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Pollinator Visitation Frequency Associated with Native and Non-native Plants in a Mid-Atlantic Piedmont (USA) Urban Garden

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ABSTRACT

The recent focus on the importance of native plants and their pollinators has highlighted the critical role of local species in their natural environment. As urban encroachment, climate change, and invasive species continues to threaten native habitats, it is increasingly important to promote the use of local green spaces as refugia for native plants and their pollinators. The aim of this project, therefore, was to identify and assess the visitation frequency of insect pollinators associated with an urban setting within the Piedmont region of Virginia, and compare their association with native versus closely-related but non-native summer-flowering plants. Several modes of insect examination were used to assess these metrics in the Brian Wesley Moores Native Plant Garden on the campus of Randolph-Macon College. We observed an overall preference for the native species on a total of four native:non-native pair comparisons, including a higher number of total insect visitors and a more diverse assortment of pollinator types. Our data supports the notion that native plant species should be prioritized in urban green spaces, as it provides the appropriate flora to support ecosystem balance in a setting threatened by human activities.

Keywords: native plants, non-native plants, pollination, urban garden

INTRODUCTION

Healthy native ecosystems are well known for their ability to provide such fundamental services as the production of consumable resources, the mitigation of climactic fluctuations, and the amelioration of anthropogenic environmental degradation (Daily et al., 1997; Tilman, 1997). In urban areas, they are also known to promote human health and well-being, in part through cultivation of a positive aesthetic (Pejchar and Mooney, 2009). Invasion of natural areas by non-native species can significantly hinder the provision of all of these benefits (Pimental, 1986; Vitousek et al., 1997). For example, plant pollination – both natural and managed – is a key ecosystem process that depends largely on the partnership between a plant and its pollinator(s) (Kearns and Inouye, 1997; Kearns et al., 1998). Effective pollination is critical to human health and agriculture, as over 80 percent of the plants grown for consumption and medicinal use rely on pollinators for reproduction and fruiting (Daily et al., 1997). Insects, in particular, are important pollinators, and at least one in every third bite of food in the American diet is courtesy of insect pollination (Klein et al., 2007; Potts et al., 2010). Over time, native plants and their pollinators have evolved a fragile co-dependence such that the loss of either member of the partnership (through pesticide use, disease, or the introduction of non-native species) can drastically reduce the survival of both (Kearns et al., 1998; Spira, 2001).

Until recently, imported European honeybees (*Apis mellifera*) have been managed as a pollination vector for many human agricultural crops. However, the onset of Colony Collapse Disorder – in which formerly healthy honeybee colonies have experienced a sudden, unexplained loss of adult workers – and subsequent financial losses to industrial agriculture has spurred research into the role and status of native insect pollinators. So far, results demonstrate that native pollinators – bees, in particular – are more than able to “pick up the slack” left by declining honeybee populations, in some cases demonstrating double the efficiency of non-native honeybees (Winfree et al., 2007; Garibaldi et al., 2013). Unfortunately, native pollinator populations are also in decline, in part as a result of habitat fragmentation (Garibaldi et al., 2013). Ongoing research supports urban agriculture and gardening as a way of providing “oases” for these native pollinators (Hennig and Ghazoul, 2012; Baldock et al., 2015) and has found that, in some cases, urban green spaces can support a diversity of insect pollinators that is concomitant with more rural, natural areas (Hennig and Ghazoul, 2012). In many cases, the targeted use of native plants in these spaces has been shown to more strongly promote overall biodiversity and ecosystem health, especially for insect pollinators co-adapted to take advantage of native resources (Frankie et al., 2002; Hanley et al., 2014).

It was the aim of this study to identify local insect pollinators and compare visitation frequency to common horticultural native and non-native summer-flowering perennials in an Ashland, VA, urban plant garden. Because of the strong co-dependence in plant/pollinator relationships, we expected native plants to play a more substantive role in pollination activity by drawing the highest abundance of local pollinators.

