THESIS

# INVESTIGATION OF FLOWERING PHENOLOGY, POLLINATOR AND INVERTEBRATE BIODIVERSITY VALUE ON URBAN GREEN ROOFS AND AN EVALUATION OF ORNAMENTAL HORTICULTURE CROPS FOR POLLINATOR VALUE

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Fall 2023

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# ABSTRACT

# INVESTIGATION OF FLOWERING PHENOLOGY, POLLINATOR AND INVERTEBRATE BIODIVERSITY VALUE ON URBAN GREEN ROOFS AND AN EVALUATION OF ORNAMENTAL HORTICULTURE CROPS FOR POLLINATOR VALUE

Urban green space, green infrastructure, and horticultural installations are gaining recognition for their potential to foster biodiversity. Green roofs are challenging growing environments for plants, characterized by extreme substrate temperatures, high light intensity, limited moisture availability, and limited substrate depth. Plants have a variety of physiological responses to these unique conditions, but little is known about how green roof growing conditions affect ecological characteristics like plant flowering phenology. Similarly, studies are only just beginning to uncover the degree to which green roofs can provision habitat and support urban biodiversity. We evaluated the flowering phenology and made in-situ pollinator observations of 15 plant taxa growing both on green roof systems and at ground level at the Denver Botanic Gardens over two growing seasons. Using the same study sites, we sampled invertebrate diversity on green roof sites and ground level using pitfall traps. Finally, using a large citizen-science dataset, we evaluated differences in pollinator visitation with a specific focus on plant nativity, cultivated origin, growth form. We found that flowering phenology is substantially earlier on green roofs compared to ground level. We also observed a greater number of pollinators on green roofs early in the season, compared to ground level, presumably due to the availability of flora resources among the observed plant taxa. We observed significantly higher substrate temperatures along with wider diurnal temperature amplitude during the growing season that may contribute to this pattern. Invertebrate abundance was substantially higher at ground-level, species richness was similar between the intensive green roof and ground-level, and we observed substantially lower abundance and richness on the extensive green roof. Divergence in flowering phenology between individual plants of the same species on green roofs and plants at ground-level may have implications for organisms that rely on floral resources in urban environments. Earlier flower initiation on green roofs may provide pollinators with unique foraging opportunities and aid targeted conservation where early-season floral resources are limited. Similarly, results from invertebrate sampling suggest that green roofs, especially intensive roofs with high vegetation coverage, species richness, and habitat heterogeneity may offer invertebrate habitat on par with ground-level urban gardens and may even support unique groups of invertebrate taxa. Our results from our citizen science pollinator observations demonstrate that non-native plants showed similar visitation compared to native plants, but origin was important with selections and species having significantly higher pollinator visitation compared to hybrid plants. Shrubs and herbaceous perennials demonstrated high pollinator visitation compared to other plant growth forms.

# ACKNOWLEDGEMENTS

In appreciation of:

The entire Bousselot Lab group: including Brian Adams, Dr. Maria Chavez, Thomas Hickey, Allisa Linfield, Kyle Ruszkowski, Amanda Guedes Salerno, Armando Villa-Ignacio, and Blake Gornick. You all contributed to making this project possible.

My advisor: Dr. Bousselot for fostering my scientific interest and starting down this circuitous path with me over four years ago. You have been deeply compassionate as I've juggled a demanding career, changed degree programs, written a book, and taken on more work than has been wise over the course of this program. I am deeply grateful.

My committee for their valuable feedback. You have helped me become a better scientist.

The GDPE program and community for welcoming a horticultural interloper into your midst and embracing possibilities for synergy and collaboration.

Denver Botanic Gardens for supporting my graduate education and making generous accommodations to allow me to attend classes and commute to campus. And of course, for the use of the green roofs, gardens, and lab facilities to complete data collection and analysis.

My Denver Botanic Gardens colleagues Sonya Anderson, Dan Johnson, Mike Kintgen, Elena Shtern, Amy Schneider, and Kevin Williams who generously allowed me to access, tag, observe, and collect samples from their beautifully stewarded garden spaces.

Denver Botanic Gardens volunteers Linda Cochran, Ann Frazier, and Bill and Betsy Georgitis whose commitment to pollinator conservation disproportionately contributed to the dataset analyzed in Chapter 3 of this manuscript.

Lisa Mason for her development of the Native Bee Watch Protocol and taking the time to train me in native bee identification.

Riley Hoffman for her long hours processing arthropod samples and helping with the identification of countless invertebrates that were beyond my skillset. I am still sorry about how many sow bugs you had to count.

Kyle Ruszkowski, whose time as an intern at Denver Botanic Gardens helped to sharpen the focus of this study and for countless hours of data collection that made it possible. I am proud of how much you have achieved since I met you.

# PREFACE

"The ecological thought understands that there never was an authentic world. This doesn't mean that we can do what we like with where we live, however. Thinking big means realizing that there is always more than our point of view. There is indeed an environment, yet when we examine it, we find it is made of strange strangers. Our awareness of them isn't always euphoric or charming or benevolent. Environmental awareness might have something intrinsically uncanny about it, as if we were seeing something we shouldn't be seeing, as if we realized we were caught in something."

-Timothy Morton. The Ecological Thought

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# CHAPTER 1. FLOWERING PHENOLOGY AND POLLINATOR VISITATION ON URBAN GREEN ROOFS COMPARED TO GROUND-LEVEL GARDENS

## 1.1 Introduction

### *Green roofs as ecosystems*

Green roofs provide urban ecosystem services including wildlife habitat, pollination services, urban heat island reduction, and stormwater management (Getter & Rowe, 2006). Recent work has encouraged green roof designers, practitioners, and horticulturists to apply ecological understanding when considering green roofs and to apply ecological theory to enhance the capacity of green roofs to support biodiversity and inform plant selection (Dvorak & Bousselot, 2021; Oberndorfer et al., 2007; Blaustein et al., 2016). The abiotic conditions of green roof systems are of particular interest because they are likely to have a direct effect on plant growth and survival.

It is widely recognized that green roof conditions present challenges to plant growth and survival, including high and low air and substrate temperatures, high light intensity, limited moisture availability, limited substrate depth, and direct exposure to weather events. Plant selection for green roofs has therefore targeted species that can cope with these conditions (Rayner et al., 2016) and selection had been especially important in semi-arid climate regions (Schneider et al., 2014; Schneider et al., 2021). Researchers have evaluated individual plant responses to green roof conditions including drought stress and substrate depth (Nektarios et al., 2015; Thuring et al., 2010), but most of these studies have operated at an organismal or physiological level. Less is known about how green roof conditions may affect broader ecological characteristics such as pollinator visitation or arthropod species richness, especially in urban areas and when compared to similar plants and cultivated green space and ecological communities at ground level.

*Phenology and Green Roofs*

Plant phenology is a crucial ecosystem characteristic that can influence many ecosystem functions and characteristics including pollination and plant reproductive success, but it remains an understudied aspect of green roof ecology. Plants on green roofs have, anecdotally, been noted to bloom earlier on rooftops than in other urban green space at ground-level in the spring. The primary reason for the observed earlier bloom time is unknown but assumed to be related to green roof air and substrate temperatures, which are presumed to be higher in both spring and fall compared to native soils at ground level. Temperate zone plants, especially day neutral species, often bloom when environmental conditions are ideal, which can be influenced by root zone temperatures (Greer et al., 2006).

Research suggests that flowering phenology is driven primarily by temperature and photoperiod in most temperate plant species and phenological events are most likely triggered by an interaction between these two variables (Zhang et al., 2004). Additionally, substrate moisture levels, which are often low on green roof systems, have been shown to advance flowering phenology in natural systems through plant physiological water stress (J. Aronson et al., 1992) and ambient heat and drought, including climate change trends, demonstrably alter the flowering phenology of plants, often reducing floral resources in natural systems (Dunne et al., 2003). In arid and semi-arid climates, moisture may be a primary trigger for flower initiation, but is also thought to interact with temperature and photoperiod to determine phenological plant response (Abd El-Ghani, 1997; Friedel et al., 1993).

Given these strong effects of temperature and drought stress on plant phenology, the green roof environment is likely to strongly alter the timing of plant life cycle events. Green roofs often exacerbate both temperature and water stress in plants, which should lead to earlier flowering than the surrounding areas at ground level, and shorter total bloom time. Simultaneously, plants in urban areas already bloom earlier than surrounding un-urbanized habitats largely due to the urban heat island effect (Neil & Wu, 2006) and green roofs are likely more sensitive to this effect than other types of urban green space due to their broad environmental exposure.

### *Substrate Temperature*

Substrate temperature on green roofs is most often investigated as it relates to building energy conservation and the insulating properties of green roofs (Lundholm et al., 2014) or how canopy density or plant type effects substrate temperature (Lundholm, 2015) rather than its effects on plant growth. It is likely that substrate temperature extremes may affect plant growth more strongly in semi-arid environments like Denver, CO than more temperate climates due to the wide diurnal temperature variations characteristic of dry, continental climates. Reyes et al. (2016) demonstrated that in a semi-arid climate, green roof substrate temperatures frequently reach plant heat-stress thresholds and that substrate depth was the primary factor controlling temperature amplitude.

### *Plant Pollinator Interactions*

The symbiosis between flowering plants and their pollinators is well established (Johnson & Steiner, 2000). The timing of flowering affects which arthropods are available to visit flowers and potentially pollinate them (Rafferty & Ives, 2011). It also can affect pollinator reproductive success, particularly for bees that rely upon pollen for reproduction (Thomson, 2010; Olgilve et al 2017). If plants on green roofs have an altered flowering phenology that results in earlier bloom in the spring and repeat bloom in fall, that would theoretically increase the window of time that flower visitors are able to forage and therefore increase their access to food sources, and potentially increase reproductive success. With pollinator populations in decline across North America (Potts et al., 2010), widening the window of time to forage may benefit pollinator species. Simultaneously, climate change has led to pollinators emerging from diapause earlier in the spring and remaining active later in the fall. For example, a study in the UK demonstrated that bumblebees emerged about 2 weeks earlier due to climate change effects (Sparks and Collison, 2007) and other work suggests similar patterns of altered pollinator emergence along rural-to-urban gradients as urbanization increases ambient temperatures (Fisogni et al., 2022).

