carbon sequestration, and nutrient mineralization in soil, become less efficient (Cardinale et al., 2012). Many of the plants which rely on insect pollination to reproduce have medicinal benefits, and there are likely others which have yet to be discovered (Kavanagh & Leung, 2020). Perhaps the clearest link between pollination and human well-being is its relevance to global food production. Insects provide pollination services for 75% of leading global food crops (Rader et al., 2014). Without the pollination services of these insects, food markets around the globe would collapse, and food security would be severely threatened. The economic value of animal pollination of food crops has been estimated at €153 billion – equivalent to about $186 billion – annually (Ollerton et al., 2011). If this estimate were to take into account all the other natural resources humans utilize which rely on insect pollination, such as timber or tourism to ecologically diverse areas, it would be even greater. The introduction of honeybees is the usual solution when native pollinators decline, but even managed hives of honeybees are at risk of collapse due to the same anthropogenic factors which harm native insect pollinators. In some cases, declines in native pollinators and therefore crop yields have led rural farms to employ human pollination, a process which requires employees to pollinate crops by hand, and is incredibly labor intensive and economically unsustainable (Partap & Ya, 2012).

Despite the high value of the services which they provide, pollinators are currently in danger. They are declining on all scales in diversity and abundance (Ollerton, 2017; Potts et al., 2010). The leading cause of pollinator decline is habitat loss and fragmentation due to land-use change and urbanization (Baldock et al., 2015; Rader et al., 2014). Habitat loss, degradation, and fragmentation can lead to reduction in food sources and a lack of sites for breeding, nesting and roosting, all of which harm pollinator populations (Gagliardi & Walker, 2018). As habitat size and connectivity decrease, as is the case with habitat loss and fragmentation, plant diversity and population size generally decrease, which then leads to similar decreases in pollinator diversity and population size (Xiao et al., 2016). Climate change is also a threat to pollination services as it can alter the timing of greening, flowering, and senescence, shorten the overall growing season, and lead to decreased precipitation and therefore plant growth and nectar production capacity in some areas (Dixon, 2012). Other threats to pollinator populations do exist, such as disease, competition from invasive competitors, and pesticide use, but loss of habitat due to land-use change only exacerbates the effects of these threats (Baldock et al., 2015; Gagliardi & Walker, 2018). Specialist species, like monarch butterflies, are generally more sensitive to the negative impacts of land use change and other anthropogenic harms (Winfree et al., 2011). Though it is not feasible to restore all native habitat for insect pollinators globally, or even in central Virginia alone, a key goal of conservation is to restore and manage small areas within hostile landscapes where insect pollinators can find refuge (Ollerton, 2017). These areas could serve as source populations for smaller sink populations living in habitats that have been damaged by land-use change, or could support migratory pollinators as they move across the country. Key features can make areas even as small a garden ideal habitat for native pollinators.

In general, ideal pollinator habitats contain large amounts of plants which can serve as larval hosts and sources of pollen and nectar. Areas with increased plant species diversity and richness have been found to better support rich and stable populations of pollinators, and the number of flowering plant species in a habitat is positively correlated with the number of pollinator species and frequency of pollinator visits in the habitat (Ebeling et al., 2008). It has also been found that wild bees are at much greater risk to competition from managed honeybees when they are in homogenous landscapes with low plant diversity (Herbertsson et al., 2016). Declining populations of wild bees as a result of managed honeybees depleting resources have been recorded in Europe, where both species are native, so it is only more likely to occur within the United States where European honeybees are introduced and therefore niche differentiation has not occurred (Herbertsson et al., 2016).

While plant species diversity and richness are linked to the presence of insect pollinators, not all plants are equally attractive to pollinators. Certain pollinators prefer certain plants and floral forms over others (Ghazoul, 2006). For example, by analyzing pollen in nest provisions, studies have found that the orchard mason bee (*Osmia lignaria lignaria*), which is native to Virginia, prefers Eastern Redbud trees, even over apple orchard pollen (Kraemer et al., 2014). The bees also harvested large amounts of pollen from Oaks, Boxelders, Willows, Ash, and Black Gum, all of which are native to Virginia (Kraemer & Favi, 2005; Plant RVA Natives Campaign, 2020). Monarch butterflies (*Danaus plexippus*), which are of high conservation concern due to decreased breeding populations across the United States, are known to rely on milkweed

(*Alsclepias* sp.) as their larval host plant (Lewandowski & Oberhauser, 2016). Monarch populations do best when there are multiple species of native milkweed available that bloom at different times throughout the breeding season, in addition to other flowers to provide nectar (Lewandowski & Oberhauser, 2016). Shady areas for resting, shallow bodies of water for drinking and bathing, and nesting boxes or bushy areas protected from predators are also features of ideal pollinator habitats (Kavanagh & Leung, 2020).

The purpose of this field survey is to assess the success of the new pollinator meadows in the Gambles Mill Eco-Corridor on the University of Richmond campus. If the right plant species are grown in these pollinator meadows, they have the potential to serve as a refuge habitat for pollinators within an urban area. As urban areas only show signs of growing in future years, it is important to include them in pollinator conservation efforts (Baldock et al., 2015). The University is also in the process of being recertified with the Bee Campus USA program, which aims to create sustainable habitats for pollinators across the country on college campuses as they are often ideal social environments for sustainable action (Bee City USA). This research will reveal if the University meets the requirements for recertification, and help in assessing action taken throughout the past year to comply with certification requirements. During the restoration of the Eco-Corridor, the Bee Campus Committee worked to establish the three pollinator meadows with the goal of supporting local and migrating pollinator species. The success of this project will be examined through this research. Other areas on campus with managed flower beds will also be examined, in order to compare their viability as pollinator habitat to the designated pollinator meadows. The goal of this research is to provide feedback to the Bee Campus Committee and Landscaping teams regarding how campus might be improved in order to better maintain ideal habitat for native pollinators.