METHODOLOGY

Study site

Our study was conducted at the Brian Wesley Moores Native Plant Garden, located on the Randolph-Macon College campus in Ashland, VA (37°45’58.4” N 77°28”35.8” W). The garden comprises a 0.19-acre plot situated at the northeastern gateway to the college and is adjacent to a residential neighborhood (Figure 1). This area is part of the Piedmont Region of the Mid-Atlantic United States and is characterized by an acidic clay loam soil and a hardiness zone of 7a – 8 (USDA). Historically, the majority of the land in this area has seen heavy agricultural use (USDA).

Plant species

We used four locally native/non-native pairs of summer-flowering perennials that are commonly included in local gardens and managed landscapes. All species (locally-native and non-native) have a demonstrated record of attracting a wide range of pollinators (Lowenstein et al., 2015; Rowe et al., 2018). Locally-native species included: *Echinacea purpurea* (purple coneflower), *Liatris spicata* (blazing star), *Asclepias tuberosa* (butterflyweed), and *Monarda fistulosa* (wild bergamot). Associated non-native species were chosen based on four criteria: 1) they were in the same family as the native species, 2) they were available from local horticulture suppliers, 3) they had similar physiology and cultivation requirements as their native counterparts, and finally, 4) they were not endemic to the Piedmont region of the United States.

Experimental design

During June – July in the summer of 2018, each combination of native/non-native was monitored during their peak bloom season, as described below. Each pair consisted of one native and one non-native plant of similar size and flower number. Native/non-native pairs were as follows: *Echinacea purpurea* and *Gaillardia aristata* 'Bijou' (Asteraceae), *Liatris spicata* and *Liatris ligulistylis* (Asteraceae), *Asclepias tuberosa* and *Asclepias curassavica* 'Red Butterfly' (Apocynaceae), and *Monarda fistulosa* and *Agastache rugosa* 'Golden Jubilee' (Lamiaceae). Non-natives were grown in sunken pots directly adjacent to the native plants to minimize site-specific abiotic differences. For monitoring, a total of six replicate pairs were studied overall on seven (*E. purpurea* and *G. aristata*), seven (*L. spicata* and *L. ligulistylis*), ten (*A. tuberosa* and *A. curassavica*), and eight (*M. fistulosa* and *A. rugosa*) different occasions, respectively.

Pollinator visitation frequency

Pollinator visitation measurements were based on previously established techniques (Frankie et al., 2002) with minor modifications. In short, inflorescences on each native/non-native replicate plant pair were monitored during each species' peak bloom season. During a 10-minute window, the total number of visiting insect pollinators was recorded for each native and non-native member of each replicate pair. We defined a pollinator "visit" as a period in which a pollinator landed on a flower long enough to engage in pollination activity. Pollinators moving from flower to flower on the same plant were not considered to have made additional "visits." However, pollinators leaving one plant and then returning within the 10-minute window were tallied for an additional "visit." The six replicates were measured in succession, with measurements taken in both the morning (08:00 – 10:00) and afternoon (14:00 – 16:00). We compared pollinator activity using a multi-factor ANOVA (Microsoft Excel v.16.16.5), assessing the effect of date, replicate ($n = 6$), time of day (morning or afternoon), and type of plant (native or non-native) on the number of pollinator visits.

The identification of insect pollinators in each plant pair was assessed by visual documentation (with reference to photographic and voucher specimens). All insects visiting a replicate pair within each ten-minute observation period were identified to genus.

RESULTS

Insect pollinators

During the course of this study, we observed 25 different insect genera at the garden during monitoring periods (Table 1). In the genus, *Bombus,* three distinct species were observed. Overall insect genera fell into the following categories: bees (eight genera), flies (four genera), wasps (one genus), butterflies (ten genera), and beetles (two genera). Cumulatively, 11 genera (44%) were observed only on native floral species. There were no insect genera observed exclusively on non-native perennials.

