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Pollinator Inventory on an Urban College Campus: The Impact and Necessity of Native Plantings

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Abstract

The aim of this study was to measure pollinator abundance and diversity across Virginia Commonwealth University's Monroe Park Campus in Richmond, Virginia, especially focusing on the impact of campus plantings on pollinators.

Methods

18 transects across VCU's Monroe Park Campus, as well as 2 at the nearby Amelia Street School native meadow planting, were established and stratified by planting composition (native/invasive) and species diversity. Each transect was inventoried every other week for pollinators from April through July of 2023. Nonparametric and median-based linear models were used to test differences in pollinator abundance and morphospecies diversity across planting types.

Results

Pollinator abundance and morphospecies richness varied greatly by planting composition. Namely, transects that had higher total plant diversity also had a higher diversity of pollinators. Transects that had a native plant presence also had higher pollinator abundance and higher pollinator diversity. These findings are evidence that native plantings in urban campuses can be used to promote the presence of pollinators.

Introduction

As human populations continue to grow and urban centers continue to expand, it is critical we understand the associated impact on biodiversity. Pollinators have become a conservation priority, as they play a crucial role in the reproductive success of most flowering plant species, shaping ecosystems and the organisms that depend on them (Ollerton et al., 2011). Urbanization presents unique challenges to pollinators, particularly when urban centers are not managed with biodiversity in mind. Reductions in green spaces and plant diversity resulting in the loss and fragmentation of natural habitats negatively impact the presence and diversity of native pollinators in urban areas (Goulson et al., 2015; Hennig and Ghazoul, 2012; Xiao, et al, 2016).

Even in the green spaces remaining, the desire to preserve aesthetic appeal can have a negative impact on biodiversity (Kermath, 2007). Residential and conservation priorities often conflict, but taking into account the needs of residents in urban areas can ensure the success of long-term conservation initiatives (Southon et al., 2017; Turo and Gardiner, 2019). For example, weeds and less frequent mowing actively promote pollinators by creating food sources and nesting sites, but can contribute to the perception of a poorly maintained landscape and even a perception of decreased safety.

When residents' needs are met, a conservation initiative is more likely to succeed and promote biodiversity while acting as a positive addition to the community. The opposite is true when residents' needs are not taken into account or when landscapes are poorly maintained. Thus, conservation measures need to be maintainable in the long-term and strike a balance between community needs and conservation needs.

Additionally, not all pollinators respond to urbanization in the same way. Urbanization tends to better support some functional traits over others such as generalism, cavity-nesting, and solitary behavior due to the landscape factors in an urban environment (Harrison et al., 2018). There is evidence to show that native plants better support specialists, and urban areas tend to have a greater abundance of nonnatives that are favored by generalists (Seitz et al., 2020; Wenzel et al., 2020). A loss of specialists in urban areas decreases the overall biodiversity. Similarly, cavity-nesting species are better supported in urban environments compared to ground-nesting species which tend to decrease in abundance as suitable nesting sites become more scarce due to higher densities of impervious surfaces (Hernandez et al., 2009). In this way, urbanization can drive homogenization of pollinator communities by supporting species with select functional traits (Harrison et al., 2018; Wilson and Jamieson, 2019).

Williams et al. (2011) found that pollinators become more reliant on nonnative plants because they are more abundant than natives in urban areas. However, certain nonnative plant species are more preferred than others, affecting the overall pattern of use by pollinators of nonnative plants. These preferred nonnative plant species can be important in extending the length of the flowering season (Mach et al., 2018; Staab et al., 2020). Suitable nonnative ornamentals can extend the availability of floral resources earlier and later into the year, providing resources when natives are otherwise scarce for pollinators with earlier or later emergence. Thus, suitable nonnative plants can bridge the resource gap in urban areas. While certain nonnative plants can still have a place in promoting biodiversity, several studies have found that pollinators, especially specialist species, prefer native plants (Fukase and Simons, 2015; Pardee and Philpott, 2014; Salisbury et al. 2015). One of the research goals in conducting this study was to determine whether there was evidence to support this on VCU's urban campus. With most plantings currently consisting of nonnative ornamentals, several garden areas have prioritized the inclusion of native species, presenting an opportunity to assess how campus landscaping is managed and how aesthetic and biodiversity interests can be balanced. Do current management practices actively prioritize not just the needs of the residents and the built environment, but the natural environment as well?

Methods

18 belt transects (6 meters long and 2 meters wide; $12m^2$) were established across campus based on varying planting types and diversity levels (Figure 1). Most plantings across campus were low in diversity and consisted mainly of ornamental plants. To reflect this, some transects were chosen for having plantings of common, regularly used ornamentals. The transects are referred to as “Shafer Street” and the “Park Street Green Space”. Additionally, two transects chosen had only turf grass and were included to act as controls and representations of large portions of this college campus and college campuses in general where large grassy areas are maintained for recreational and aesthetic needs. These transects are “Cabell Library” and “West Grace South”, both referring to buildings with large tracts of grass surrounding them.

Some plantings, mainly those at the Learning Garden and Monroe Park, had more plant diversity or more native species. The three transects at the community garden had high native plant diversity because of a native plant corridor that surrounds the garden. Multiple transects were at Monroe Park because of its significance to the university and the variety of plant species in the bordering planters.