Planting combinations and diverse functional planting groups appear to enhance abiotic ecosystem functions such as water capture, evapotranspiration, and ambient temperature reduction on green roofs (Lundholm et al., 2010) Similarly, green roofs have been shown to host comparable measures of biodiversity compared to green space counterparts at ground level (Filazzola et al 2019). However, research investigating pollinator richness on green roofs has been conflicting. Native bee diversity has been shown to be lower on green roofs than surrounding reference habitats, and bee abundance has been shown to increase with plant diversity and complexity of planting composition (Tontietto et al 2011). Other work indicates that green roofs have significantly higher abundance of some species of native bees than ground level and may provide unique habitat and foraging opportunities compared to sites at ground level (Colla et al., 2009).

### *Study Aims*

The aims of this study were to: 1) quantify flowering time and duration of plants growing on green roofs compared to ground-level, 2) determine if any apparent differences in phenology were related to differences in substrate temperatures between locations, and 3) determine if pollinator foraging on green roofs exhibits different temporal patterns compared to ground level while also describing differences in pollinator abundance and diversity between the two spaces.

## 1.2 Materials and Methods

### 1.2.1 Study Site

The study was conducted at the Denver Botanic Gardens in Denver, Colorado (39.732072, -104.960823). Observations occurred on two green roof installations and at various locations within a 24-acre campus of ornamental gardens at ground-level and all observations were made within a 200m radius of one another. The primary green roof used in this study is a large mixed-intensive green roof, the Mordecai Children's Garden (Figure 1). The installation contains diverse horticultural plantings, the planting bed area is 1230 $m^2$, substrate depth ranges from 5cm to 61cm, and the overall height rises 5-8m above grade. A second 195$m^2$ extensive green roof is on site located 4m above grade and has substrate depths ranging from 10 cm to 45.7 cm (Figure 2). Both green roofs have similar substrate media; the larger intensive green roof consists of 75% expanded shale aggregate, 20% compost and 5% zeolite whereas the smaller extensive green roof has media composed of 80% expanded shale and 20% compost.

Figure 1. The mixed intensive green roof site at Denver Botanic Gardens.

Figure 2. The extensive green roof site at Denver Botanic Gardens.

### 1.2.2 Local Climate Conditions

Denver, Colorado (USA) is a cold steppe climate according to the Köppen-Geiger climate classification. The climate is characterized by hot summers and cold, dry winters. The mean temperature is 10.3°C and mean annual precipitation is 363 mm (US Department of Commerce, n.d.). The majority of precipitation comes in the spring (March-May) or in mid-summer storms driven by the North American monsoon. Denver, CO has a significant urban heat island effect with daily summer urban-rural temperature differences of 3.3°C (Smith et al., n.d.).

### 1.2.3 Plant Selection and Inclusion Criteria

Ground-level gardens at Denver Botanic Gardens house many of the same plant species as the onsite green roofs, therefore we evaluated 15 plant species (Table 1) that are represented on both a green roof system onsite and at ground-level on the main campus of ; six species were observed in 2019 and the full array of 15 were observed in 2020. Plants were selected based on availability (already growing on one of the green roofs and at gr), a wide phenological range (i.e., early, mid, and late-season bloom times), and a broad taxonomic range. Accession records from BG-BASE, a database application written primarily to handle the information management needs of institutions holding collections of biological material, including botanic gardens, arboreta and herbaria, were used to control for differences in plant age or origin; only accessions 3-10 years old were included to minimize phenological differences associated with plant age. Accessions from wild collected germplasm were excluded meaning that evaluated plants were of cultivated origin. Five of the species are native to the US state of Colorado and eight are native to the continental US (table 1).

Table 1. Plant species evaluated in the study. Bloom times are subdivided as follows: early (April-May), mid (June-July), and late (August-October).

| **Scientific Name** | **Species Code** | **Common Name** | **Growth Form** | **Family** | **Provenance** | **Bloom Time** |
|---|---|---|---|---|---|---|
| *Allium* 'Millenium' | ALMI | Ornamental Onion | Forb | Liliaceae | Eurasia | Mid |
| *Chrysothamnus nauseosus* ssp. *nauseosus* | CHNA | Baby Blue Rabbitbrush | Shrub | Asteraceae | US (CO) | Late |
| *Dianthus plumarius* | DIPL | Feather Pinks | Forb | Caryophyllaceae | Europe | Early/Mid |
| *Echium russicum/amoenum* | ECRU | Red Feathers | Forb | Boraginaceae | Eurasia | Early/Mid |
| *Eriogonum jamesii* | ERJA | James' Buckwheat | Forb | Polygonaceae | US (CO) | Mid |
| *Geum triflorum* | GETR | Prairie Smoke | Forb | Rosaceae | US (CO) | Early |
| *Ipomopsis aggregata* | IPAG | Scarlet Gilia | Forb (biennial) | Polemoniaceae | US (SW) | Mid/Late |
| *Liatris spictata* | LISP | Blazing Star | Forb | Asteraceae | US | Mid |
| *Penstemon pinifolius* | PEPI | Pineleaf penstemon | Subshrub | Plantaginaceae | US (SW) | Mid |
| *Penstemon strictus* | PEST | Rocky Mountain Penstemon | Forb | Plantaginaceae | US (CO) | Mid |
| *Dasiphora fruticosa* | DIFR | Shrubby cinquefoil | Shrub | Rosaceae | US (CO) | Early/Mid |
| *Pulsatilla vulgaris* | PUVU | Pasqueflower | Forb | Ranunculaceae | Eurasia | Early |
| *Salvia cyanescens* | SACY | Turkish Sage | Forb | Lamiaceae | Eurasia | Mid |
| *Teucrium cossonii* | TECO | Fruity germander | Subshrub | Lamiaceae | Eurasia | Late |
| *Thymus serphyllum* 'Pink Chintz' | THSE | Ornamental Thyme | Creeping Forb | Lamiaceae | Eurasia | Early/Mid |

### 1.2.4 Substrate Temperature and Abiotic Conditions

During the course of the study HOBO temperature data loggers (HOBO Pendant® MX MX2201) were installed in the soil within 2m of every observed plant at a depth of 15 cm and recorded temperature readings every 15 minutes. Air temperature and other weather data were collected onsite using an automated weather station and precipitation data were measured onsite as part of the Community Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS). We extracted monthly mean high and low temperatures and average monthly precipitation over the course of the study period. Irrigation rates as well as any key maintenance that would affect the study plants was noted over the course of the study. Selected plant species were growing under analogous conditions in both green roof and ground-level locations, including similar exposure, aspect, and irrigation schedule. Edaphic conditions were not controlled due to the observational nature of the study, however soils at ground level were high in coarse inorganic material, similar to the green roof media (see edaphic properties in Table 2).

Table 2. Edaphic characteristics of green roof and ground-level garden soil and soilless media (AG = Ground Level, GR = Green roof).

| **Location** | **pH** | **EC (mmhos/cm)** | **NO3 (ppm)** | **P (ppm)** | **K (ppm)** | **%OM** | **% Sand** | **% Silt** | **% Clay** | **Texture Class** |
|---|---|---|---|---|---|---|---|---|---|---|
| **AG1** | 7.4 | 0.9 | 15.3 | 22 | 95 | 3.4 | 82 | 3 | 15 | Sandy Loam |
| **AG2** | 7.5 | 0.9 | 3.4 | 38 | 234 | 4.9 | 62 | 20 | 18 | Sandy Loam |
| **AG3** | 7.5 | 0.9 | 41.1 | 62 | 331 | 8.0 | 69 | 13 | 18 | Sandy Loam |
| **AG4** | 7.7 | 0.9 | 22.6 | 83 | 556 | 8.4 | 67 | 15 | 18 | Sandy Loam |
| **AG5** | 7.6 | 0.9 | 5.7 | 59 | 352 | 6.0 | 67 | 10 | 23 | Sandy Loam |
| **AG6/7** | 7.5 | 0.8 | 22.4 | 48 | 147 | 4.0 | 72 | 10 | 18 | Sandy Loam |
| **GR1** | 7.8 | 1.0 | 12.9 | 64 | 125 | 5.1 | 70 | 13 | 18 | Sandy Loam |
| **GR2** | 7.9 | 0.8 | 5.0 | 38 | 119 | 8.6 | N/A | N/A | N/A | N/A |

### 1.2.5 Phenology Observations

Five individual plants per species on both the green roof and the ground-level gardens (total of 10 plants per species) were marked with zinc labels and evaluated weekly for flower development, bloom time, fruit, and seed development during the growing seasons (March 15th through October 31) of 2019 and 2020. We recorded the timing and number of flowers, timing and presence of flower buds, fruits or seed capsules, and ripe fruits or seeds. The presence of fruit or seeds was recorded when seed capsules or fruits began to swell and ripe fruits and seeds were recorded when seeds were dehiscent and mature.

Since flower morphology and arrangement of inflorescences on flowers differs among plants, we defined our floral units in several different ways to make data collection feasible and provide useful comparisons. For plants with distinct unclustered flowers, and plants with clustered stems of flowers (e.g., *Dianthus plumarius* and *Penstemon strictus*, respectively) we counted individual flowers. For plants with small, clustered inflorescences composed of many indistinct individual flowers (e.g., *Eriogonum jamesii*), we estimated the total number of flowers by counting flower heads and multiplying by the average number of flowers per head. For plants with composite flowers, we counted capitula (e.g., *Ericameria nauseosa* ssp. *nauseosa*). Plant width was recorded as an average of diameter measurements on an x-y horizontal axis to control for the effect of plant size on flower counts. Mat-forming plants with indistinguishable individuals were observed by counting all floral units within 90 $cm^2$ square quadrats with 5 samples per location. For woody shrubs, one primary stem was marked, its length measured, and observations only included inflorescences on the tagged stem. Phenology observations of vegetative stages (leaf budding and flush) were not made as the focus of this study was flowering phenology.

### 1.2.6 In-situ Observations of Flower Visitors

In accordance with Mason et al.'s (2018) methodology, we conducted two-minute observations of five individuals from each observed plant species every week during the growing season, between 9:00 a.m. to 11:00 a.m. Morphospecies were utilized to classify flower visitors during the in-situ observations, following the protocol established by Mason et al. (2018). Only visiting arthropods that made contact with the floral reproductive structures within the designated two-minute observation window were tallied. Species replicates lacking active flowers with intact reproductive structures were excluded from the observations.