Native/non-native pair visitation frequency

E. purpurea and *G. aristata*

The Piedmont native *E. purpurea* was compared to *G. aristata*, which is native to western and northern North America (USDA). Pollination measurements were conducted on these species between June 13 – July 19th, 2018, when the plants were in bloom locally.

Overall, *E. purpurea* experienced more pollinator visits than *G. aristata* (F_1 = 110.328, P < 0.001) (Figure 1A). Pollinator visitation also varied by collection date for all replicate pairs (F_6 = 4.701, P < 0.001), and more visitations were recorded during morning versus afternoon visits (F_1 = 103.754, P < 0.001).

More insect genera were observed on *E. purpurea* than on *G. aristata* during our monitoring period (Table 1). Insects seen interacting only with *E. purpurea* included seven bee taxa, four types of flies, and seven different butterflies or moths.

L. spicata and *L. ligulistylis*

The Piedmont native *L. spicata* was compared to *L. ligulistylis* (native to Central/Midwestern North America, USDA). *L. spicata* was found to attract a higher overall number of pollinator genera than *L. ligulistylis* (F_1 = 61.647, P < 0.001) (Figure 1B), although visitation frequency also varied by sample date (F_6 = 11.039, P < 0.001).

A wider variety of insect taxa was observed visiting *L. spicata* compared to *L. ligulistylis* (Table 1). In total, nine bee, two fly, eight different butterfly or moth, and one beetle taxa were observed visiting the native/non-native pair, and eleven of these seen were unique to *L. spicata*.

A. tuberosa and *A. curassavica*

The Piedmont native *A. tuberosa* was compared to *A. curassavica*, a Central/South American native (USDA). The native species, *A. tuberosa*, experienced a higher pollinator visitation frequency than *A. curassavica* (F_1 = 23.204, P < 0.001) (Figure 1C). In addition, visitation frequency was greater for both species during afternoon measurement periods (F_1 = 11.8, P < 0.001) and in some replicate pairs (F_5 = 3.413, P < 0.01).

More insect taxa were observed visiting *A. tuberosa* than *A. curassavica* (Table 1). The pollinators observed with this plant pairing were mostly bees – six taxa pollinated both native/non-native plant pairs, with only *Agopostemon virescens* and *Xylocopa virginica* unique to *A. tuberosa*. Only one butterfly species was observed during our monitoring periods; however, *D. plexippus* (Monarch butterfly) caterpillars were found on both plants later in the summer.

M. fistulosa and *A. rugosa*

The Piedmont native *M. fistulosa* was compared to *A. rugosa*, an East-Asian native. Insect pollinators visited *M. fistulosa* more frequently than *A. rugosa* (F_1 = 71.746, $P < 0.001$) Figure 1D), although both native and non-natives saw more frequent visitation during the afternoon (F_1 = 4.522, $P < 0.05$), and visits to both plant species decreased as the season progressed (F_7 = 6.043, $P < 0.001$).

M. fistulosa attracted more total insect groups than *A. rugosa* (Table 1). Between native/non-native pairs, we observed six bees, three flies, one wasp, and three butterfly or moth taxa. Two bee genera, *Halictus* and *Ceratina*, were unique visitors to the non-native *A. rugosa*.

DISCUSSION

Our goal in this investigation was to compare the visitation frequency as well as the overall variety of insect pollinators associated with native versus non-native perennial plants in an urban garden setting. As horticultural consumers are typically presented with a variety of touted “pollinator-friendly” perennials, the relative efficacy of native versus non-natives in this regard is an important factor for amateur gardeners to consider. Our findings revealed that, when comparing pairs of related, perennial native and non-native “pollinator-friendly” plant species, the natives were consistently visited by a higher total number of insects. Moreover, of the total variety of insect genera observed during our course of study, nearly half were associated only with native perennial species.