The “Pollak Roof Garden” and “Harris Rain Garden” were chosen as transects that had been intentionally planted, but varied from other typical ornamental plantings and didn’t have the same use-value as the community garden. The Harris Rain Garden was planted as a sustainability initiative with the goal of reducing stormwater runoff. The Pollak roof garden was installed with the same intent and is the only rooftop planting on campus. The transects at the Life Sciences building were likewise planted intentionally as a way of bayscaping campus and were chosen for this reason. A lack of maintenance, however, has resulted in transects low in diversity or native species.

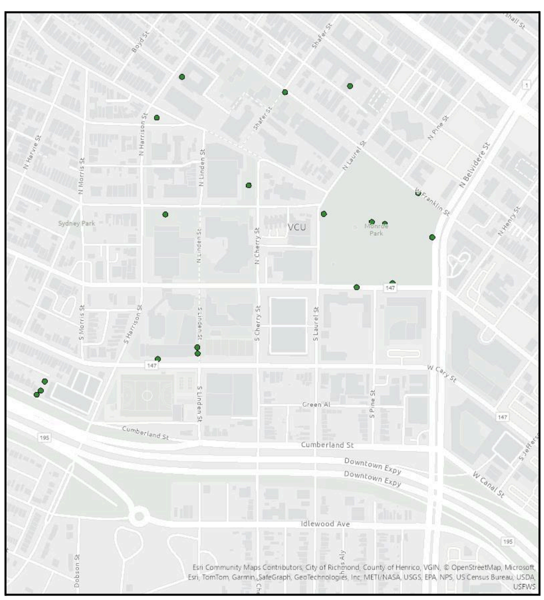

Figure 1. Transect locations on VCU’s Monroe Park Campus.

Additionally, VCU manages a native plant meadow and urban forest at the nearby Amelia Street School where two additional transects were inventoried during the month of July to compare to the campus plantings. The meadows have a high diversity in plant species, all of which are native. One transect had only one plant species, mountain mint [*Pycnanthemum virginianum*], while the second had 14 different native species.

Each transect was inventoried every other week (half were inventoried one week, the other half the next week, etc.) from April through July, with the exception of the Amelia Street School plantings which were inventoried only during July. The time at which inventories were conducted varied, mainly in the first several weeks, with each set of inventories taking approximately an hour and a half to complete. The majority of inventories were conducted between approximately 2:30 P.M. and 4:30 P.M., with some exceptions for scheduling conflicts and inclement weather. The earliest time inventory was conducted was at 10:45 A.M. during the second week of inventory. The latest inventory was conducted was at 5:34 P.M. when inventory was interrupted by a rain shower with two transects yet to be completed. Inventory was paused and resumed following the end of rain. As such, the majority of transects were inventoried during the hottest period of the day and during a time when pollinators are generally active. Daily temperature summaries were obtained from the National Oceanic and Atmospheric Administration (NOAA)'s Climate Data Online database. The daily summaries were recorded at the Richmond International Airport. It should be noted that Richmond International Airport is approximately 8 miles away and temperatures on VCU's campus may be affected by the urban heat island effect. Daily average temperatures ranged from 52-80 degrees Fahrenheit on days of inventory and daily maximum temperatures ranged from 64-91 degrees Fahrenheit, the high range of values being a result of inventories across the span of four months.

A timer was set for 3 minutes and the length of the transect was walked during this time while counting and noting the pollinators observed. Pollinators were grouped by various morphotaxa: honey bee, bumble bee, carpenter bee, sweat bee, longhorn bee, leafcutter bee, wasp, hoverfly, butterfly, moth, and beetle. These morphotaxa were determined based on the most common pollinators observed at transects during initial inventory and the most commonly observed pollinators in previous years based on citizen science data from iNaturalist. Though these morphotaxa are not entirely comprehensive, they can offer an understanding of the overall presence, or lack thereof, of pollinators in a given transect.

Statistical Analysis

All data analysis was performed with R Statistical Software (v4.3.2; R Core Team 2021) using packages "tidyverse", "lubridate", "fsa", "mblm", and "rcompanion" (Wickham et al., 2019; Grolemund and Wickham, 2011; Ogle et al., 2023; Komsta, 2019; Mangiafico, 2023). Pollinator abundance and richness was modeled as a function of planting type and diversity. Pollinator abundance was measured by the total observation counts at each transect and richness was measured by the total number of morphotaxa present at each transect. Lists of plantings were compiled in July and stratified by levels of diversity, species count, native and nonnative species counts, as well as percent and area that was native. Transects were grouped into diversity levels (low, medium, and high) based on the number of plant species present when inventoried in July. Low transects had 1-3 plant species, medium transects had 4-6, and high transects had 7 or more. Percent native was calculated as a function of the number of native plant species compared to the total number of plant species. Native area was calculated as an approximation under the assumption that the total area of the transect (12 m^2) was covered with plant matter, which was not always true as in the case of some bare patches of soil and surrounding concrete infrastructure.

The final dataset was created by making a row for each individual transect and combining the date and length at which the data was observed. When observations were recorded during inventory, separate counts were noted for 0-2 meters, 2-4 meters, and 4-6 meters to make data entry easier. This column was dropped when making the final dataset, so observation counts are for the entire transect rather than a part of it. Diversity was measured as morphospecies richness (total number of morphospecies observed across all surveys); pollinator abundance was measured as the cumulative number of all individuals from all morphospecies observed across all surveys.