### 1.2.7 Data Analysis

Mean first budding observations, flowering day, flowering duration, and weekly flower count was calculated for each plant species. Mean first flowering data was calculated by converting dates to calendar (ordinal) days and calculating the mean day number on which open flowers were first observed on a given plant species at each location. Maximum flowering day was calculated by converting dates into calendar (ordinal) days and taking the mean of the day on which, the maximum number of flowers were observed given plant species over the course of the growing season. Standard deviations were calculated for each mean and maximum flowering dates. Flower counts were totaled for each species at ground level and on the green roofs and, to account for plant size, were normalized by dividing the total flower count by the size index of the plant.

Mean monthly, mean monthly maximum, and mean monthly minimum substrate temperatures and standard deviations were calculated and temperature amplitude was calculated by calculating the difference between daily high and low temperatures for each day of the month and standard deviations were calculated for the difference in temperature. All data were analyzed in R and visualized using Microsoft Excel or the ggplot2 package in R (R Core Team (2022).

## 1.3 Results

### 1.3.1 Plant Phenology

Over the course of the study we made 2480 flowering phenology observations. In 2019, five out of the six observed plant taxa bloomed earlier on the green roof than at ground-level, while one species (*Salvia*) bloomed 2.4 days later on the green roof (Table 3, Figure 3). In 2020, fourteen out of fifteen plant taxa bloomed earlier on the green roofs compared to ground-level, with *Penstemon pinifolius* initiating flowering concurrently in both locations (Table 3, Figure 3). Mean first flowering date was an average of 5.3 days (range: -2.4-15) earlier in 2019 and 9.4 (range: 0- 32.5) days earlier in 2020 for plants growing on the green roofs compared to ground-level (Table 3).

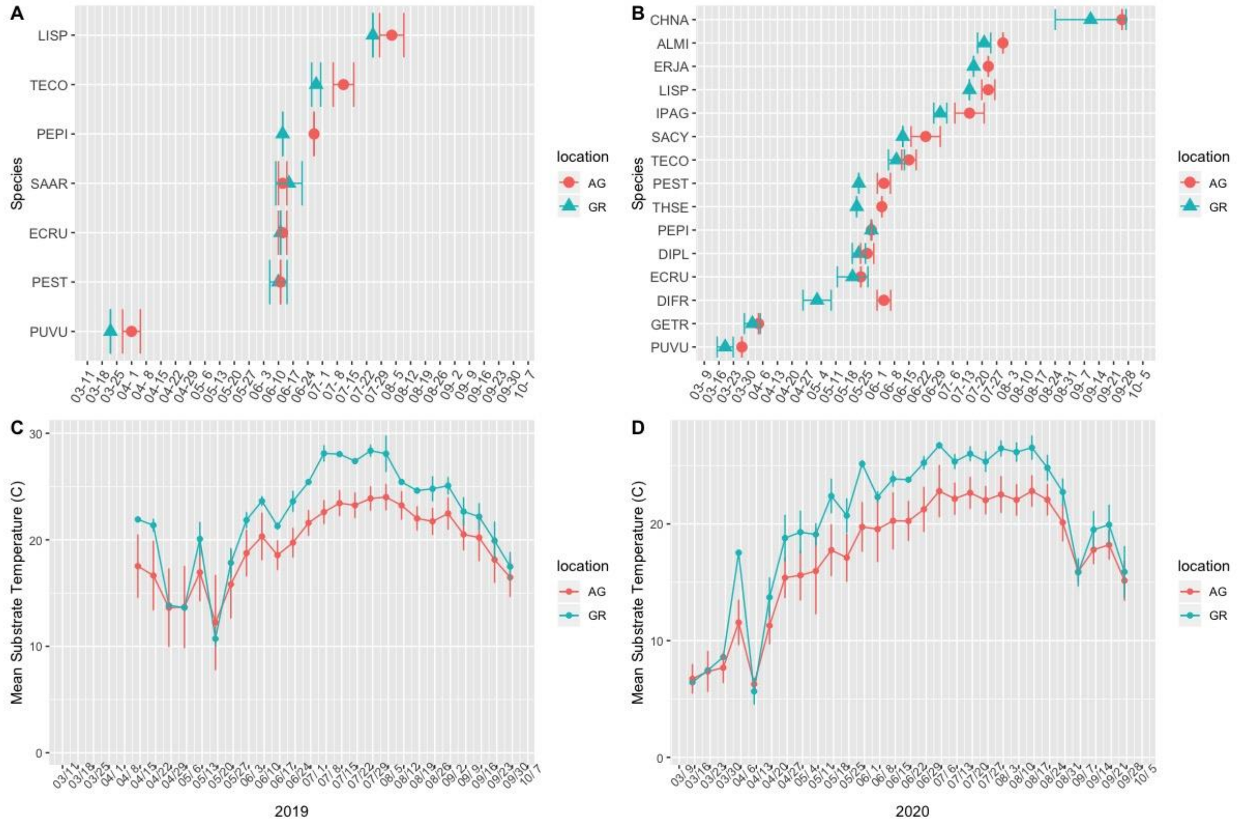

Figure 3. Mean first flowering date in the 2019 (A) and 2020 (B) growing seasons and mean substrate temperature during the 2019 (C) and 2020 (D) growing seasons. Error bars represent the standard deviations (+/-) of the means. AG = Ground Level and GR = Green Roof.

The difference in first flowering date was greatest among early blooming (e.g., *Pulsatilla vulgaris* and *Geum triflorum)* and late blooming plant taxa (e.g., *Chrysothamnus nauseosus* ssp. *nauseosus*; Table 3). There was considerable variation in both first flowering date and flowering duration between years for both locations (i.e., species did not bloom at the same time year-to-year), but plants on the green roofs (excepting *Salvia*) all bloomed relatively earlier despite absolute changes in first flowering date (Figure 3, Table 3).

Flowering duration was more variable than initiation date of flowering, and plants growing on the green roof locations did not seem to have substantially different flowering duration than those at ground-level. In 2019, 5 out of 6 species flowered for a shorter duration on the green roof relative to ground-level (Figure 4). However, during the 2020 season, only 4 out of 15 species flowered for a longer duration at ground level compared to the green roof locations (Figure 5). One notable exception was *Ipomopsis aggregata,* which had a flowering duration of 22 days on the green roof location and 111 days at ground level.

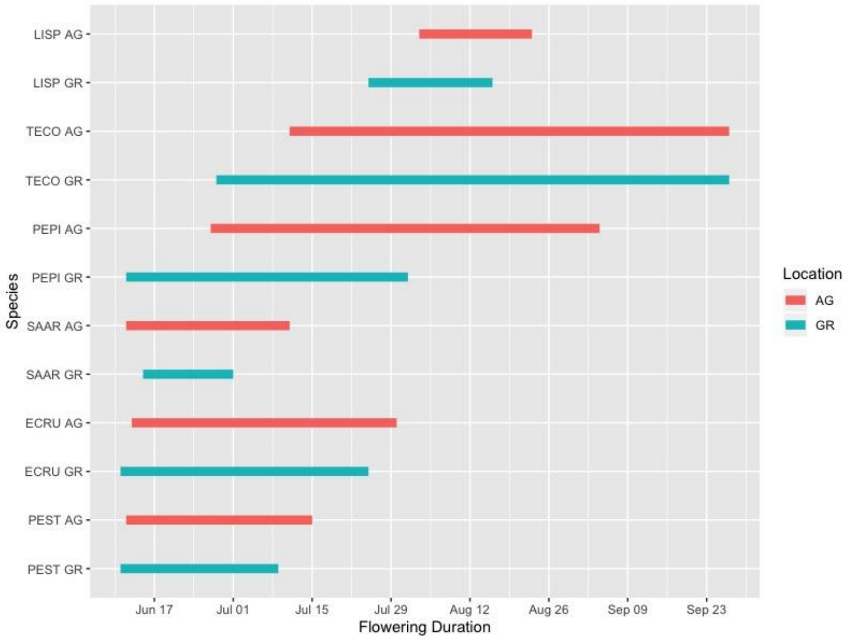

Figure 4. Flowering phenology of observed plant taxa during the 2019 growing season. AG = ground-level, GR = green roof.

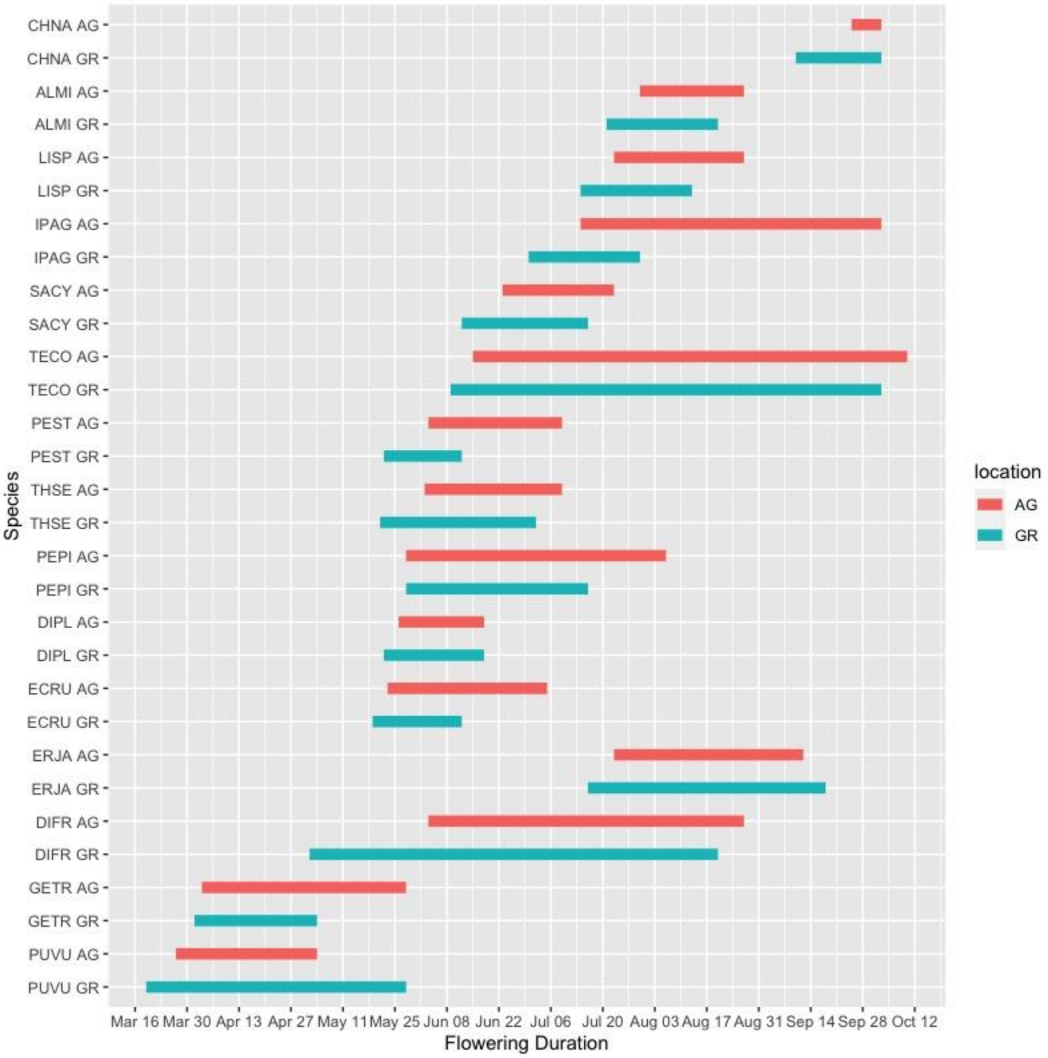

Figure 5. Flowering phenology of observed plant taxa during the 2020 growing season. AG = ground-level, GR = green roof.