Our findings suggest that, when given a choice between two genetically and visually similar flowering perennials, more insects are likely to interact with a local native than with a non-native species. These results are consistent with studies performed under similar environs. For instance, Hanley et al. (2014) found that specialist bumblebees (*Bombus* spp.) in urban gardens tended to forage preferentially on plants native to their own biogeographical ranges. Likewise, a study by Fukase and Simons (2016) found that increased native plant species richness in urban Canadian gardens was correlated positively with pollinator foraging in those areas. These results, and those of our own study, argue for the preferential inclusion of locally native – rather than similar, non-native – plant species in urban landscape gardens.

Note must also be taken, however, of the difference between the need and niche requirements of different insect pollinators. Simply because a plant is native does not unilaterally make it more attractive to a visiting insect. Specialist pollinators, for instance, may require particular nutrients or habitats, while generalists are widely adaptable. For instance, *Bombus impatiens* (Eastern bumble bee) is well-documented as a generalist pollinator and is widely managed for the pollination of agricultural crops (Kleijn and Raemakers, 2008). In our study, *B. impatiens* was the only insect observed interacting with all eight plant species. Several studies have noted the likelihood of non-native plant species to appeal more strongly to generalist pollinators (Albrecht et al., 2014) and question the need to prioritize native plantings in urban gardens (Hanley et al., 2014; Goddard et al., 2010). However, the mechanisms for this preference remain unclear and are likely species-specific, based on particular floral characteristics (Corbet et al., 2001; Poythress and Affolter, 2018). Until the mechanisms responsible for these observations are clarified, it is unwise to generalize the value of native versus non-native plants to plant-pollinator interactions.

During the course of our study, we also observed several insect taxa that visited only native plants. In a few cases, an insect pollinator was seen on one native plant species and no others. *Vanessa virginiensis* (American painted lady), for instance, visited only the native *E. purpurea*. *V. virginiensis* is a specialist butterfly whose larvae preferentially feed on plants in the family Asteraceae (such as *E. purpurea*) (Holm, 2014). Specialist insects, whether pollinators or otherwise, are closely dependent on their coevolutionary floral counterparts. The inclusion of beneficial host plants in urban gardens has been suggested to increase the abundance of specialist pollinations in those areas (Harrison and Winfree, 2015), and have the potential to provide resources in fragmented urban habitats.

Interestingly, all of the 10 butterfly genera observed in our study visited one or more native plant species. Of these, 7 visited natives exclusively. We observed a unanimous preference for *E. purpurea* over *G. aristata*, and *L. ligulistylis* was the only non-native visited by more than one type of butterfly. One reason for such a distinct disparity in visitation frequency may stem from our use of horticultural cultivars as non-native counterparts in this study. Horticultural cultivars are wild-type plants that have been bred specifically to present certain qualities. In the case of urban landscape gardens, such qualities might include differences in flower color or morphology. These changes, while desirable to the urban gardener, may be unappealing to pollinators or other insects (Comba et al., 1999). Emergent studies have suggested that horticultural cultivars may provide less benefit in terms of nutrient quality and floral reward (Comba et al., 1999; Corbet et al., 2001; Pothyress and Affolter, 2018). Although the study of horticultural cultivars versus non-cultivars was not a part of our study, it is worth note that, *L. ligulistylis*, the non-native most frequented by butterflies, was also the only non-native non-cultivar.

Prolificacy of urban green space is a good option for many reasons. In our study, the demonstrated pollinator preference for native plant species supports the prioritization of native plant species in urban landscapes. As has been shown in previous studies, increasing the proportion of native plants can also increase the proportion of rare or specialized pollinators (Fukase and Simon 2016). In our study, pollinator preference for the native was maintained despite the choice for a nearby non-native, although several scaled factors may have influenced this preference (Mitchell et al., 2009; Kantsa et al., 2018), from providing an idealized reward to fine-tuning its accessibility. While such was not our goal, the identification and assessment of these factors are also likely to play a role in increasing and preserving pollinator activity in urban landscape gardens.