Because of the smaller sample size and non-normal distribution that was found during initial summary statistics, non-parametric tests were performed. Namely, a Kruskal-Wallis and the associated post hoc Dunn test, as well as Theil-Sen median-based linear models were run for both pollinator abundance and pollinator richness. Having used a median-based linear model with the Theil-Sen regression, Efron's pseudo R-squared value was calculated to better explain how much variance was explained by each predictor variable.

Results

674 pollinators were observed for 11 morphotaxa across all transects on the Monroe Park Campus with an additional 779 pollinators observed at Amelia Street School, totaling 1453. Bumble bees had the highest number of observations, although wasps, leafcutter bees, and honey bees also had high observations across transects.

The Kruskall-Wallis tests reported a significant p-value for both abundance and richness: 0.001904 and 0.0009621, respectively (Figure 2).

The post-hoc Dunn test showed a significant p-value for abundance with low to medium and low to high plant diversity, but not medium to high plant diversity (Figure 3). The same was true for the Dunn test with pollinator richness (Figure 4).

The relationships between pollinators and plant species count, native plant count, and percent native were tested using median based linear models (Figures 5 and 6). P-values were significant for each predictor, but Efron's r-squared was negative for plant species count and percent native with pollinator abundance, indicating that the p-values for these tests may not be reliable, mostly likely due to overdispersion of the data. For each other predictor, Efron's r-squared was positive and was highest for pollinator abundance and native plant count at 0.449. Native plant count with pollinator taxa was the next highest at 0.293, indicating that the best predictor of pollinator morphotaxa diversity was the abundance of native plants within transects.

For the data set including Amelia Street, Efron's r-squared was significant for pollinator abundance and percent native at 0.0973 and for pollinator taxa and total plant species count at 0.195 (Figures 10 and 11).

Discussion

Statistical analysis showed that university planting composition, especially native plant diversity, is important for both pollinator abundance and richness. In moving from low to medium levels of plant diversity, the abundance and richness of pollinators increased significantly. Even a relatively smaller addition of plant species was shown to bring positive outcomes.

Additionally, native plant count was the strongest predictor for both pollinator abundance and richness, though total plant species count and percent native plants were significant for pollinator richness as well. This highlights the need for not just a greater diversity in plantings, but a greater emphasis on natives especially. In line with other research outcomes, native plants seem to promote a more diverse array of pollinators. As Seitz et al. (2020) found, this may be in part due to the ability for natives to support more specialist species. Future research on VCU's campus should gather empirical data on the specific plant species that are most preferred by various pollinator taxa to better inform future planting plans.

Limitations

The greatest limitation of this study is the short-term nature of the inventory. Inventory was collected during the spring and summer months of one year only due to time constraints. Future research would benefit from analysis of several years worth of data to limit year-to-year changes in pollinator presence.

Sampling was limited to 18 transects across campus. While transects were chosen in an attempt to be representative of the typical plantings on campus, they are not exhaustive. This is especially the case at the Monroe Park transects where plantings surrounding the park varied greatly in both plant composition and diversity. Additionally, inventory at the Amelia Street School only started in July and thus had fewer data points for comparison.

For the most part, inventory was completed in the late afternoon, but there were a few instances of inventory completed in the late morning, which may have had an impact on pollinator presence.

Conclusions

There has been strong evidence to suggest, both in this study and others, that higher plant diversity, with an emphasis on native plant diversity, promotes pollinator presence (Baldock et al., 2019; Fukase and Simons, 2016; Salisbury et al., 2015). However, current landscape management practices on campus do not prioritize plant diversity or native plant selection. This begs the question of the intent and purpose behind campus landscaping. This question can be thought about on different scales and in different contexts, from a community and university perspective, to a larger paradigm that determines how a society looks at its natural environment.

Campus-wide landscape management is a reflection of the larger practices of landscape management seen in various public and private spaces. Its greatest motivator is the singular and simplistic goal of creating an aesthetically pleasing visual environment (Thayer, 1989). While there is nothing wrong with promoting aesthetic design in a space, it overlooks the other outcomes that can be achieved by different landscape management practices. While many universities give aesthetics precedence in landscape design, there is an opportunity to create a new, more sustainable standard. Sustainable landscape management offers manifold benefits. It promotes biodiversity, especially on urban campuses like VCU's that are otherwise lacking. Biodiversity is facing an alarming crisis, in large part due to anthropogenic habitat loss (Ehrlich and Wilson, 1991). Promoting biodiversity in ever-expanding urban areas can become a critical way of promoting overall biodiversity (Liang et al., 2023; Nilon et al., 2017). Beyond the benefits to the natural environment, sustainable landscape practices can be beneficial for the student body and the surrounding community. Access to natural spaces is key for health and well-being outcomes, especially in urban areas where these spaces are more infrequent and harder to come by (Reyes-Riveros et al., 2021). While non-biodiverse landscaping can also promote well-being, Kermath (2007) notes that sustainable urban landscaping additionally increases "perceptions of natural heritage, sense-of-place, ecological literacy and the role of campus landscapes in the larger community".