**Table 3.** Initiation date of flowering, difference in flowering time (GR-AG), maximum number of flowers, total number of flowers, and duration of flowering among our study species. Plant species are abbreviated with the first two letters of the genus and species (i.e., *Echium russicum* = ECRU).

| **Species** | **Year** | **First Flowering Date (GR)** | **First Flowering Date (AG)** | **Mean Flowering Advance (AG-GR, days)** | **Max Flower Number (GR)** | **Max Flower Number (AG)** | **Flowering Duration GR (Days)** | **Flowering Duration AG (Days)** |
|---|---|---|---|---|---|---|---|---|
| **ECRU** | 2019 | 11-Jun | 12-Jun | 1.8 | 70.6 | 73.6 | 17.6 | 27.8 |
| **LISP** | 2019 | 25-Jul | 3-Aug | 9.2 | 725.8 | 715.8 | 10.0 | 12.8 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **PEPI** | 2019 | 12-Jun | 27-Jun | 15 | 78.6 | 151.4 | 50.0 | 54.0 |
| **PEST** | 2019 | 10-Jun | 11-Jun | 1 | 82.4 | 158.6 | 23.6 | 32.8 |
| **SAAR** | 2019 | 15-Jun | 12-Jun | -2.4 | 216.2 | 133.8 | 12.2 | 20.2 |
| **TECO** | 2019 | 28-Jun | 11-Jul | 12.8 | 295.4 | 493.6 | 90.8 | 78.0 |
| **ALMI** | 2020 | 21-Jul | 30-Jul | 9.4 | 145.4 | 55.0 | 29.0 | 22.4 |
| **CHNA** | 2020 | 10-Sep | 25-Sep | 14.4 | 2063.3 | 2223.9 | N/A* | N/A* |
| **DIFR** | 2020 | 2-May | 3-Jun | 32.7 | 8.9 | 12.3 | 107.3 | 19.8 |
| **DIPL** | 2020 | 22-May | 26-May | 4.2 | 12.9 | 49.7 | 30.4 | 99.4 |
| **ECRU** | 2020 | 19-May | 23-May | 3 | 21.3 | 38.3 | 19.6 | 24.8 |
| **ERJA** | 2020 | 16-Jul | 23-Jul | 7 | 624.0 | 1075.1 | 121.4 | 73.6 |
| **GETR** | 2020 | 1-Apr | 4-Apr | 4.2 | 11.0 | 12.0 | 33.2 | 24.8 |
| **IPAG** | 2020 | 30-Jun | 14-Jul | 12.6 | 19.7 | 33.1 | 22.0 | 111.0 |
| **LISP** | 2020 | 14-Jul | 23-Jul | 8.4 | 749.9 | 134.5 | 26.2 | 35.0 |
| **PEPI** | 2020 | 28-May | 28-May | 0 | 55.5 | 115.4 | 43.0 | 45.8 |
| **PEST** | 2020 | 22-May | 3-Jun | 16.4 | 18.2 | 10.6 | 23.0 | 32.0 |
| **PUVU** | 2020 | 19-Mar | 27-Mar | 11.2 | 9.9 | 3.5 | 47.2 | 72.2 |
| **SACY** | 2020 | 12-Jun | 23-Jun | 13 | 44.6 | 12.4 | 35.0 | 74.8 |
| **TECO** | 2020 | 9-Jun | 15-Jun | 5.8 | 160.1 | 121.3 | 112.6 | 53.0 |
| **THSE** | 2020 | 21-May | 2-Jun | 15 | 213.9 | 400.0 | 64.0 | 36.0 |

Although we recorded the number of flowers for all observed plant taxa, these data were highly variable and did not demonstrate a clear pattern at the species level. However, when considering total flower production across the growing season, the plants on the green roofs produced more flowers early in the season (March, April, May) compared to ground level during both the 2019 and 2020 growing season, even when flower count was normalized by plant size (figure 6A, 6B). During the mid to late growing season (June-September), however, the plants at ground level produced more flowers than the plants on the green roofs, although this pattern was highly species-specific.

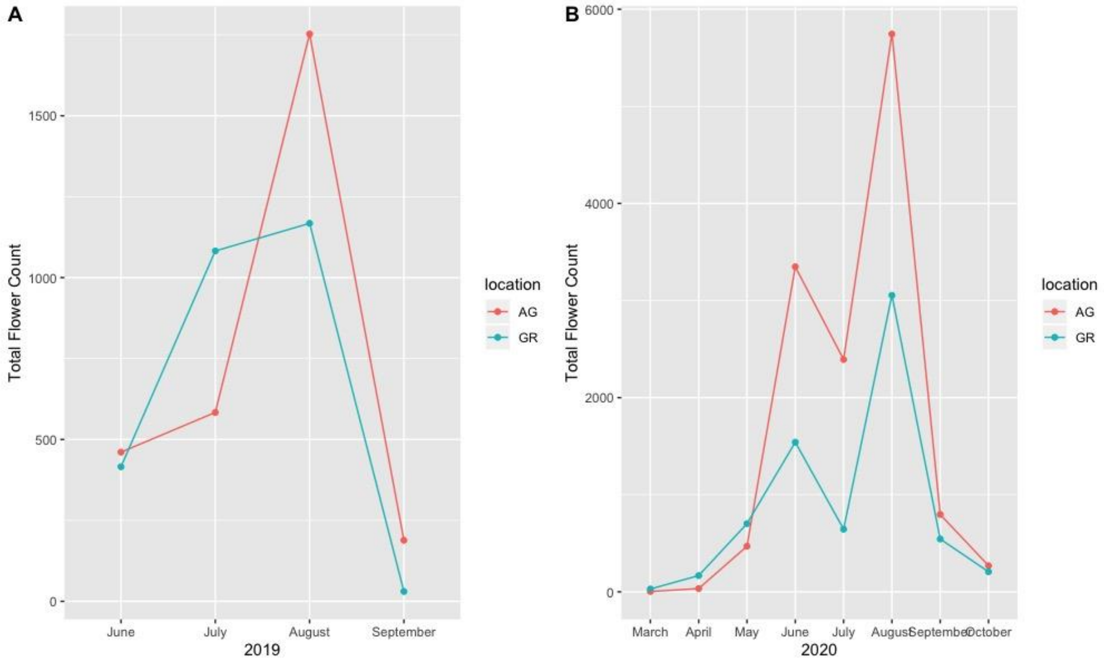

**Figure 6.** Total number of observed flowers (normalized by plant size) during the 2019 (A) and 2020 (B) growing seasons on the green roofs compared to ground level.

Mean substrate temperatures were substantially higher on the green roofs (M= 20.28°C, SD =0.46 ) than at ground level (M = 16.54°C, SD =1.47) in both 2019 and 2020 (Figure 7). The maximum substrate temperature in 2019 and 2020 on the green roofs was 40.9°C and 36.9°C respectively, compared to 30.3°C and 27.4°C at ground level. Additionally, the diurnal temperature amplitude of the green roof substrates was greater than at ground-level. Over the course of each growing season, the green roof substrate routinely experienced larger temperature oscillations (i.e., temperature amplitude) compared to ground level (Figures 8, 9). In 2019 the mean temperature amplitude was 14.9°C (SD = 2.0°C) at ground level and 25.7° C (SD = 3.2°C) on the green roofs, while during the 2020 growing season the mean temperature amplitude was 13.7°C (SD = 3.19°C) at ground level compared to 22.0°C (SD = 2.9°C) on the green roofs and the difference in substrate temperature amplitudes was greatest early in the growing season, specifically April and May, excepting April 2020 (Figure 9). Temperature data during March are incomplete because of data logger failure (presumably due to temperature stress on the battery units), however the incomplete data show temperature amplitude values similar to April and May. Greater temperature amplitude on the green roofs was due to maximum temperatures, which routinely exceeded ground level temperatures, rather than lower minimum temperatures, which were comparable to ground level minimum temperatures (figure 10).

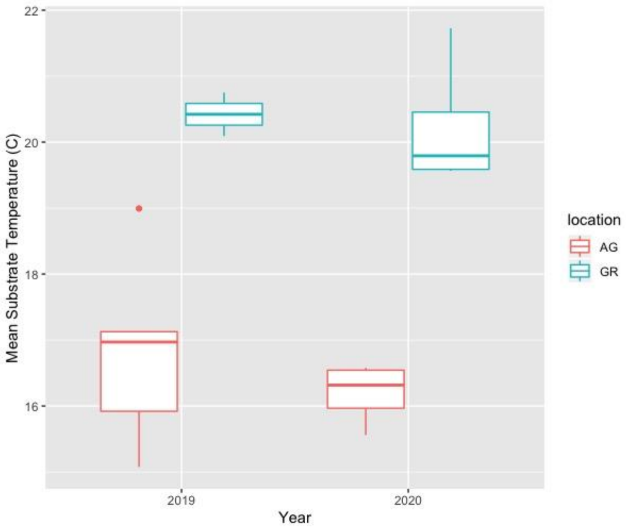

Figure 7. Comparison of green roof and ground-level mean substrate temperature (°C) during the growing season (Apr-Oct.).