To conclude, our study provides a baseline for understanding pollinator presence in our local area and supports the argument for including native flowering perennials in the garden. With worldwide insect populations in likely decline (Hallmann et al., 2017; Lister and Garcia, 2018), urban green spaces are proving to be even more essential. Future studies on plant-pollinator relationships and the role of native species in the urban landscapes will lend a more ecological understanding to our horticultural choices and help us to harmonize the aesthetics with the efficacy of our own local gardens in the larger, urban ecosystem.

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NR participated in study design, data collection and analysis, and manuscript preparation. BS participated in study design, data analysis, and manuscript preparation. SR and EM participated in data collection and analysis.

LITERATURE CITED

Albrecht, Matthias, Padrón, Benigno, Bartomeus, Ignasi, and Traveset, Anna. 2014. Consequences of plant invasions on compartmentalization and species' roles in plant-pollinator networks. *Proceedings of the Royal Society B* 281: 20140773

Baldock, Katherine C.R., Goddard, Mark A., Hicks, Damien M., Kunin, William E., Mitschunas, Nadine, Osgathorpe, Lynne M., Potts, Simon G., Robertson, Kirsty M., Scott, Anna V., Stone, Graham N., Vaughan, Ian P., and Memmott, Jane. 2015. Where is the UK's pollinator biodiversity? The importance of urban areas for flower-visiting insects. *Proceedings of the Royal Society B* 282: 20142849

Comba, Livio, Corbet, Sarah A., Barron, A., Bird, A., Collinge, S., Miyazaki, N., and Powell, M. 1999. Garden flowers: insect visits and the floral reward of horticulturally-modified variants. *Annals of Botany* 83: 73–86

Corbet, Sarah A., Bee, Jennie, Dasmahapatra, Kanchon, Gale, Stephan, Gorringe, Elizabeth, La Ferla, Beverly, Moorhouse, Tom, Trevail, Andrea, Van Bergen, Yfke, and

Vorontsova, Maria. 2001. Native or exotic? Double or single? Evaluating plants for pollinator-friendly gardens. *Annals of Botany* 87(2): 219–232

Daily, Gretchen C., Alexander, Susan, Ehrlich, Paul R., Goulder, Larry, Lubchenco, Jane, Matson, Pamela A., Mooney, Harold A., Postel, Sandra, Schneider, Stephen H., Tilman, David, and Woodwell, George M. 1997. Ecosystem services: benefits supplied to human societies by natural ecosystems. *Issues in Ecology* 2: 1-16

Frankie, Gordon W., Thorp, Robbin W., Schindler, Mary H., Ertter, Barbara, and Przybylski, Margaret. 2002. Bees in Berkeley? *Fremonita* 30 (3-4): 50-58

Fukase, J., and Simons, Andrew M. 2016. Increased pollinator activity in urban gardens with more native flora. *Applied Ecology and Environmental Research* 14(1): 297-310

Garibaldi, Lucas A., Steffan-Dewenter, Ingolf, Winfree, Rachael, Aizen, Marcelo A., Bommarco, Riccardo, Cunningham, Saul A., Kremen, Claire, Carvalheiro, Luísa G., Harder, Lawrence D., Afik, Ohad, Bartomeus, Ignasi, Benjamin, Faye, Boreux, Virginie, Cariveau, Daniel, Chacoff, Natacha P., Dudenhöffer, Jan H., Freitas, Breno M., Ghazoul, Jaboury, Greenleaf, Sarah, Hipólito, Juliana, Holzschuh, Andrea, Howlett, Brad, Isaacs, Rufus, Javorek, Steven K., Kennedy, Christina M., Krewenka, Kristin M., Krishnan, Smitha, Mandelik, Yael, Mayfield, Margaret M., Motzke, Iris, Munyuli, Theodore, Nault, Brian A., Otieno, Mark, Petersen, Jessica, Pisanty, Gideon, Potts, Simon G., Rader, Romina, Ricketts, Taylor H., Rundlöf, Maj, Seymour, Colleen L., Schüepp, Christof, Szentgyörgyi, Hajnalka, Taki, Hisatomo, Tscharntke, Teja, Vergara, Carlos H., Viana, Blandina F., Wanger, Thomas C., Westphal, Catrin, Williams, Neal, and Klein, Alexandra M. 2013. Wild pollinators enhance fruit set of crops regardless of honey bee abundance. *Science* 339: 1608-1611