In this sense, there is a great opportunity to promote education, connectedness, and appreciation for the natural environment for both the student body and the surrounding community that is interwoven with it. Developing a stronger sense-of-place allows students to consider how people interact with one another and their environment (Häggström and Schmidt, 2020). In this way, landscaping with intent can make the urban campus an active element in education both inside and outside of the traditional classroom setting. Few university core curriculums include an environmental literacy requirement, meaning few non-environmental majors are exposed to sustainability issues (Rowe, 2002; Vallée, 2023). However, teaching environmental literacy fosters a connection to the natural environment that can lead to environmentally responsible behavior. Incorporating sustainability into the core curriculum, either as a required course or as a meaningful addition to already required courses, is key for creating an environmentally-literate student body. Native landscaping on campuses can act as a teaching aid by allowing students to learn about species native to the region and their importance in promoting biodiversity. It also creates an opportunity for hands-on learning through the establishment and maintenance of plant meadows. While expanding environmental literacy in core university curriculums can be effective in the long-term, there are strategies in the short-term that can move the university towards more sustainable practices. Replacing ornamental plantings on campus with natives and reducing the use of pesticides can lead to an increase in pollinator presence, while creating informational signage and hosting student volunteer groups facilitates learning.

The university already has successful initiatives in place. The two Amelia Street transects had more pollinator observations than the remaining Monroe Park Campus transects combined. The native meadows planted there have been incredibly successful in promoting pollinator abundance and diversity. It has also been an active site, along with the Learning Garden, for volunteer groups. With the proper resources and support, these initiatives can be expanded throughout campus.

Universities have a unique role in being catalysts of innovation. The role of universities as social institutions is to promote progress through the means of education. In many fields, universities act as leaders bringing about change for individuals, communities, and society as a whole (Kermath, 2007; Purcell et al., 2019). In this way, universities have a unique ability to be advocates in promoting sustainability and implementing conservation initiatives. One such facet of sustainability within institutions is landscape management. While often overlooked, it is actually a reflection of the values of an institution. Universities can either adhere to current paradigms or be leaders in shaping new ones that are more just to their students, their communities, and the environment that they so depend on.

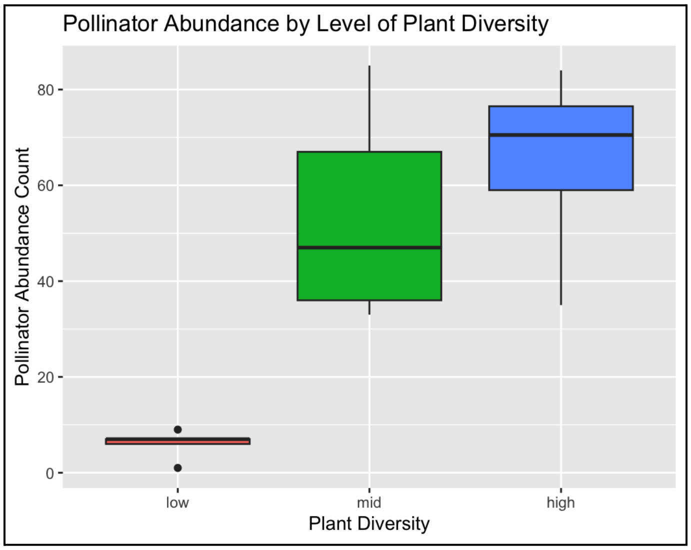

Figure 2. Effect of plant diversity on pollinator abundance. Pollinator abundance was significantly greater at medium and high levels of plant diversity compared to low levels.

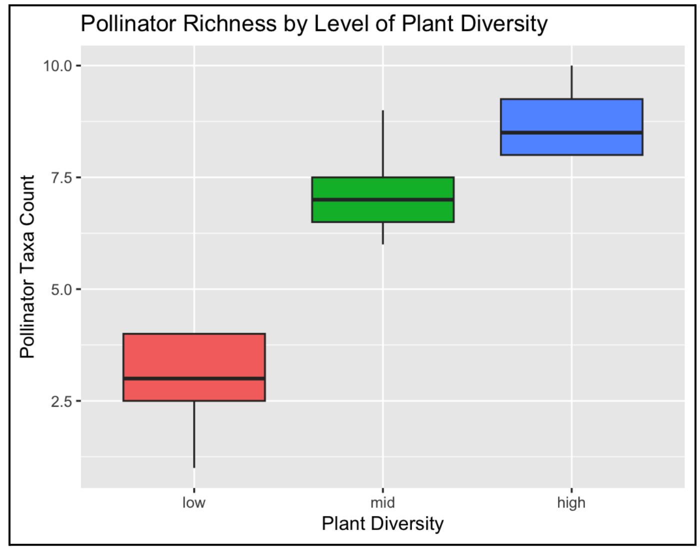

Figure 3. Effect of plant diversity on pollinator richness. There were significantly more morphotaxa present at medium and high levels of plant diversity compared to low levels.