I hypothesize that the pollinator meadows will provide more suitable pollinator habitat than the managed flower beds, but that the meadows will require more maintenance than they have received since their installation in order to better promote healthy pollinator populations. The flowers planted in the managed flower beds are usually chosen for aesthetics, and are therefore not necessarily native to central Virginia or especially attractive to pollinators. These flowers are also intended to bloom together at one time, as opposed to emerging at different points throughout the season, which has been shown to benefit pollinators (Lewandowski & Oberhauser, 2016). However, fertilizer use has likely increased flower and blossom size among these beds, which can increase pollen and nectar sources and therefore attract pollinators (Ebeling et al., 2008). The pollinator meadows were purposefully planted with native plants including Virginia Wildrye, Black-eyed Susan, Goldenrod, Swamp Sunflower, and Buttonbush. Native plants have been found to better support pollinator populations, and these plants in particular are known to attract butterflies and bees (Plant RVA Natives Campaign, 2020; Lewandowski & Oberhauser, 2016). Milkweed, which is highly attractive to insect pollinators, particularly Monarch butterflies, was also planted within the Eco-Corridor (Lewandowski & Oberhauser, 2016). However, there is no guarantee that all of these plants survived after being initially planted in the pollinator meadows, and therefore may no longer be present. These native plants may need to be replanted or replaced depending on how well they have done in the pollinator meadows since they were first planted.

Methods:

1. *Site Description*

This study took place on the University of Richmond campus, located in Richmond, VA. The campus spreads across 378 acres and includes 16 formal flower beds, all of which are managed by the Landscape Services Department. The study was conducted in the month of November, during which some of these flower beds were partially empty as the Landscape Services Department was in the process of changing the plants in them. Much of the landscaping done on campus is for aesthetic purposes, as the university takes pride in maintaining what the Princeton Review called the nation's "most beautiful campus" (University News). The Landscaping Services Department follows an Integrated Pest Management plan which does include manually pulling plants which are considered weeds from flower beds and ornamental grasses, as well as the use of herbicides and insecticides when deemed necessary (Sandman 2019).

The Gambles Mill Eco-Corridor restoration project was completed on campus in early 2020. The project was headed by the Office of Sustainability and included the construction of a multi-use path along Gambles Mill trail, removal of invasive plants, management of storm water, and the restoration of Little Westham Creek, which flows out of Westhampton Lake and eventually into the James River. Students, faculty, staff, and community members provided input for the project, and established the following themes as important to the end goal: nature, community, reflection, education, and well-being. Three pollinator meadows were created containing native plants, and native trees, shrubs, and perennials are still in the process of being planted at the wastewater remnant site. Over the summer of 2020, members of the Bee Campus Committee also worked to establish milkweed in the pollinator meadows.

2. *Data Collection*

This study compared pollinator habitat in the three pollinator meadows in the Gambles Mill Eco-Corridor and three managed flower beds on the UR campus. The pollinator meadows were referred to as Pollinator Meadows 1, 2, and 3. Pollinator Meadow 1 was the meadow at the end of the Eco-Corridor, closest to River Road. Pollinator Meadow 2 was the meadow behind the "Pollinators" sign in the middle of the Eco-Corridor. Pollinator Meadow 3 was the meadow behind the community garden, near the start of the Eco-Corridor. The managed beds were the Gumenick Quadrangle, Jepson Quad, and the Cannon Memorial Chapel quatrefoil. The Gumenick Quadrangle was chosen because it is maintained by the Landscape Services Department, contains flowering plants, and includes a fountain which runs during part of the year and may provide an ideal water sources for pollinators. The Jepson Quad was chosen because it is also maintained by the Landscape Services Department, and contains flowers as well as other shrubs and trees that may attract pollinators. Initially, the third managed site was going to be the Westhampton Green. However, at the time of the study some of the managed flower beds on campus were in the process of being replanted, and did not contain as many flowers as usual. The Westhampton Green appeared to have fewer flowering plants than expected, so it was not included in observation. The Chapel quatrefoil was chosen as the third managed site. This site is managed by the Landscape Services Department, included flowering plants at the time of the study, and is located near the two campus bee hives, which are between the Wilton Center and the Steam Plant. This proximity made the Chapel quatrefoil an important site to observe, as it would be a valuable resource for the bees from the nearby hives if it contained ideal pollinator habitat. The relative location of each of these sites on campus can be seen in the map depicted in Figure 1.

Within each of these six sites, observations were made in five 1x1 meter quadrats. Observations were made in Pollinator Meadows 1 and 2 on 8 November 2020, and in the remaining sites on 14 November 2020. In Pollinator Meadows 1 and 2 the quadrats were measured using strides, and in the remaining sites the quadrats were measured using two measuring tapes. Within each quadrat, the approximate percent ground cover, approximate number of individual plants, and the presence of pollinators were recorded. If a pollinator was present, the species was identified using a Virginia Butterflies and Pollinators guide. The number of plant species within each quadrat was also estimated and pictures were taken of each potential plant species. These photos were then entered into the iPhone app PlantNet in order to identify the species. The results from PlantNet were compared with a guide to Native Plants of Virginia's Capitol Region. If the plant species suggested by PlantNet was on the guide and the pictures on the guide resembled those taken in the field then the plant was identified as that species. If none of the results were present on the guide, then they were entered into a Google search. Pictures from Google were reviewed along with information regarding the plant species range in order to determine if it was a match for the photo taken in the field. Some plants were only identified to the genus level if multiple species appeared similar and were common in Virginia. Some plants were left unidentified if it was too difficult to determine the species. The nativity of the plant species identified was then determined using either the Native Plants of Virginia's Capitol Region Guide or a Google search.