Goddard, Mark A., Dougill, Andrew J., and Benton, Tim G. 2010. Scaling up from gardens: biodiversity conservation in urban environments. *Trends in Ecology and Evolution* 25(2): 90-98

Hallmann, Caspar A., Sorg, Martin, Jongejans, Eelke, Siepel, Henk, Hofland, Nick, Schwan, Heinz, Stenmans, Werner, Müller, Andreas, Sumser, Hubert, Hörren, Thomas, Goulson, Dave, and de Kroon, Hans. 2017. More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLoS ONE* 12(10): e0185809

Hanley, Mick E., Awbi, Amanda J., and Franco, Miguel. 2014. Going native? Flower use by bumblebees in English urban gardens. *Annals of Botany* 113(5): 799-806

Harrison, Tina, and Winfree, Rachael. 2015. Urban drivers of plant-pollinator interactions. *Functional Ecology* 29: 879-888

Hennig, Ernest I., and Ghazoul, Jaboury. 2012. Pollinating animals in the urban environment. *Urban Ecosystems* 15(1): 149-166

Holm, Heather. 2014. Pollinators of native plants. Pollination Press LLC, Minnetonka MN. 305 pp.

Kantsa, Aphrodite, Raguso, Robert A., Dyer, Adrian G., Oleson, Jens M., Tscheulin, Thomas, and Petanidou, Theodora. 2018. Disentangling the role of floral sensory stimuli in pollination networks. *Nature Communication* 9: 1041

Kearns, Carol A., and Inouye, David W. 1997. Pollinators, flowering plants, and conservation biology. *BioScience* 47(5): 297–307

Kearns, Carol A., Inouye, David W., and Waser, Nickolas M. 1998. Endangered mutualisms: the conservation of plant-pollinator interactions. *Annual Review of Ecology and Systematics* 29: 83–112

Kleijn, David, and Raemakers, Ivo. 2008. A retrospective analysis of pollen host plant use by stable and declining bumble bee species. *Ecology* 89(7): 1811-1823

Klein, Alexandra-Maria, Vaissière, Bernard E., Cane, James H., Steffan-Dewenter, Ingolf, Cunningham, Saul A., Kremen, Claire, and Tscharntke, Teja. 2007. Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B* 274: 303–313

Lister, Bradford C., and Garcia, Andres. 2018. Climate-driven declines in arthropod abundance restructure a rainforest food web. *Proceedings of the National Academy of Sciences USA* 115 (44): E10397-E10406

Lowenstein, David M., Matteson, Kevin C., and Minor, Emily S. 2015. Diversity of wild bees supports pollination services in an urbanized landscape. *Oecologia* 179(3): 811-821

Mitchell, Randall J., Irwin, Rebecca A., Flanagan, Rebecca J., and Karron, Jeffrey D. 2009. Ecology and evolution of plant-pollinator interactions. *Annals of Botany* 103(9): 1355-1363

Pejchar, Liba, and Mooney, Harold A. 2009. Invasive species, ecosystem services and human well-being. *Trends in Ecology and Evolution* 24(9): 497-504

Pimentel, David. 1986. Biological invasions of plants and animals in agriculture and forestry. In *Ecology of Biological Invasions of North America and Hawaii*. Harold A. Mooney and James A. Drake, *eds*. Springer-Verlag, New York NY, Vol. 58, pages 149-162