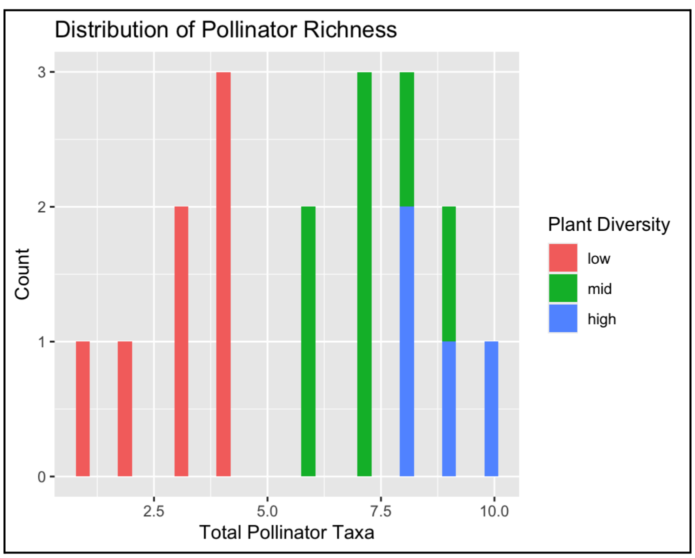

Figure 4. Distribution of pollinator richness across transects filled by plant diversity levels. Transects with higher counts of pollinator morphotaxa correspond with higher levels of plant diversity.

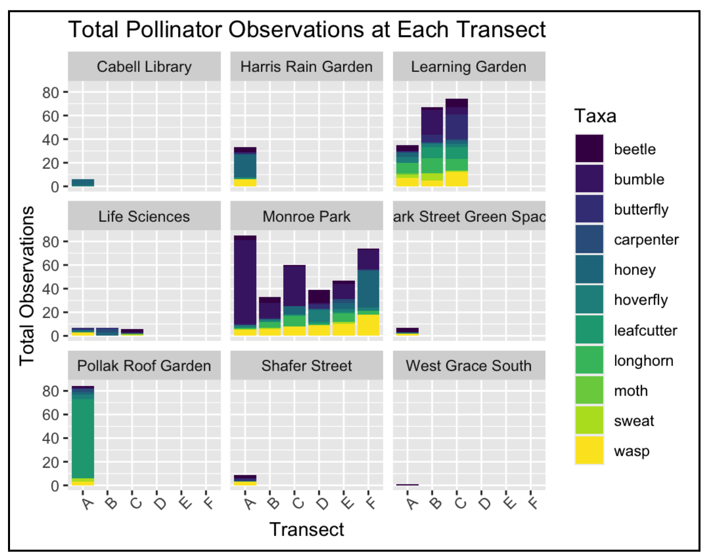

Figure 5. Total pollinator observations at each transect grouped by morphotaxa separated into individual bars to account for some locations having more transects. The Learning Garden and Monroe Park had the highest concentrations of native plants.

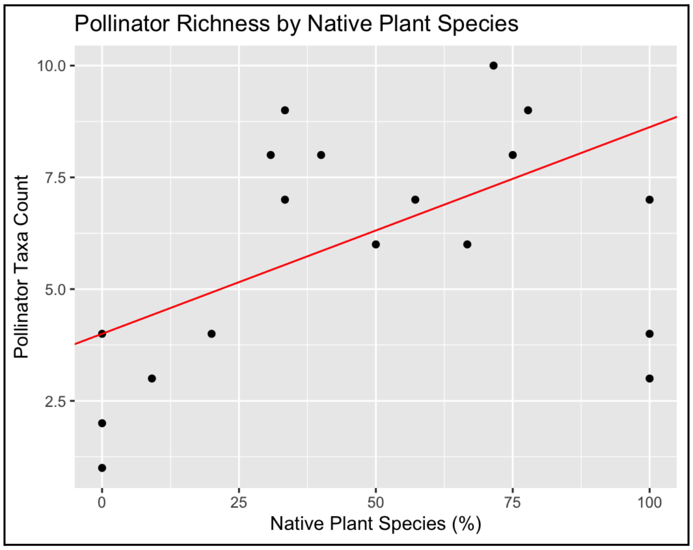

Figure 6. The effect of native species percent on pollinator richness.

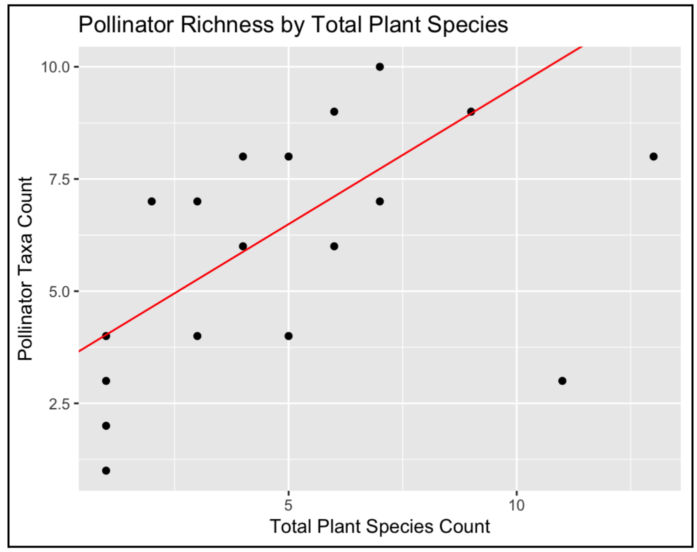

Figure 7. The effect of the total plant species count on pollinator richness.