3. *Data Analysis*

In order to determine the quality of pollinator habitat provided by each site type (pollinator meadows or managed flower beds) the percent ground cover values observed in each quadrat at a single site were averaged to get a value for that site. Each site was then rated based on its percent ground cover using the Braun-Blanquet scale. The number of individual plants observed in each quadrat were also averaged at each site. Two two-tailed t-tests assuming unequal variances were then performed to determine if any difference in ground cover or number of individual plants between site types was significant. The plant species observed across all of the quadrats of each site type were aggregated to provide total numbers of species observed within both site types for comparison. The percent of species observed which were native to the area was then calculated for each site type for comparison. The presence and species identifications of any pollinators observed in each site type were also compared.

Results:

1. *Percent Ground Cover*

The average percent ground cover values for Pollinator Meadows 1, 2, and 3 were 3.4%, 99%, and 88%, and the values for the Gumenick Quadrangle, Jepson Quad, and Chapel Quatrefoil were 33%, 47%, and 38% (Table 1; Figure 2). The overall average percent ground cover across all of the pollinator meadows was 63.47% and 39.3% across all of the managed flower beds. However, a t-test found that this difference was not significant. The pollinator meadows had greater variation in ground cover, with Pollinator Meadow 1 receiving a + on the Braun-Blanquet scale (the lowest score), while Pollinator Meadows 2 and 3 both received a 5 (Table 2). The managed flower beds were similar in ground cover, and all scored a 3 on the Braun-Blanquet Scale (Table 2).

2. *Plant Abundance*

The average number of individual plants found in a single quadrat within Pollinator Meadows 1, 2 and 3 were 3.4, 11.6, and 13.6, and the average number found within a single quadrat in the Gumenick Quadrangle, Jepson Quad, and Chapel Quatrefoil were 2, 4, and 4.8 (Table 1; Figure 3). The overall average number of individual plants found in a quadrat within a pollinator meadow was 9.53, and only 3.6 for a quadrat within a managed flower bed. However, a t-test found that this difference was not significant.

3. *Plant Species Richness*

A greater number of plant species were observed and identified within the pollinator meadows than in the managed flower beds. Across the three pollinator meadows, 19 species were identified, 7 species were identified to the genus level, and 7 species were left unidentified. Across the three managed flower beds, 13 species were identified, 2 species were identified to the genus level, and 4 species were left unidentified (Figure 4). Table 3 shows a complete list of the plant species identified to at least the genus level in each site type.

4. *Plant Species Nativity*

A greater percent of the plants identified to at least the genus level in the pollinator meadows were native to the area than in the managed flower beds (Figure 5). In the pollinator meadows, about 77% of these plants were native, while in the managed flower beds about 53% of these plants were native. Table 3 includes the nativity of each plant species identified to at least the genus level in each site type.

5. Pollinator Presence

Overall more pollinators were observed in pollinator meadows than in managed flower beds. No pollinators were observed in Pollinator Meadow 1 or the Gumenick Quadrangle. Two skipper butterflies and one buckeye butterfly were observed in Pollinator Meadow 2. One bumblebee was observed in Pollinator Meadow 3. One honeybee was observed in the Jepson Quad. One dronefly and one skipper butterfly were observed in the Chapel Quatrefoil (Table 1).

Discussion and Conclusions:

The results of this study supported the hypothesis that the pollinator meadows contain more ideal pollinator habitat than the managed flower beds on campus. Communities with high plant diversity have been found to enhance pollinator diversity (Ebeling et al., 2008). Plant diversity can be measured in part by examining species abundance – or the number of individuals of a species present in an area – and species richness – or the number of total species present in an area (DeLong, 1996). Plant cover, which in this study was rated on the Braun-Blanquet scale can also be used as an indicator of diversity (Bonham et al., 2004). It has also been found that communities containing high abundances of non-native plants are visited by pollinators significantly less than communities with low abundances of non-native plants or none at all (Dietzsch et al., 2011). Even if pollinators are attracted to non-native plants, they may be invasive and outcompete native plants, leading to decreased biodiversity in the community which would eventually negatively impact pollinator populations. Therefore, because the pollinator meadows had overall higher plant abundance, species richness, Braun-Blanquet ground cover scores, and plant nativity, it can be assumed that they can better support insect pollinators compared to the managed flower beds. More pollinators were also spotted within the pollinator meadows than in the managed flower beds, but this data is limited.

Many of the plants observed in the pollinator meadows are described as beneficial and attractive to pollinators on the *Native Plants for Virginia's Capitol Region* guide. Both *Chamaecrista fasciculata* (common partridge-pea) and *Monarda fistulosa* (wild bergamot) were found in the pollinator meadows and are described as ideal larval hosts for multiple caterpillar species. *Clematis virginiana* (virgin's bower), *Oenothera biennis* (common evening-primrose), *Panicum virgatum* (switchgrass), *Rudbeckia hirta* (black-eyed Susan), and *Vaccinium pallidum* (early lowbush blueberry) were all found in the pollinator meadows and are described as attractive to pollinators including bees, butterflies, and hummingbirds. *Solidago sp.* (goldenrod) was described as both an important larval host for butterflies and source of nectar attractive to other pollinators. Lists like these can be useful even when they are based primarily on general observations and experience of gardeners as opposed to empirical studies. A study found that even when these lists of plants attractive to pollinators are not based on hard data, there is often empirical data which can be found supporting these recommendations, and these lists raise public awareness of the important of protecting pollinators and their habitats (Garbuzov & Ratnieks, 2014).