Potts, Simon G., Biesmeijer, Jacobus C., Kremen, Claire, Neumann, Peter, Schweiger, Oliver, and Kunin, William E. 2010. Global pollinator declines: trends, impacts and drivers. *Trends in Ecology and Evolution* 25(6): 345-353

Poythress, J.C., and Affolter, James M. 2018. Ecological value of native plant cultivars versus wild-type native plants for promoting Hemipteran diversity in suburban areas. *Environmental Entomology* 47(4): 890-901

Rowe, Logan, Gibson, Daniel, Landis, Douglas, Gibbs, Jason, and Isaacs, Rufus. 2018. A comparison of drought-tolerant prairie plants to support managed and wild bees in conservation programs. *Environmental Entomology* 47(5): 1128-1142

Spira, Timothy P. 2001. Plant-pollinator interactions: a threatened mutualism with implications for the ecology and management of rare plants. *Natural Areas Journal* 21(1): 78-88.

Tilman, David. 1997. Biodiversity and ecosystem functioning. In *Nature's Services: Societal Dependence on Natural Ecosystems*. Gretchen C. Daily, editor. Island Press, Washington, DC, pages 93-112

Vitousek, Peter M., D'Antonio, Carla M., Loope, Lloyd L., Rejmánek, Marcel, and Westbrooks, Randy. 1997. Introduced species: a significant component of human-caused global change. *New Zealand Journal of Ecology* 21(1): 1–16

United States Department of Agriculture (USDA): Natural Resources Conservation Service. https://plants.usda.gov/

Winfree, Rachael, Williams, Neal M., Dushoff, Jonathan, and Kremen, Claire. 2007. Native bees provide insurance against ongoing honey bee losses. *Ecology Letters* 10: 1105-1113

TABLE 1. Insects observed interacting with study plants during monitoring periods.

Pollinators		Native	Non-native	Native	Non-native	Native	Non-native	Native	Non-native
Latin	**Common**	***E. purpurea***	***G. aristata***	***L. spicata***	***L. ligulistylis***	***A. tuberosa***	***A. curassavica***	***M. fistulosa***	***A. rugosa***
Bombus pensylvanicus	American bumble bee	x						x	
Bombus impatiens	Eastern bumble bee	x	x	x	x	x	x	x	x
Bombus griseocollis	Brown-belted bumble bee			x					
Xylocopa virginica	Eastern carpenter bee	x		x		x		x	
Ceratina spp.	Small carpenter bee					x	x		x
Halictus spp.	Sweat bee	x		x		x	x		x
Agapostemon virescens	Green sweat bee	x	x	x	x	x			
Lasioglossum spp.	Sweat bee	x	x	x		x	x	x	x
Augochlora pura	Sweat bee			x	x	x	x		
Apis mellifera	Honey bee	x		x	x	x	x	x	x

Syritta pipiens	Thick-legged hoverfly	x		x		x			
Toxomerus geminatus	Syrphid fly	x	x	x	x	x		x	
Eristalis tenax	Drone fly	x	x					x	
Lucilia sericata	Green bottle fly	x	x			x	x	x	
Vespula spp.	Yellow jacket wasps							x	x
Speyeria cybele	Great spangled fritillary	x							
Vanessa virginiensis	American painted lady	x							
Pieris rapae	Cabbage white	x		x	x				
Alypia octomaculata	Eight-spotted forester	x		x					
Danaus plexippus	Monarch	x		x	x				
Polites themistocles	Tawny-edged skipper	x		x			x		
Epargyreus clarus	Silver-spotted skipper	x		x	x			x	x

Erynnis spp.	Dusky wing skipper			x					
Phycoides spp.	Crescent butterfly					x			
Hemaris diffinis	Snowberry clearwing			x				x	
Diabrotica undecimpunctata howardii	Spotted cucumber beetle			x					
Labidomera clivicollis	Milkweed leaf beetle					x	x		

FIGURE 1. Aerial view of the Randolph-Macon College Brian Wesley Moores native plant garden. Plant pair locations are indicated with circles (Red = *E. purpurea*, Blue = *L. spicata*, Orange = *A. tuberosa*, Magenta = *M. fistulosa*). For scale, the square drone landing pad along the walking path is 3' x 3'. Photo credit to John McManus (Randolph-Macon College), taken on Oct. 28th, 2018.