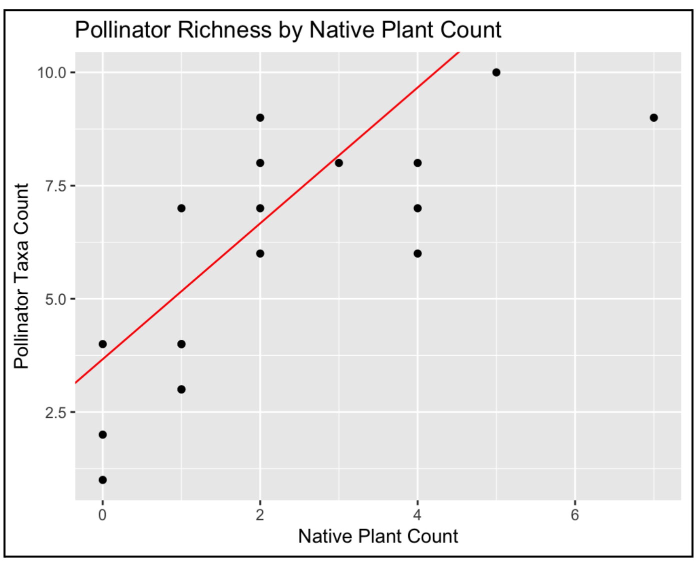

Figure 8. The effect of the native plant count on pollinator abundance.

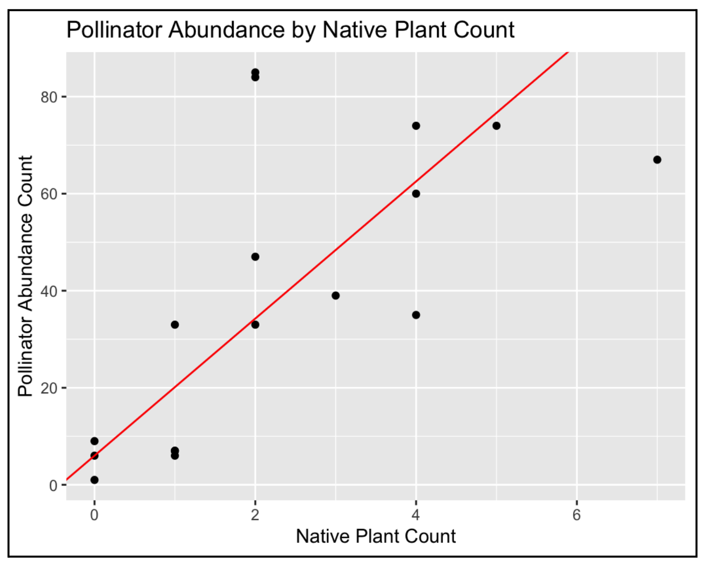

Figure 9. The effect of the native plant count on pollinator richness.

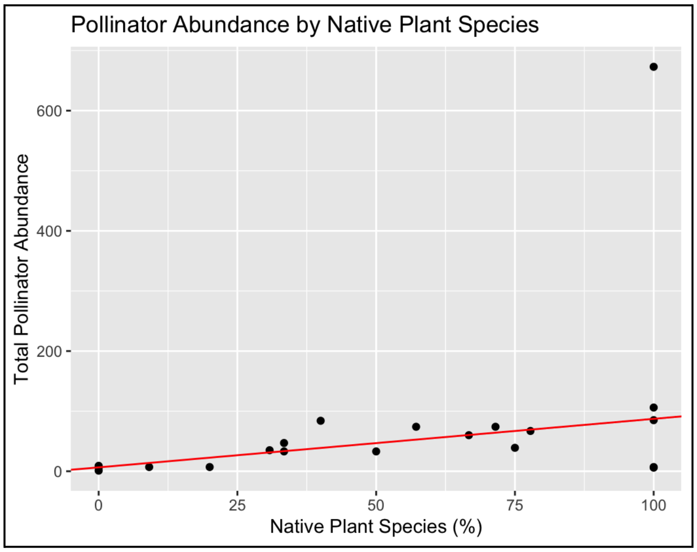

Figure 10. The effect of percent native plants on pollinator abundance including the transects at Amelia Street School.

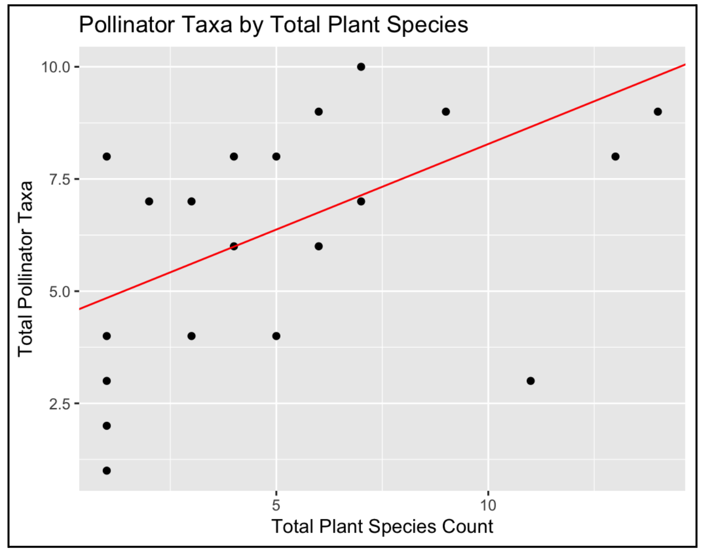

Figure 11. The effect of total plant species count on pollinator richness including the transects at Amelia Street School.