While the data did suggest that the pollinator meadows provide better pollinator habitat than the managed flower beds, there were multiple limitations to this study which affected the results. The study was conducted during mid-November, which is not the ideal time of year to conduct a pollinator or plant survey. Very few pollinators were spotted during the study, as insect pollinators are much more active during the summer months than in the fall and winter. For this reason, the number of pollinators observed in each site type are not necessarily representative of the pollinator communities which each could support. Additionally, the plant communities in both the pollinator meadows and managed flower beds were not at their peak during the time of observation. In the pollinator meadows, many plants had already died or gone dormant. This made it impossible to fully assess plant abundance or species richness, as some plants which are present in the spring and summer may not have been present at the time of the study. This also made it difficult to identify some of the plants in the pollinator meadows. The majority of the unidentified species in the pollinator meadows were dormant, so they lacked identifiable features like leaves and blossoms. In the managed flower beds, the Landscape Services Department had pulled up many of the flowers which are usually in the Jepson Quad to begin the process of replanting. This decreased ground cover, plant abundance, and species diversity in this site. Some of the plants in the Chapel Quatrefoil were also dormant, making them difficult to identify.

This study was also potentially affected by human error. During the field surveys, it was difficult to count individual plants in the more densely covered quadrats. When grass was covering much of the quadrat, it was counted as one individual unless there were distinct clumps of grass or multiple species of grass. There is likely some error in the counts of plant abundance. There is also likely some error in the plant species identifications. When plants had blossoms or unique leaves it was much easier to identify them using the PlantNet app. When photos were entered into the PlantNet app, multiple results were generated. Often times, more than one of these results were common in the area. When there were not active blossoms or leaves on the plant which was photographed, it was difficult to determine which result was a match. This likely resulted in some error in identifying the species, which would then affect the data regarding nativity across site types. However, this error was constant across all of the sites, so it did not affect either site type disproportionately.

Based on this study, multiple recommendations can be made regarding the continued management of the pollinator meadows and managed flower beds on campus in order to best support native insect pollinator populations. Even though the pollinator meadows provide better pollinator habitat than the managed flower beds, they can still be improved. Pollinator Meadow 1 has much less ground cover than Pollinator Meadows 2 or 3 or any of the managed flower beds (Table 1). Plant abundance was also much lower in Pollinator Meadow 1 than Pollinator Meadows 2 or 3, and was similar to the plant abundance in the managed flower beds (Table 1). Much of Pollinator Meadow 1 was empty soil and mulch, leaving space to add more plants. Pollinator Meadow 1 contained mostly grasses, so planting flowers would be useful in attracting insect pollinators and providing them with nectar resources. The pollinator meadows could also be improved by planting more milkweed, as it is very important to monarch butterflies. Though members of the Bee Campus Committee planted some milkweed in the meadows over the summer of 2020, very little was observed during this study. During its early development, milkweed is highly sensitive to competition for light and soil from other plants, so it is likely that much of the milkweed planted did not survive to establish itself in the meadows (Evetts & Burnside, 1975). It may be necessary to clear some areas within the meadows before planting new milkweed in order to reduce competition for light and soil. Milkweed could also be planted in Pollinator Meadow 1 to take advantage of the open space there. Additionally, invasive *Ampelopsis brevipedunculata* (porcelain-berry) was observed in the pollinator meadows, so efforts to reduce invasives in the eco-corridor could be continued, with a focus on this species (Table 3).

While the managed flower beds were found to provide less ideal habitat than the pollinator meadows, they should not be ignored in efforts to improve habitat on campus as a whole. Pollinators were spotted within the managed flower beds (Table 1), so insect pollinators are taking advantage of the resources they provide. The managed flower beds are also maintained year-round, which can help to sustain pollinator populations when native wild plants are no longer blooming in the fall and winter. In the future, when deciding what species to plant in these managed flower beds, and the remaining formal flower beds across campus, the Landscape Services Department could select species which are known to attract pollinators. Pollinator syndromes, or the floral characteristics associated with certain pollinators could also be considered while still choosing flowers which are visually appealing. For example, bees are associated with bright white, yellow, and blue flowers, flies with pale and dull dark brown and purple flowers with translucent patches, beetles with dull white or green flowers, and butterflies with bright red and purple flowers (Gagliardi & Walker, 2018). While many of the plants identified in the managed flower beds were not native (Figure 5; Table 3), because the beds are so closely maintained, it is unlikely that these plants will spread beyond the beds and become invasive.

This study was valuable in helping to determine how effective the Gambles Mill Eco-Corridor restoration project was in improving pollinator habitat, and assessing habitat across campus as a whole. The restoration of pollinator services is a key, but underappreciated aspect of ecological restoration projects (Dixon, 2009). The Office of Sustainability and the Bee Campus Committee ensured that supporting pollinator services was a part of the restoration project, but it will be important to maintain the pollinator meadows and continue to improve them over time. Insect pollinator services should be prioritized in the development of an Eco-Corridor management plan. Projects focusing on pollinator conservation could be enacted in the future which embody the themes of nature, community, reflection, education, and well-being. For example, the Office of Sustainability and the Bee Campus Committee could collaborate to establish an initiative to construct solitary bee houses to place around the Eco-Corridor. Students from local middle-schools in the community could participate in this initiative, modeled after the program described in “Building Bee Houses: Designing and Constructing Solitary Bee Houses for Scientific Investigations” (Wang et al., 2017). Projects like these could engage the community and help young students learn about engineering design, scientific inquiry, and the ecological importance of pollinators.