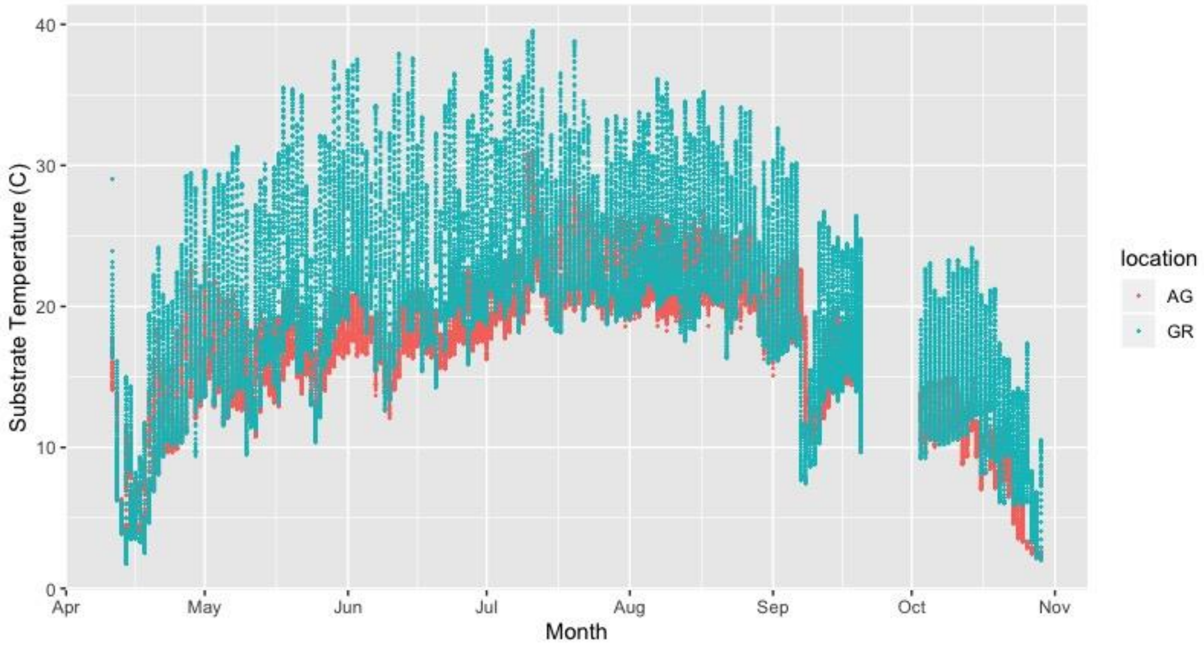

Figure 8. Substrate temperature on the intensive green roof compared to ground-level during the 2020 growing season.

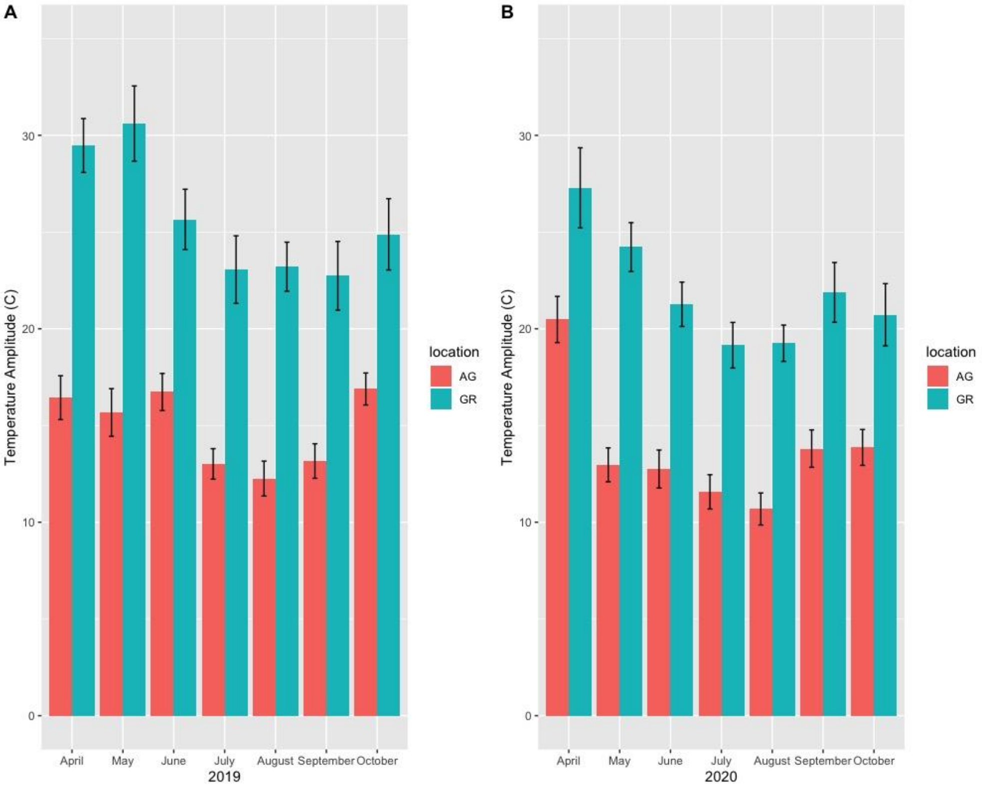

Figure 9. Monthly mean substrate temperature amplitude (high-low daily temperatures) on the green roofs compared to ground level sites during the 2019 (A) and 2020 (B) growing seasons.

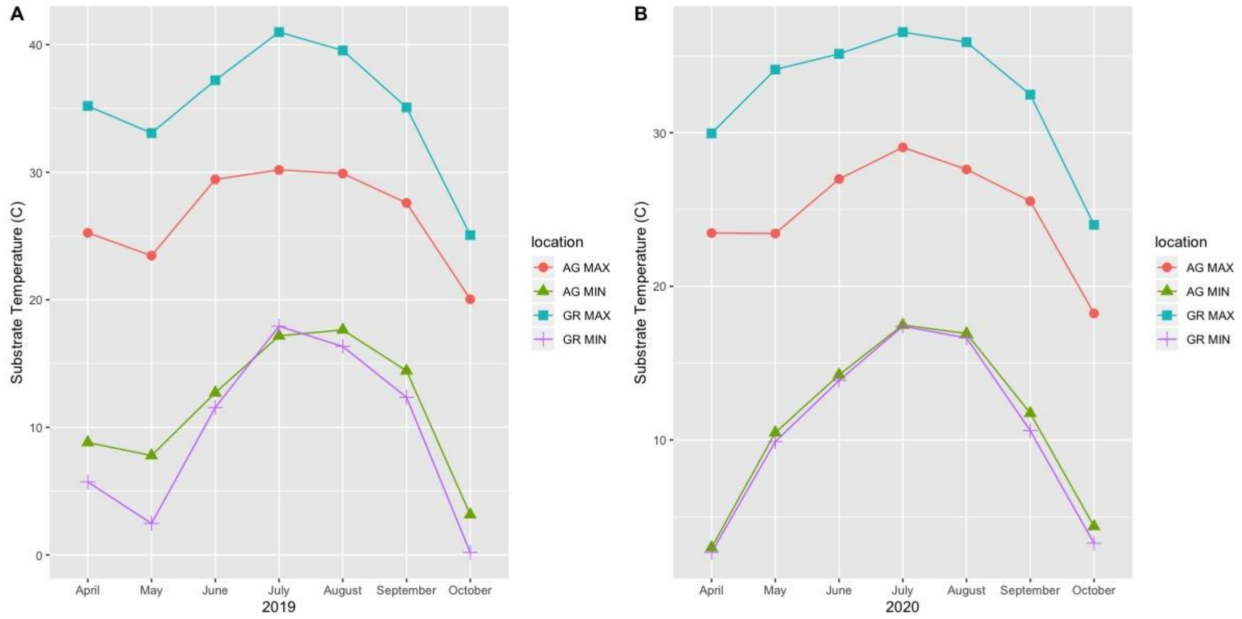

Figure 10. Monthly maximum and minimum substrate temperatures during the 2019 (A) and 2020 (B) growing seasons.

Table 4. Mean monthly average temperatures (°C), mean monthly maximum temperatures(°C), and precipitation(mm)(*CoCoRaHS*, n.d.) at Denver Botanic Gardens in 2019 and 2020 over the course of the study.

| | Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mean** | 2019 | 0.00 | -2.06 | 1.72 | 9.50 | 10.89 | 18.67 | 24.28 | 24.11 | 20.72 | 6.50 | 2.33 | 0.94 | 9.78 |
| | 2020 | 1.44 | -2.17 | 5.83 | 7.94 | 15.33 | 21.72 | 24.72 | 25.00 | 18.56 | 9.89 | 6.50 | 0.61 | 11.28 |
| **Max** | 2019 | 7.00 | 5.17 | 8.17 | 17.06 | 17.72 | 26.72 | 32.83 | 32.50 | 29.72 | 14.72 | 9.83 | 7.39 | 17.39 |
| | 2020 | 8.89 | 4.39 | 13.33 | 16.17 | 23.89 | 30.94 | 33.56 | 34.17 | 27.06 | 19.06 | 14.83 | 7.50 | 19.50 |
| **Precip** | 2019 | 45.47 | 24.64 | 42.16 | 4.83 | 61.98 | 3.81 | 40.64 | 32.00 | 4.06 | 40.64 | 33.53 | 10.41 | 344.17 |
| | 2020 | 1.78 | 34.04 | 57.66 | 24.64 | 15.49 | 41.40 | 15.75 | 3.56 | 24.64 | 10.67 | 18.54 | 14.99 | 263.14 |

Table 5. Summary of substrate monthly mean temperature(°C), annual mean temperature(°C), maximum annual temperature(°C), and minimum annual temperature(°C) for the green roof and ground-level plant locations during the growing season (Apr-Oct) in 2019 and 2020.

| | Year | Apr | May | Jun | Jul | Aug | Sep | Oct | **Avg Temp** | **Max Temp** | **Min Temp** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AG | 2019 | 15.65 | 14.67 | 19.51 | 22.78 | 22.63 | 19.85 | 10.26 | **16.82** | **30.03** | **3.65** |
| GR | 2019 | 19.39 | 15.22 | 22.65 | 27.47 | 25.93 | 22.36 | 9.93 | **20.42** | **40.99** | **0.19** |
| AG | 2020 | 10.69 | 16.15 | 19.15 | 21.80 | 21.96 | 17.65 | 11.35 | **16.97** | **27.84** | **2.86** |
| GR | 2020 | 14.87 | 20.91 | 23.55 | 25.25 | 24.99 | 18.17 | 11.04 | **20.23** | **36.91** | **1.12** |

### 1.3.2 Pollinator Visitation

Over the course of the study we observed a total of 1795 individual pollinators, among those 1550 were bees. During both 2019 and 2020, a greater number of pollinators were observed on the green roofs compared to ground level (2019: GR= 270, AG=197, 2020: GR=795, AG=533) (Tables 6 and 7). All bee morpho species groups outlined in Mason et al (2018) along with other pollinator groups included in the study (Diptera, Coleoptera, Vespidae were represented at on the green roofs. Honeybees (*Apis mellifera*) were the most common pollinator regardless of location, comprising 61% and 74% of all observations in 2019 and 2020, respectively. The next most abundant pollinator groups for all locations were flies and striped sweat bees (Figure 13). The relative abundance of pollinator groups was similar between the green roofs and ground level for both years (Figure 13). During the 2020 growing season, which encompassed a full range of observations from March-October, no pollinators were observed at ground level during weeks 12-14, corresponding to a time period during which there were no floral resources among the observed plant taxa at ground level (Figure 12).