References

Aguilera, G., Ekroos, J., Persson, A. S., Pettersson, L. B., & Öckinger, E. (2019). Intensive management reduces butterfly diversity over time in urban green spaces. *Urban Ecosystems*, *22*, 335–344. https://doi.org/10.1007/s11252-018-0818-y

Baldock, K. C. R., Goddard, M. A., Hicks, D. M., Kunin, W. E., Mitschunas, N., Morse, H., Osgathorpe, L. M., Potts, S. G., Robertson, K. M., Scott, A. V., Staniczenko, P. P. A., Stone, G. N., Vaughan, I. P., & Memmott, J. (2019). A systems approach reveals urban pollinator hotspots and conservation opportunities. *Nature Ecology & Evolution*, *3*, 363–373. https://doi.org/10.1038/s41559-018-0769-y

Baldock, K. C. R., Goddard, M. A., Hicks, D. M., Kunin, W. E., Mitschunas, N., Osgathorpe, L. M., Potts, S. G., Robertson, K. M., Scott, A. V., Stone, G. N., Vaughan, I. P., & Memmott, J. (2015). Where is the UK's pollinator biodiversity? the importance of urban areas for flower-visiting insects. *Proc Biol Sci*, *282*(1803). https://doi.org/10.1098/rspb.2014.2849

Ehrlich, P. R., & Wilson, E. O. (1991). Biodiversity Studies: Science and Policy. *Science*, *253*(5021), 758–762. http://www.jstor.org/stable/2879117

Fukase, J., & Simons, A. M. (2016). Increased pollinator activity in urban gardens with more native flora. *Applied Ecology and Environmental Research*, *14*(1), 297–310. https://doi.org/10.15666/aeer/1401_297310

Garbuzov, M., & Ratnieks, F. L. W. (2014). Quantifying variation among garden plants in attractiveness to bees and other flower-visiting insects. *Functional Ecology*, *28*(2), 364–374. http://www.jstor.org/stable/24033671

Goulson, D., Nicholls, E., Botías, C., & Rotheray, E. L. (2015). Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science*, *347*(6229), 1435–1435. http://www.jstor.org/stable/24746613

Grolemund G., Wickham H. (2011). "Dates and Times Made Easy with lubridate." *Journal of Statistical Software*, *40*(3), 1-25. <https://www.jstatsoft.org/v40/i03/>.

Häggström, M., & Schmidt, C. (2020). Enhancing children's literacy and ecological literacy through critical place-based pedagogy. *Environmental Education Research*, *26*(12), 1729–1745. https://doi.org/10.1080/13504622.2020.1812537

Harrison, T., Gibbs, J., & Winfree, R. (2018). Phylogenetic homogenization of bee communities across ecoregions. *Global Ecology and Biogeography*, *27*(12), 1457–1466. https://doi.org/10.1111/geb.12822

Hennig, E. I., & Ghazoul, J. (2012). Pollinating animals in the urban environment. *Urban Ecosystems*, *15*(1), 149-166. doi:https://doi.org/10.1007/s11252-011-0202-7

Hernandez, J. L., Frankie, G. W., & Thorp, R. W. (2009). Ecology of urban bees: A review of current knowledge and directions for future study. *Cities and the Environment*, *2*(1). https://doi.org/10.15365/cate.2132009

Hülsmann, M., von Wehrden, H., Klein, A.-M., & Leonhardt, S. D. (2015). Plant diversity and composition compensate for negative effects of urbanization on foraging bumble bees. *Apidologie*, *46*, 760–770. https://doi.org/10.1007/s13592-015-0366-x

Kermath, B. (2007). Why go native? Landscaping for biodiversity and sustainability education. *International Journal of Sustainability in Higher Education*, *8*(2), 210–223. https://doi.org/10.1108/14676370710726661

Komsta L. (2019). *mblm: Median-Based Linear Models*. R package version 0.12.1, <https://CRAN.R-project.org/package=mblm>.

Liang, H., He, Y., Theodorou, P., & Yang, C. (2023). The effects of urbanization on pollinators and pollination: A meta‐analysis. *Ecology Letters*, *26*(9), 1629–1642. https://doi.org/10.1111/ele.14277

Mach, B. M., & Potter, D. A. (2018). Quantifying bee assemblages and attractiveness of flowering woody landscape plants for urban pollinator conservation. *PloS ONE*, *13*(12), e0208428. https://doi-org.proxy.library.vcu.edu/10.1371/journal.pone.0208428

Mangiafico S.S. (2023). *rcompanion: Functions to Support Extension Education Program Evaluation*. Rutgers Cooperative Extension, New Brunswick, New Jersey. Version 2.4.34, <https://CRAN.R-project.org/package=rcompanion/>.

Nilon, C. H., Aronson, M. F. J., Cilliers, S. S., Dobbs, C., Frazee, L. J., Goddard, M. A., O'Neil, K. M., Roberts, D., Stander, E. K., Werner, P., Winter, M., & Yocom, K. P. (2017). Planning for the Future of Urban Biodiversity: A Global Review of City-Scale Initiatives. *BioScience*, *67*(4), 332–342. https://www.jstor.org/stable/90007771

Ogle D.H., Doll J.C., Wheeler A.P., Dinno A. (2023). *FSA: Simple Fisheries Stock Assessment Methods*. R package version 0.9.5, <https://CRAN.R-project.org/package=FSA>.