The University of Richmond campus can serve as an important refuge habitat for insect pollinators within the highly developed area of Richmond. The area directly surrounding campus is highly monocultured due to the Country Club of Virginia's golf course and household lawns. Because of this, campus, and the pollinator meadows in particular, provide some of the most diverse habitat available to insect pollinators in the area. Much uncertainty exists regarding the most effective and efficient ways to improve pollinator habitat on a large scale (Ehmke et al., 2015). However, this study has made it clear that the UR campus already provides important resources to local insect pollinators which may be scarce otherwise. A continued emphasis on pollinator services on campus has the potential to increase local pollinator populations and inspire change on college campuses across the country.

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Tables and Figures:

Pollinator Habitat Research Sites

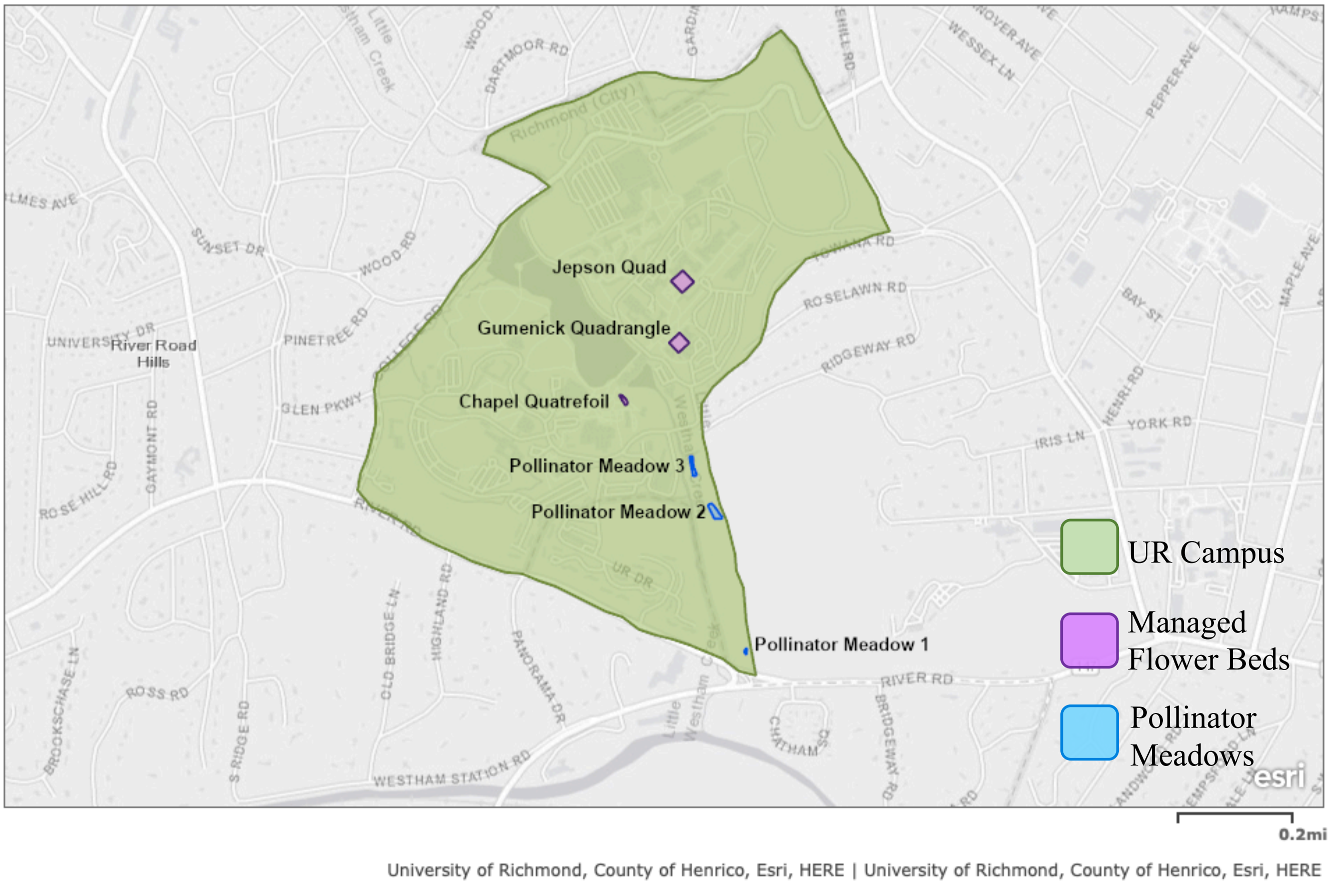

Figure 1: This map shows the location of the six study sites. The size of each site is approximated.

Table 1. Summary of data recorded during field surveys of potential pollinator habitat on campus.