Table 6. The aggregated *in situ* observations following the protocol developed by Mason et al. (2018) the green roof sites (GR) and the sites at ground level (AG) during the 2019 growing season. Other pollinator observations include Flies (Diptera), Beetles (Coleoptera), and Wasps (Family Vespidae).

| Honey Bee | | Bumble Bee | | Hairy Leg Bee | | Green Metallic Bee | | Striped Sweat Bee | | Tiny Dark Bee | | Hairy Belly Bee | | Cuckoo Bee | | Fly | | Beetle | | Wasp | | Total Pollinator | | Native Bees | | Other Pollinators | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR |
| 98 | 189 | 6 | 5 | 2 | 1 | 4 | 2 | 15 | 16 | 6 | 0 | 13 | 5 | 0 | 0 | 27 | 49 | 1 | 0 | 25 | 3 | 197 | 270 | 46 | 29 | 53 | 52 |

Table 7. The aggregated *in situ* observations following the protocol developed by Mason et al. (2018) the green roof sites (GR) and the sites at ground level (AG) during the 2020 growing season. Other pollinator observations include Flies (Diptera), Beetles (Coleoptera), and Wasps (Family Vespidae).

| Honey Bee | | Bumble Bee | | Hairy Leg Bee | | Green Metallic Bee | | Striped Sweat Bee | | Tiny Dark Bee | | Hairy Belly Bee | | Cuckoo Bee | | Fly | | Beetle | | Wasp | | Total Pollinator | | Native Bees | | Other Pollinator | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR | AG | GR |
| 400 | 556 | 8 | 25 | 3 | 4 | 0 | 10 | 61 | 72 | 9 | 8 | 0 | 22 | 3 | 7 | 39 | 82 | 0 | 1 | 10 | 8 | 533 | 795 | 84 | 148 | 49 | 91 |

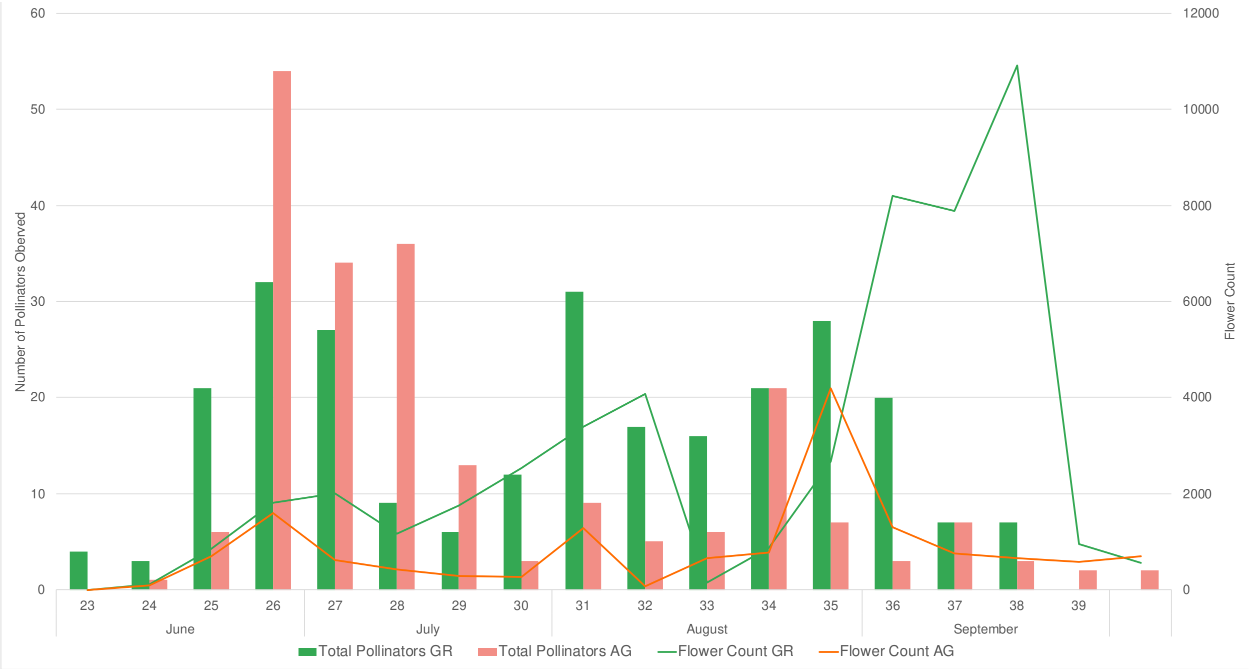

Figure 11. Weekly pollinator visitation and flower counts for study plants on the green roof (GR) and ground level (AG) during the 2019 growing season.

Figure 12. Weekly pollinator visitation and flower counts for study plants on the green roof (GR) and ground level (AG) during the 2020 growing season.

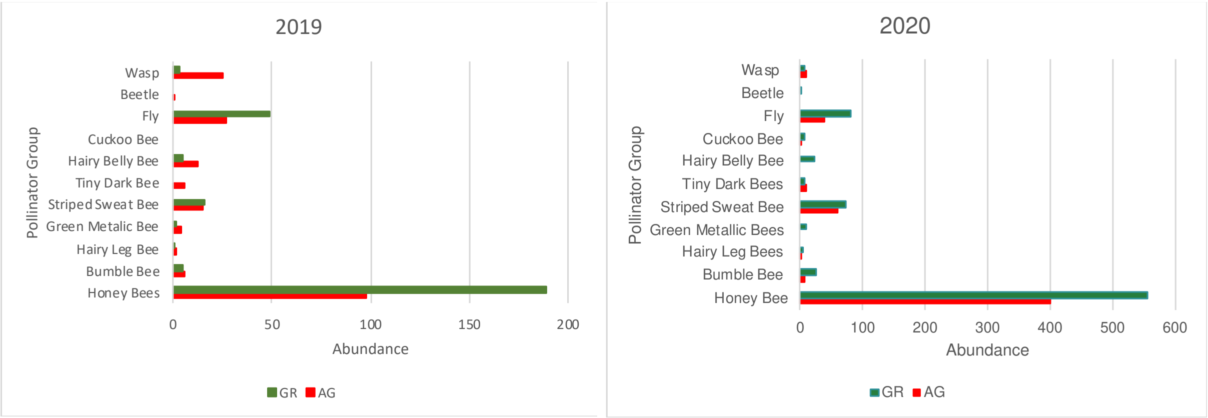

Figure 13. Total abundance of pollinator groups recorded in 2019 (left) and 2020 (right) at each location (GR = Green Roof, AG = Ground Level).

## 1.3 Discussion

### 1.3.1 Green Roof Phenology

Overall, the phenology of nearly every species was advanced on the green roofs compared to their ground-level counterparts. Duration of flowering was variable, and no clear pattern could be discerned from the data between plants grown on the green roofs compared to those at ground level. Some of the variability was likely due to the observational nature of the study which could not precisely control every aspect of the plant growing conditions. Importantly, work in the same climate using a similar suite of plants demonstrated that flowering phenology was advanced relative to green roof counterparts in an experimental system (Ruszkowski, 2023). This work represents the first data that green roof plant phenology is accelerated compared to ground-level, and, notably found that peak flowering times were also accelerated on the green roof plots compared to those at ground level. Ruszkowski (2023), however, found no evidence that phenological patterns on green roofs were associated with differential pollinator visitation timing. This may be because the main observation window for pollinators and plants occurred between June and early September which excluded shoulder seasons, the time when notable differences in visitation rates were observed in this study.

The number of inflorescences and duration of flowering were extremely variable likely due to species-specific characteristics. For example, stress tolerating species (Grime, 1988) like *Eriogonum jamesii*, *Penstemon pinifolius,* and *Teucrium cossonii* exhibited relatively small temporal differences in flowering phenology compared to the other taxa that were studied. All three of these species inhabit highly moisture limited systems on shallow, nutrient poor substrates and therefore have less of a phenological response to altered environmental conditions, a concept supported by work in natural systems (Zhang et al., 2004). The overall phenological pattern of green roofs will almost certainly be affected by plant selection due to differential responses to environmental conditions.

### 1.3.2 Variation in study abiotic conditions

The primary green roof used for this study has unusually deep substrate in most locations, often over 30cm. There is negative association between temperature and substrate depth (Reyes et al., 2016) meaning that extensive and semi-intensive systems, would be likely to have even higher substrate temperatures and extremes than our main study roof. Indeed, the single taxon (IPAG) that was observed on the smaller extensive green roof had earlier flower initiation and substantially shorter flowering duration compared to its counterparts at ground level (12.6 days earlier (mean = 9.4 days, see Figure 2). Additionally, over the course of the study we noted other plant species (including *Echium russicum*) on the extensive roof had conspicuously early flower initiation and short flowering durations compared to ground-level, however they were not included in the analysis as they did not meet study inclusion criteria. Given that extensive and semi-intensive green roof system are far more common than intensive systems, the observed phenological trends on a large, intensive green roof may be relatively modest compared to extensive systems. Additionally, since Denver Botanic Gardens is a public garden that must maintain display standards for public visitors, the large intensive green roof received additional irrigation during periods of drought to maintain the aesthetic value of the space. It is unclear how this might have affected our results, but it may have acted to dampen the magnitude of the observed phenological differences by moderating substrate temperatures (Reyes et al., 2016) and lessening plant drought stress.