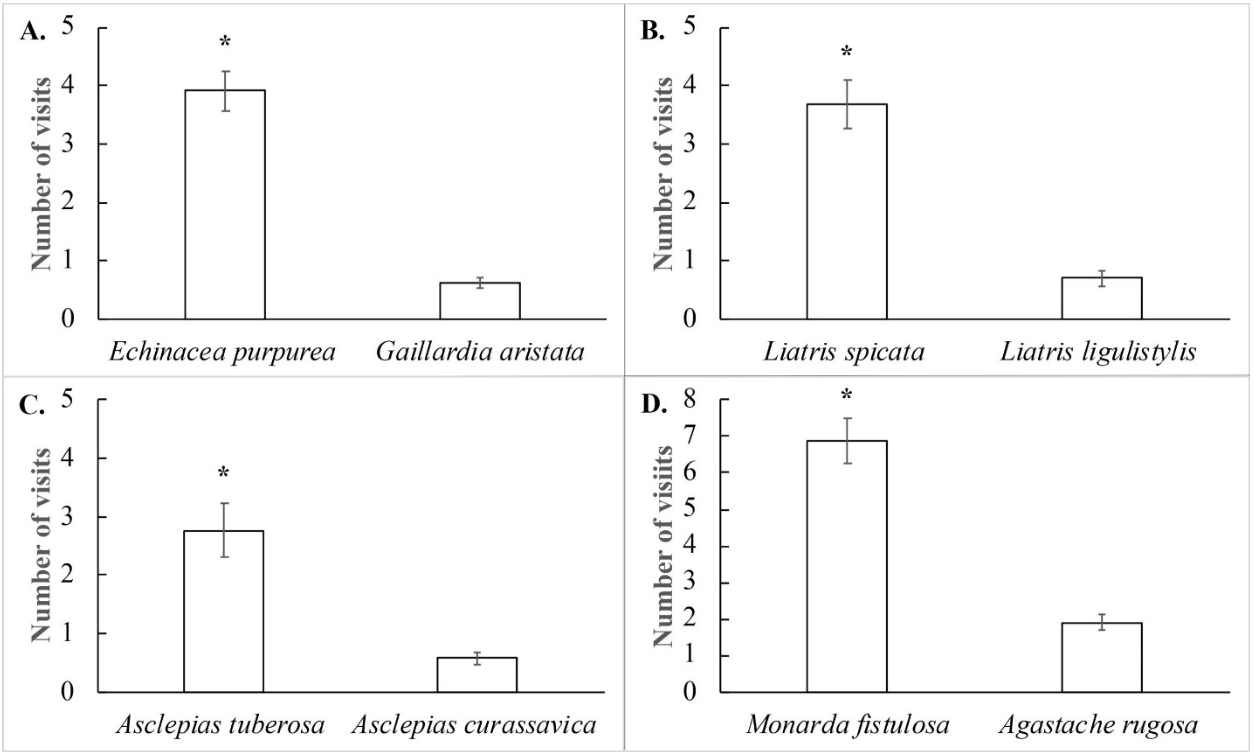

Figure 2. Comparison of mean pollinator visitation frequency to native/non-native paired plant sets showed a significantly higher number of visits made to native plants. Asterisks (*) represent significant differences ($p<0.001$) in visitation frequency. Error bars represent ±SE.