Site	Average Number Individual Plants per Quadrat	Total Number Plant Species Observed	Average Percent Ground Cover	Pollinators Spotted	Pollinator Species
Pollinator Meadow 1	3.4	6	3.4	no	n/a
Pollinator Meadow 2	11.6	18	99	yes	2 Skippers, 1 Buckeye
Pollinator Meadow 3	13.6	17	88	yes	1 Bumblebee
Gumenick Quadrangle	2	4	33	no	n/a
Jepson Quad	4	10	47	yes	1 Honeybee
Chapel Quatrefoil	4.8	9	38	yes	1 Dronefly, 1 Skipper

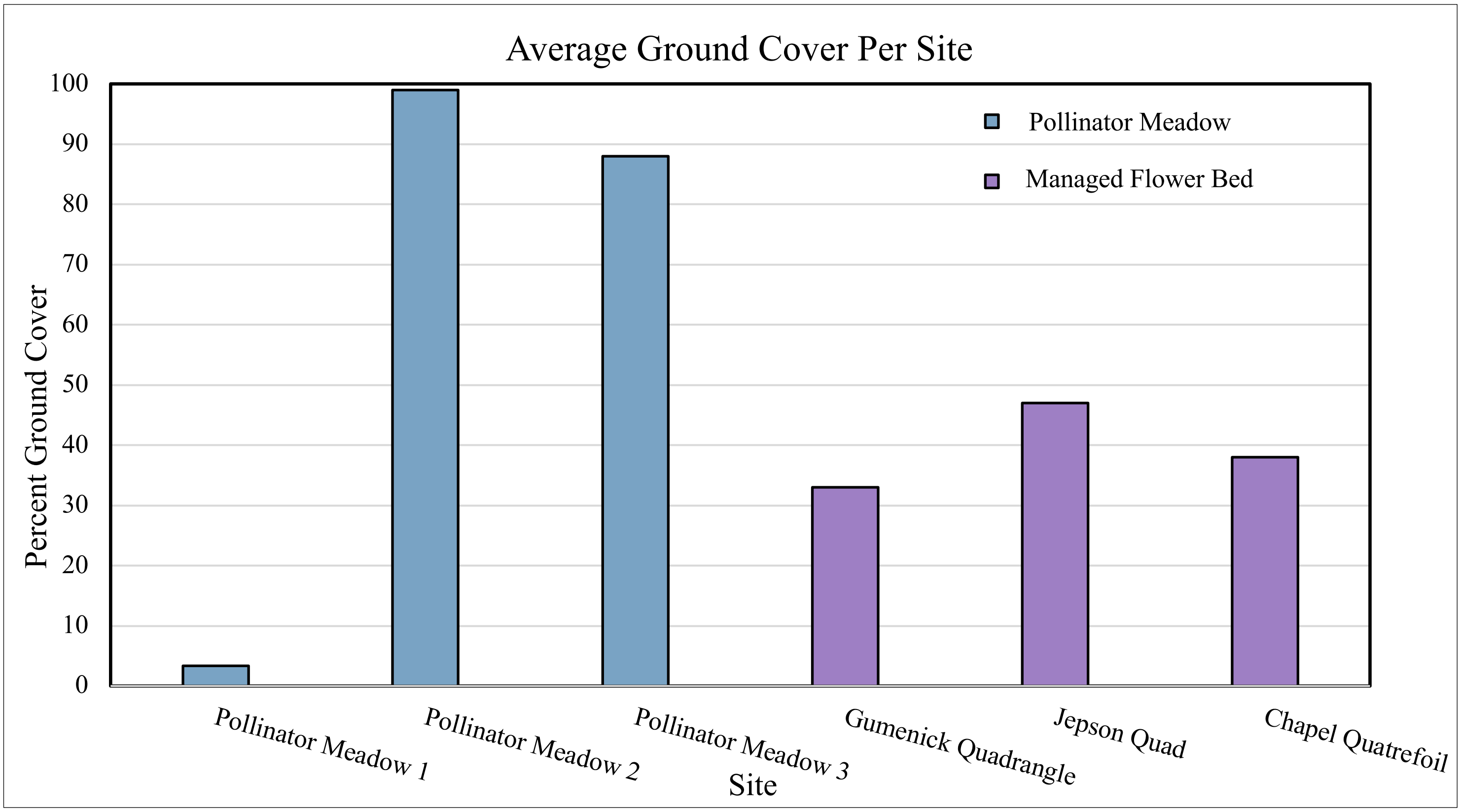

Figure 2. Bar chart illustrating the difference in average percent ground cover across all sites. Managed flower beds had more consistent ground cover but pollinator meadows had greater overall groundcover.

Table 2: Summary of average percent ground cover at each site and its Braun-Blanquet Score. The Braun-Blanquet cover-abundance scale is an efficient way to analyze vegetation quickly. A "+" indicates that percent ground cover was less than 5 and there were few individuals.

Site	Average Percent Ground Cover	Braun-Blanquet Score
Pollinator Meadow 1	3.4	+
Pollinator Meadow 2	99	5
Pollinator Meadow 3	88	5
Gumenick Quadrangle	33	3
Jepson Quad	47	3
Chapel Quatrefoil	38	3