### 1.3.3 Implications for Pollinators and Sampling Considerations

Earlier flowering times can potentially benefit urban pollinator conservation efforts. Certain bee species are showing earlier emergence in the season, likely influenced by global temperature increases and the urban heat island effect (Bartomeus et al., 2011). Green roof plant species that bloom earlier than their ground-level counterparts, in particular, offer unique foraging opportunities for urban pollinators. There is a growing concern known as the plant-pollinator phenological gap, which results from mismatches in the timing of pollinator emergence and plant blooming due to climate change. This asynchrony can limit pollinators for plant reproduction and early-season foraging opportunities for bees (Kudo & Ida, 2013). Leveraging the adjusted bloom schedules of green roof plant species could help reduce this phenological gap, enhancing pollinator abundance and diversity management within urban ecosystems. Our results demonstrate that it is possible for flowering phenology to advance several weeks and for pollinators to take advantage of the earlier floral resources. However, the results also suggest that intentionally managing phenology on green roofs will require a deeper investigation into the environmental characteristics of green roofs and species-level qualities of plants that modulate observed phenological shifts.

Observation methodology will also have an impact on the results of pollinator surveys and may have influenced the results of this study. While sampling only between 9am and 11am standardized our methodology, it’s possible that certain bees and other pollinators active at different times of day were excluded. Similarly, in-situ observations made sightings of Lepidoptera and birds unlikely, as they are not expected to fly in close proximity to human observers. Pan traps have been a common choice for bee collections in previous studies (Colla et al., 2009; Ksiazek et al., 2012; Pardee and Philpott, 2014; Tonietto et al., 2010). The pan trap method tends to capture a higher proportion of small bee species (Ksiazek et al., 2012), and would help to obtain a more comprehensive sample in addition to in-situ observations. Following the approach of Pardee and Philpott (2014) future studies should consider a combination of pan traps, netting, and in-situ pollinator observations to better encompass small-bodied bee species (Ksiazek et al., 2012) when attempting to infer the general pollinator and bee diversity of green roofs compared to ground level habitats.

### 1.4 Conclusions

This study provides evidence that substrate temperatures are significantly higher on green roof systems with greater temperature extremes compared to ground-level. Greater temperature extremes are driven by substantially higher daytime substrate temperatures on green roof systems, which has implications for plant growth, phenology, and survival. We also demonstrate that flowering phenology is advanced on green roof systems relative to ground level and that substrate temperature differences appear to be associated with the timing of earlier flowering phenology in some cases. This suggests that differences in flowering phenology on green roofs may be driven by extreme substrate temperatures, likely in concert with other abiotic factors such as air temperatures, limited substrate depth, and low water availability. The observational nature of the study makes it impossible to apply causality to the observed phenomenon of earlier flowering phenology on our green roof systems, but the consistency of the phenology observations over two growing seasons suggest this may be a widespread phenomenon on green roofs, especially in semi-arid climates. Similarly, we found evidence of increased pollinator foraging on the green roofs during early in the season compared to ground level, presumably due to the availability of floral resources while they remained absent at ground level. Earlier flowering phenology has implications for ecological green roof design and may open unique foraging opportunities to pollinators on green roofs and increase floral resources during key periods in the growing season in urban environments.

# CHAPTER 2. DIFFERENCES IN INVERTEBRATE COMMUNITIES ON TWO URBAN GREEN ROOFS COMPARED TO GROUND LEVEL GARDEN HABITATS

“They paved paradise and put up a parking lot.” – Joni Mitchell

## 2.1 Introduction

### *2.1.1 Urbanization and Biodiversity*

Urbanization is an escalating global phenomenon, with over half of the world's population now residing in cities (United Nations, 2018). This rapid urban expansion has profound impacts on local ecosystems, including habitat loss, fragmentation, and increased human disturbance (McKinney, 2002). For example, in the United States, more than 5% of the entire land surface of the United States is now comprised of urban and other developed regions (Census Bureau, 2020). This figure exceeds the combined land area of national and state parks and privately conserved areas. Alarmingly, the expansion of urban areas in the United States is occurring at a substantially faster rate than the preservation of land for parks and conservation purposes (McKinney, 2002). Projections indicate that over the next 25 years, the developed area in the United States is expected to grow by 79%, increasing the proportion of the total land area classified as developed from 5.2% to 9.2% (Alig et al., 2004).

When an area is urbanized, the existing community is typically replaced by a cosmopolitan assemblage of species, leading to biotic homogenization among regions. (McKinney, 2006). A significant body of work has demonstrated reductions in bird diversity with urbanization (reviewed in Morelli et al., 2016). In plants, diversity generally decreases among native plants but can increase overall with the addition of nonnative plants (M. Aronson et al., 2014; Kühn &

Klotz, 2006). To date, there have been relatively few studies that have examined invertebrate diversity in urban environments, but these also report mixed results, with some showing an increase in species richness and abundance, while others demonstrate decreases among major insect and other invertebrate groups (Jones & Leather, 2012).

### *2.1.2 Green Infrastructure and Invertebrate Biodiversity*

Preservation of existing green space and implementation of green infrastructure interventions in urban areas are key strategies to maintain and improve urban invertebrate populations. Green roofs have gained prominence as an innovative tool for urban sustainability, offering a broad range of benefits. Green roofs are widely acknowledged for their capacity to improve energy efficiency, reduce stormwater runoff, and enhance air quality (Berndtsson, 2010; Getter & Rowe, 2006). These benefits have spurred their adoption in urban planning and design, contributing to urban sustainability. However, the potential role of green roofs in supporting biodiversity, and the resulting implications for urban ecology and conservation biology, remained understudied. Invertebrates, encompassing diverse groups such as arthropods, annelids, mollusks, and others form the cornerstone of terrestrial ecosystems, fulfill critical roles in nutrient cycling, pollination, decomposition, and pest control (Hättenschwiler et al., 2005) . Losey and Vaughan (2006) estimate that the total value of ecological services provided by wild insects (not including honey bees or other invertebrates such as non-insect arthropods, annelids, or mollusks) is in excess of $57 billion USD per year in the United States alone, substantiating an economic rationale for conservation as well.

### *2.1.3 Green Roofs and Invertebrate Diversity*

As cities continue to expand and natural habitats become increasingly fragmented, green roofs may serve as refuges and corridors for invertebrate species, facilitating dispersal, gene flow, and the formation of metapopulations in urban settings (Lundholm, 2015; MacIvor et al., 2018). Over the past two decades, a body of literature has emerged examining the characteristics of invertebrate communities found on green roof systems and the factors that influence these communities. Due to the patchy distribution of green roofs, few broad-scale studies exist, but numerous case studies are available that highlight the suitability of green roofs for supporting invertebrate populations and the factors that influence their composition and abundance. To my knowledge, the only systematic review on the subject reports that out of twelve studies comparing invertebrate biodiversity on green roofs, ten show lower invertebrate abundance, richness, and diversity on green roofs compared to ground-level areas (Wang et al., 2022).

### *2.1.4 Substrate Characteristics and Depth*

Green roof physical characteristics, including media characteristics and depth, may be key predictors of invertebrate diversity. Extensive green roofs typically feature shallow substrates and low-maintenance vegetation and serve primarily as stormwater management tools, requiring minimal maintenance. In contrast, intensive green roofs feature deeper substrates, allowing for a more diverse selection of plant species. Semi-intensive green roofs strike a balance between the two, offering a mix of ecological function and aesthetic appeal (Oberndorfer et al., 2007). These typological differences create a diverse range of environmental conditions on green roofs, from the extreme conditions of extensive green roofs to the more hospitable environments of intensive green roofs, offering a range of habitats for urban invertebrates. For example, green roofs have been shown to harbor depauperate microarthropod communities, potentially due to moisture which limits the success of both the vegetation and terrestrial macroinvertebrates (Rumble & Gange, 2013). The physical characteristics of green roofs will, of course, likely covary with vegetation features as deeper substrates will support a greater diversity and complexity of vegetation (Dusza et al., 2017).

### *2.1.5 Vegetation Characteristics and Plant Selection*

Biodiversity-focused design, including intentional habitat heterogeneity, high vegetation complexity, and plant diversity almost universally increases invertebrate species diversity on green roofs. A survey of green roofs throughout the Netherlands demonstrated that invertebrate species richness was positively correlated with plant species richness as well as substrate depth (Drukker et al., 2018). Similarly, parasitoid wasp morphospecies richness was higher on roofs with greater plant species richness and higher vegetation complexity (Diethelm & Masta, 2022). A study that surveyed Coleoptera (beetle) diversity on green roofs and surrounding at-grade green space in Portland, Oregon, USA concluded that green roofs designed for biodiversity (featuring more complex vegetation, higher vegetation coverage, and richer plant palettes) harbored a greater number of beetle species compared to extensive green roofs designed primarily for stormwater detention (Gonsalves et al., 2021). Providing abundant floral resources was shown to expedite the colonization of green roofs and influence invertebrate community composition and a natural experiment that monitored a roof conversion project in Melbourne, AUS demonstrated that invertebrate composition was driven primarily by floral density (Berthon et al., 2023).

### *2.1.6 Building Height, Size, and Surrounding Environment*

The location of green roofs, both geographically in their relative proximity to other green spaces, and height from grade have been shown to strongly influence green roof invertebrate communities, primarily due to the variability of invertebrate mobility and dispersal abilities (MacIvor & Ksiazek, 2015). Green roofs in Melbourne, AUS harbored invertebrate communities similar to ground level. The richness and abundance of the invertebrate taxa on roofs increased with percent cover of green space surrounding the roof, and decreased, for some taxa, with roof height (Dromgold et al., 2020). Similarly, native bee nesting activity was negatively correlated with building height in a study of vegetated roofs in Toronto, Canada (MacIvor, 2016).