Ollerton, J. (2017). Pollinator Diversity: Distribution, Ecological Function, and Conservation. *Annual Review of Ecology, Evolution, and Systematics*, *48*, 353–376. http://www.jstor.org/stable/44864284

Ollerton, J., Winfree, R., & Tarrant, S. (2011). How many flowering plants are pollinated by animals? *Oikos*, *120*(3), 321–326. http://www.jstor.org/stable/29783517

Pardee, G. L., & Philpott, S. M. (2014). Native plants are the bee's knees: Local and landscape predictors of bee richness and abundance in backyard gardens. *Urban Ecosystems*, *17*(3), 641-659. doi:https://doi.org/10.1007/s11252-014-0349-0

Pawelek, J., Frankie, G. W., Thorp, R. W., & Przybylski, M. (2009). Modification of a community garden to attract native bee pollinators in urban San Luis Obispo, California. *Cities and the Environment*, *2*(1). https://doi.org/10.15365/cate.2172009

Purcell, W. M., Henriksen, H., & Spengler, J. D. (2019). Universities as the engine of transformational sustainability toward delivering the Sustainable Development Goals: "Living labs" for sustainability. *International Journal of Sustainability in Higher Education*, *20*(8), 1343–1357. https://doi.org/10.1108/ijshe-02-2019-0103

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Reyes-Riveros, R., Altamirano, A., De La Barrera, F., Rozas-Vásquez, D., Vieli, L., & Meli, P. (2021). Linking public urban green spaces and human well-being: A systematic review. *Urban Forestry & Urban Greening*, *61*, 127105. https://doi.org/10.1016/j.ufug.2021.127105

Rowe, D. (2002). Environmental literacy and sustainability as core requirements: Success stories and models. *Teaching sustainability at universities*, 79-103.

Salisbury, A., Armitage, J., Bostock, H., Perry, J., Tatchell, M., & Thompson, K. (2015). Editor's choice: Enhancing gardens as habitats for flower‐visiting aerial insects (pollinators): Should we plant native or exotic species? *Journal of Applied Ecology*, *52*(5), 1156–1164. https://doi.org/10.1111/1365-2664.12499

Seitz, N., vanEngelsdorp, D., & Leonhardt, S. D. (2020). Are native and non‐native pollinator friendly plants equally valuable for native wild bee communities? *Ecology and Evolution*, *10*(23), 12838–12850. https://doi.org/10.1002/ece3.6826

Sivakoff, F. S., Prajzner, S. P., & Gardiner, M. M. (2018). Unique bee communities within vacant lots and urban farms result from variation in surrounding urbanization intensity. *Sustainability*, *10*(6), 1926. https://doi.org/10.3390/su10061926

Southon, G. E., Jorgensen, A., Dunnett, N., Hoyle, H., & Evans, K. L. (2017). Biodiverse perennial meadows have aesthetic value and increase residents' perceptions of site quality in urban green-space. *Landscape and Urban Planning*, *158*, 105–118. https://doi.org/10.1016/j.landurbplan.2016.08.003

Staab, M., Pereira-Peixoto, M., & Klein Alexandra-Maria. (2020). Exotic garden plants partly substitute for native plants as resources for pollinators when native plants become seasonally scarce. *Oecologia*, *194*(3), 465-480. doi:https://doi.org/10.1007/s00442-020-04785-8

Thayer, R. L. (1989). The Experience of Sustainable Landscapes. *Landscape Journal*, *8*(2), 101–110. http://www.jstor.org/stable/43324023

Turo, K. J., & Gardiner, M. M. (2019). From potential to practical: conserving bees in urban public green spaces. *Frontiers in Ecology and the Environment*, *17*(3), 167–175. https://www.jstor.org/stable/26623779

Vallée, M. (2024), "How and why US universities fail to impart environmental literacy to all students", *International Journal of Sustainability in Higher Education*, Vol. 25 No. 9, 60-77. https://doi.org/10.1108/IJSHE-07-2022-0241

Wenzel, A., Grass, I., Belavadi, V. V., & Tscharntke, T. (2020). How urbanization is driving pollinator diversity and pollination – A systematic review. *Biological Conservation*, *241*, 108321. https://doi.org/10.1016/j.biocon.2019.108321

Wickham, H., Averick M., Bryan J., Chang W., McGowan L.D., François R., Grolemund G., Hayes A., Henry L., Hester J., Kuhn M., Pedersen T.L., Miller E., Bache S.M., Müller K., Ooms J., Robinson D., Seidel D.P., Spinu V., Takahashi K., Vaughan D., Wilke C., Woo K., Yutani H. (2019). Welcome to the tidyverse. *Journal of Open Source Software*, *4*(43), 1686, doi: 10.21105/joss.01686 <https://doi.org/10.21105/joss.01686>.

Williams, N. M., Cariveau, D., Winfree, R., & Kremen, C. (2011). Bees in disturbed habitats use, but do not prefer, alien plants. *Basic and Applied Ecology*, *12*(4), 332–341. https://doi.org/10.1016/j.baae.2010.11.008

Wilson, C. J., & Jamieson, M. A. (2019). The effects of urbanization on bee communities depends on floral resource availability and bee functional traits. *PLoS ONE*, *14*(12). https://doi.org/10.1371/journal.pone.0225852

Xiao, Y., Li, X., Cao, Y., & Dong, M. (2016). The diverse effects of habitat fragmentation on plant–pollinator interactions. *Plant Ecology*, *217*(7), 857–868. http://www.jstor.org/stable/24751107