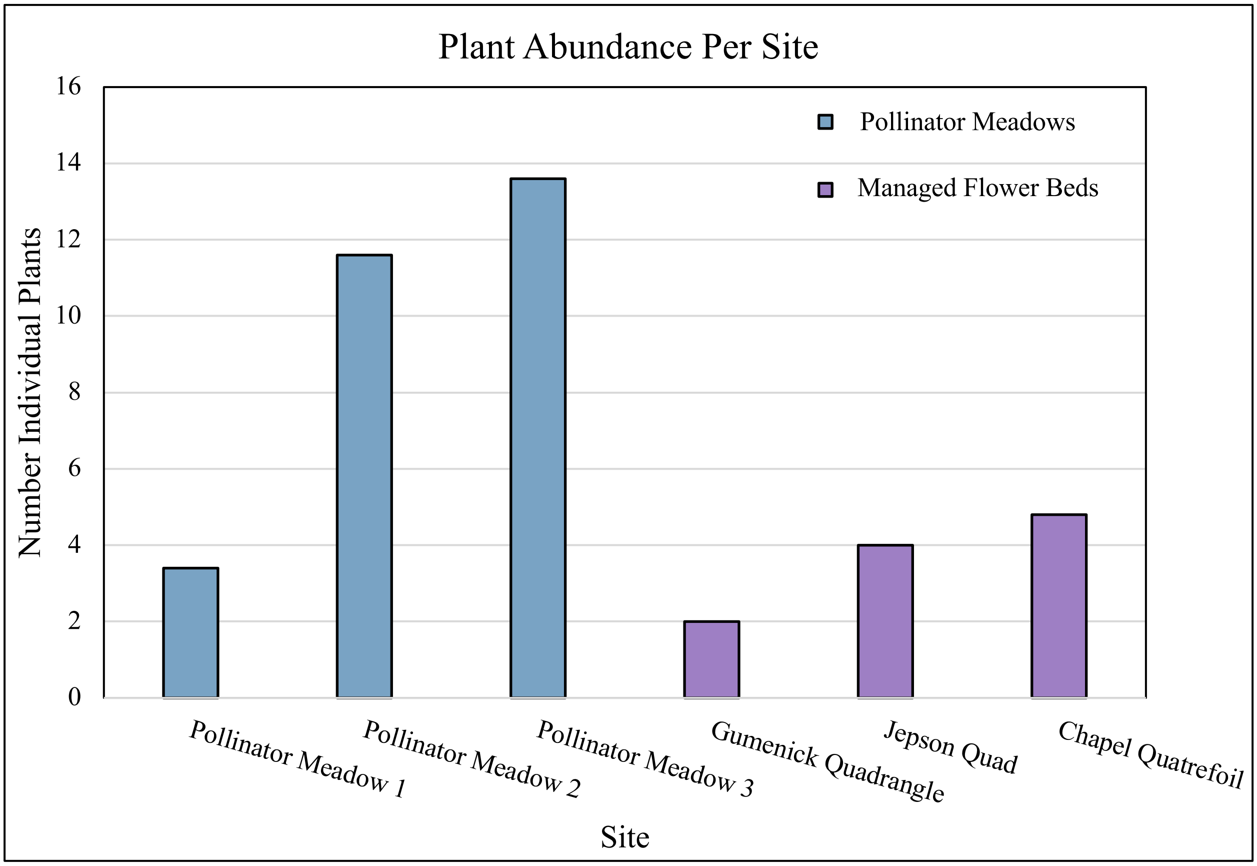

Figure 3: Bar chart illustrating the difference in average number of individual plants observed in each site. Pollinator meadows contained a higher average number of individual plants than managed flower beds.

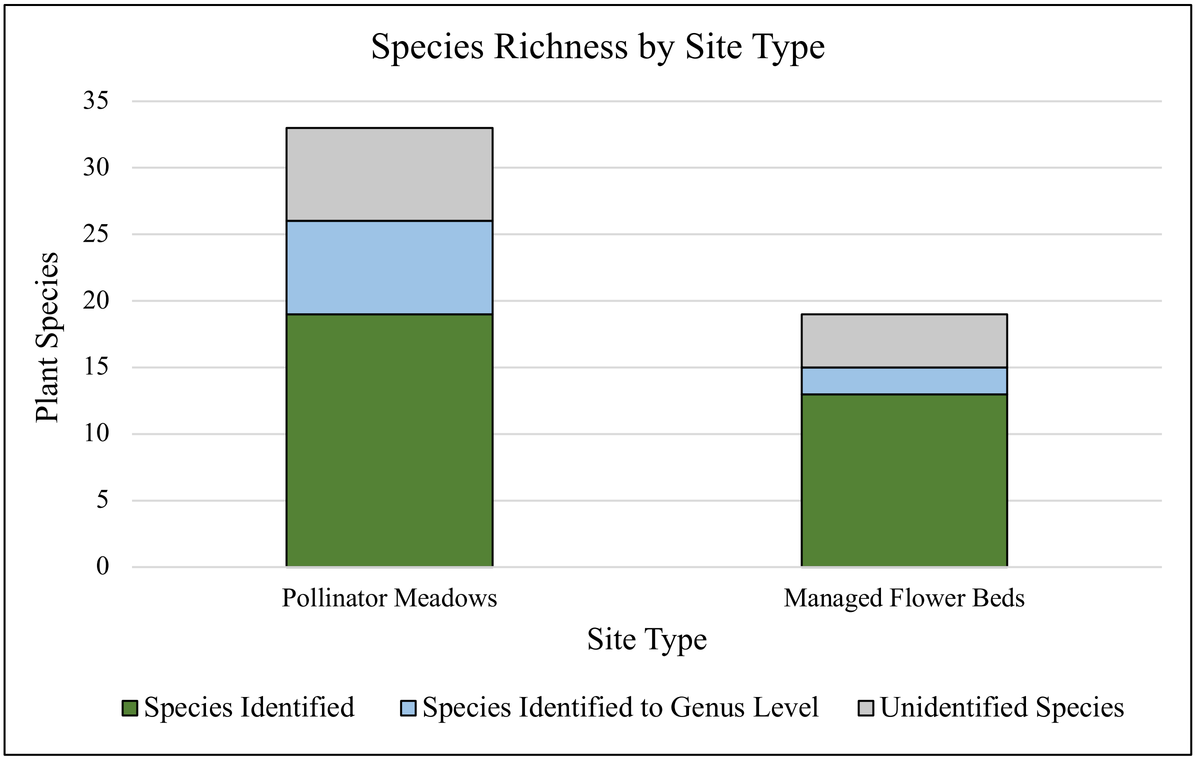

Figure 4. Bar chart illustrating the difference in plant species richness between pollinator meadows and managed flower beds. Richness was higher overall in pollinator meadows.

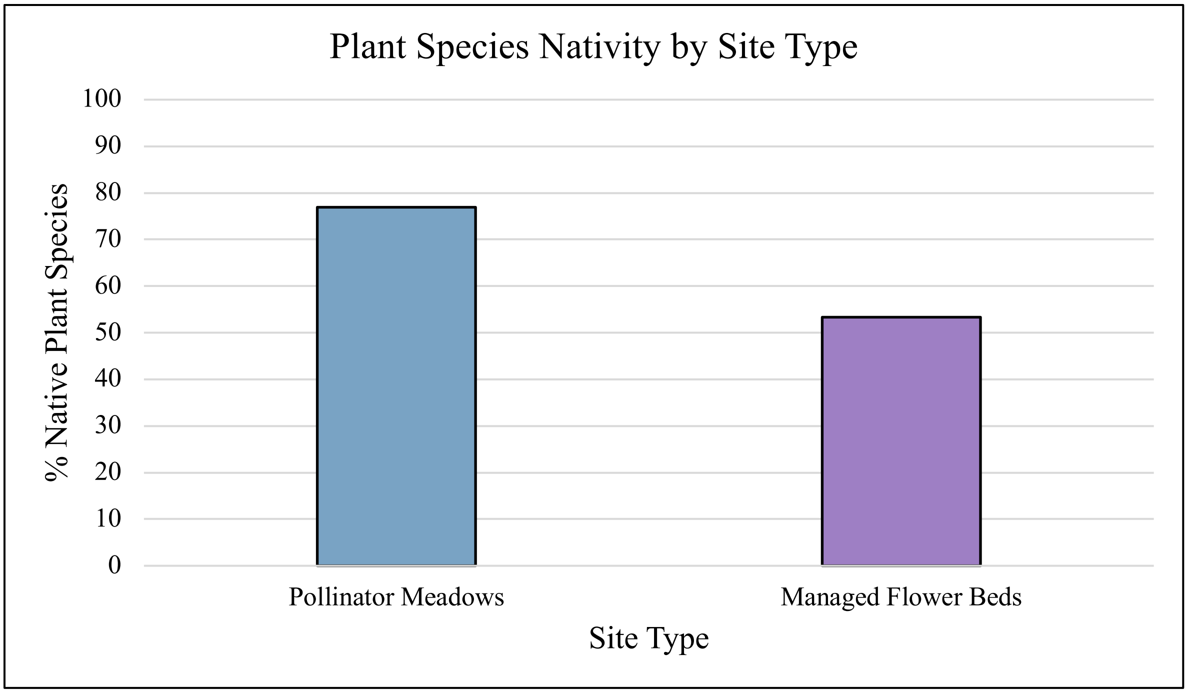

Figure 5. This bar chart illustrates the difference in plant nativity across site types. Of the 26 species identified to at least the genus level in the pollinator meadows, about 77% were native. Of the 15 species identified to at least the genus level in the managed flower beds, about 53% were native.

Table 3: Complete list of plant species observed across all sites identified to at least the genus level. Species nativity and the site type(s) in which the species were observed are included.

Species	Nativity	Site Type
Acalypha virginica	Native	Pollinator Meadow
Agrimonia eupatoria	Native	Pollinator Meadow
Alliaria petiolate	Non-native	Both
Ampelopsis brevipedunculata	Non-native	Pollinator Meadow
Artemisia vulgaris	Non-native	Pollinator Meadow
Asclepias sp.	Native	Pollinator Meadow
Carex blanda	Native	Pollinator Meadow
Chamaecrista fasciculata	Native	Pollinator Meadow
Chicorium intybus	Native	Pollinator Meadow
Clematis virginiana	Native	Managed Flower Bed
Echinacea purpurea	Native	Managed Flower Bed
Eupatorium pilosum	Native	Pollinator Meadow
Fimbristylis vahlii	Native	Pollinator Meadow
Geranium sp.	Native	Pollinator Meadow
Hosta plantaginea	Non-native	Managed Flower Bed
Juncus effuses	Non-native	Managed Flower Bed
Liriope muscari	Non-native	Managed Flower Bed
Monarda fistulosa	Native	Pollinator Meadow
Oenothera biennis	Native	Pollinator Meadow
Panicum virgatum	Native	Pollinator Meadow
Persicaria maculosa	Non-native	Pollinator Meadow
Rhododendron simsii	Non-native	Managed Flower Bed
Rosa arvensis	Non-native	Managed Flower Bed
Rudbeckia hirta	Native	Pollinator Meadow
Salix sp.	Native	Pollinator Meadow
Senecio vulgaris	Native	Pollinator Meadow
Solanum americanum	Native	Managed Flower Bed
Solidago sp.	Native	Pollinator Meadow
Stellaria media	Native	Managed Flower Bed
Succisa pratenis	Non-native	Pollinator Meadow
Trifolium sp.	Native	Both
Tussilago farfara	Non-native	Pollinator Meadow
Vaccinium pallidum	Native	Pollinator Meadow

Verbesina sp.	Native	Pollinator Meadow
Verbesina virginica	Native	Managed Flower Bed
Viola tricolor	Non-native	Managed Flower Bed
Vitis sp.	Native	Both
Waldsteinia fragarioides	Native	Managed Flower Bed