Others have determined that “spillover effects”, whereby nearby biodiverse green roofs can increase the invertebrate species richness of other green roofs (Berthon et al., 2023). Although many studies suggest that green roof effectiveness as invertebrate habitat is highly dependent on location and their horizontal and vertical connection to other habitats, other results suggest a “build-it-and-they-will-come” principle prevails, wherein local roof conditions are more important than roof size or the surrounding landscape (Schindler et al., 2011; Kyrö et al., 2018).

### *2.1.7 Conservation*

Although there is ample evidence to suggest green roofs support a wide diversity of invertebrate species, there is less evidence to suggest they represent a useful strategy for conservation, especially for rare or endangered species and most studies report primarily common species inhabiting green roofs (Madre et al., 2013). However, other studies demonstrate green roofs can harbor rare or uncommon species. In a survey of nine green roofs in London, UK, Kadas (2006) found that 10 percent of surveyed species were officially listed as nationally rare or scarce.

An assessment of bees found on green roofs in Switzerland similarly found that 10 out of 77 species were of conservation concern (Brenneisen, 2006) and green roofs in Finland were shown to harbor two rare snail species (Páll-Gergely et al., 2014). Surveys of beetles in Portland, Oregon, USA (Gonsalves et al., 2021) indicated that green roofs may harbor unique, but not necessarily rare or endangered, invertebrate communities compared to ground level. Still, others suggest caution in advocating for the conservation benefits of green roofs as their value for rare and endangered taxa remains poorly understood (Williams et al., 2014) and there is ample evidence to suggest that ground-level green infrastructure solutions remain a more sensible solution and harbor a greater abundance and diversity of invertebrate species compared to green roofs (MacIvor & Lundholm, 2011).

This study aims to add to the growing body of work examining green roof invertebrate biodiversity through a case study of invertebrate communities on two green roofs in Denver, Colorado, USA, and a comparison to nearby ground-level gardens. The majority of other work has examined green roof biodiversity in wetter and warmer climates.

## 2.2 Materials and Methods

This study occurred at the Denver Botanic Gardens (USA) at the same study sites as described in Guidi and Bousselot (2023). The primary green roof used in the study is a large 1230 $m^2$ mixed-intensive green roof (referred to as Green roof 1 (GR1) in this chapter) along with a second 195$m^2$ extensive green roof (referred to as Green roof 2 (GR2), or the extensive green roof in this chapter). Both green roofs have similar substrate media; the larger intensive green roof consists of 75% expanded shale aggregate, 20% compost, and 5% zeolite whereas the smaller extensive green roof has media composed of 80% expanded shale and 20% compost. Both green roofs are accessible to the public and harbor diverse horticultural plantings.

To sample terrestrial ground-dwelling invertebrates, pitfall traps were placed at randomly selected locations within one meter of a subset of study plants that were under observation for phenology and pollinator data as part of the concurrent study described in Guidi and Bousselot (2023). This design ensured that environmental conditions (exposure, slope, substrate, irrigation, etc.) would be analogous between trapping sites as these were controlled for study plants in the concurrent research work. Traps consisted of 300 mL plastic cups filled with 75 mL of 75% ethylene glycol solution as a preserving agent and approximately 1 mL dish soap as a surfactant (Kadas, n.d.; MacIvor & Ksiazek, 2015) and were placed with the rim of the cup flush with the soil surface. Eight traps were placed at each location and were checked weekly to ensure they were functioning and emptied every two weeks between May 1st and September

15th 2020. Invertebrate samples were rinsed with water and stored in 70% ethyl alcohol until processing and identification. Vegetation coverage was measured by placing a 1 $m^2$ quadrat over the center of each pitfall trap and visually estimating vegetation cover. A full vegetation survey, including plant richness and abundance, and maximum vegetation height was recorded in a 2 m radius surrounding each trap location. Green roof substrate depth was also recorded at each pitfall trap located on a green roof (Table 8).

Table 8. Site characteristics surrounding pitfall trap locations, including plant species richness, vegetation cover, and substrate depth of green roofs.

| Location | Trap | Plant Species Richness ($1m^2$) | Vegetation Cover % | Plant Species Richness ($2m^2$) | Substrate Depth |
|---|---|---|---|---|---|
| **Ground Level** | 1 | 7 | 70% | 12 | N/A |
| | 2 | 7 | 60% | 8 | N/A |
| | 3 | 7 | 75% | 8 | N/A |
| | 4 | 8 | 80% | 12 | N/A |
| | 5 | 11 | 70% | 13 | N/A |
| | 6 | 5 | 55% | 18 | N/A |
| | 7 | 8 | 45% | 24 | N/A |
| | 8 | 9 | 65% | 29 | N/A |
| **Intensive Green Roof (GR1)** | 1 | 10 | 50% | 18 | 32cm |
| | 2 | 8 | 45% | 25 | 25cm |
| | 3 | 7 | 20% | 15 | 32cm |
| | 4 | 7 | 45% | 18 | 18cm |
| | 5 | 4 | 10% | 13 | 62cm |
| | 6 | 4 | 5% | 10 | 40cm |
| | 7 | 5 | 35% | 24 | 44cm |
| | 8 | 8 | 79% | 22 | 38cm |
| **Extensive Green Roof (GR2)** | 1 | 4 | 10% | 5 | 11.5cm |
| | 2 | 4 | 5% | 5 | 11.5cm |
| | 3 | 5 | 10% | 6 | 11.5cm |
| | 4 | 3 | 15% | 4 | 11.5cm |
| | 5 | 5 | 10% | 6 | 11cm |
| | 6 | 3 | 10% | 4 | 11.5cm |

| | | | | | |
|---|---|---|---|---|---|
| | 7 | 3 | 15% | 3 | 11.5cm |
| | 8 | 4 | 5% | 5 | 11.5cm |

Identification of invertebrates was conducted in collaboration with entomology students in the Colorado State Agricultural Biology department. Given the large number of samples and the infeasibility of identification of each individual to the species level, a morpho-species identification approach was used to identify samples to the genus level, however, some samples could only be identified to the family or suborder level due to difficulty with identification or degradation of sample quality. The abundance of each morpho-group recorded and or samples that contained a large quantity of the same invertebrate type, a pan estimation method was utilized to estimate the number of individuals: Invertebrates were spread evenly on a pan overlaid with a numerical grid and a subset of individuals from a subset of randomly selected coordinates were counted to estimate the total number. Biomass measurements were obtained after identification by drying samples from each pitfall trap collection for at least 24 hours at 60°C.

Data were analyzed to compare the total invertebrate abundance, morpho-species richness, and biomass between the green roof and ground-level pitfall trap locations. The Shannon index and Simpson index were calculated using the pooled community data from each sampling site (AG, GR1 ,and GR2). The Shannon Index, also known as the Shannon-Weiner Index is used to quantify the uncertainty of the identity of a species chosen from a community at random from a community, therefore giving weight to both abundance and richness and is calculated as $H'=-\sum_{i=1}^{S} p_i * \ln p_i$ where $p_i$ = proportion of individuals of species $i$, and $S$ is species richness (Roswell et al., 2021). The Simpson index, on the other hand, is a measure of dominance which computes the probability that two randomly selected species will be the same and is calculated as $D=\sum i=1S(niN)^2$ where $n_i$ is the number of individuals in species $i$, N is the total number of individuals of all species, and $S$ is species richness. The final calculation was transformed to 1-D to yield a more intuitive probability where a higher value represents a higher diversity value (Simpson Index - Murdoch University, n.d.).

Vegetation data were plotted against the invertebrate abundance of pooled trap data to infer a relationship between vegetation characteristics and invertebrate abundance. Descriptive statistics were supplemented with a full inventory of each taxonomic group found at the study sites.

### 2.3 Results and Discussion

A total of 65882 invertebrates were identified over the course of the study representing 21 taxonomic orders and 378 unique identifiable morpho species units (to sub-order, Family, or Genus level). Notably, among the taxa identified, isopods (suborder Oniscidea) accounted for 70% of all identified specimens (46,249 individuals) across all samples. Excluding isopods, the most common orders found were Araneae, Coleoptera, Diptera, and Hymenoptera.

Invertebrate abundance was considerably higher at ground level compared to either green roof location, but the extensive green roof (GR2) had particularly low abundance with only 2% of ground level and 3.2% of Green Roof 1 abundance. The taxonomic richness was similar between the ground-level site and Green Roof 1 with 253 and 241 morpho species represented, respectively, however the morphospecies richness for Green Roof 2 was 59, substantially lower than the other two sites (Table 10). Every invertebrate order cataloged as part of this study was represented at ground level, however Haplotaxida, Odonata, and Scutigeromorpha were absent from Green Roof 1 and Haplotaxida, Lithobiomorpha, Mantodae, Neuroptera, Odonata, and Pseudoscorpiones were absent from Green Roof 2 (table 9). The orders absent at the green roof sites, were also had low abundance values (2 or fewer) at ground level. Overall biomass was also higher at ground-level compared to either green roof, and Green Roof 2 had <1% of the total dry biomass (figure 14).

Table 9. Total number of Individuals collected in pitfall traps from each observed order (and one subclass) of invertebrates.

| **Taxon** | **AG** | **GR1** | **GR2** |
|---|---|---|---|
| Araneae | 1902 | 1193 | 65 |
| Coleoptera | 401 | 586 | 71 |
| Dermaptera | 375 | 0 | 1 |
| Diptera | 374 | 1005 | 22 |
| Haplotaxida | 2 | 0 | 0 |
| Hemiptera | 254 | 319 | 43 |
| Hymenoptera | 680 | 900 | 102 |
| Isopoda | 31450 | 14760 | 38 |
| Julida | 89 | 73 | 9 |
| Lepidoptera | 18 | 13 | 1 |
| Lithobiomorpha | 1 | 6 | 0 |
| Mantodae | 2 | 2 | 0 |
| Neuroptera | 1 | 1 | 0 |
| Opiliones | 178 | 322 | 1 |
| Odonata | 1 | 0 | 0 |
| Orthoptera | 29 | 11 | 1 |
| Polydesmida | 93 | 25 | 2 |
| Polyxenidae | 42 | 55 | 85 |
| Pseudoscorpiones | 2 | 1 | 0 |
| Scutigeromorpha | 1 | 0 | 1 |
| SUBCLASS: Collembola | 3100 | 5944 | 40 |
| Thysanoptera | 7 | 20 | 2 |
| Trombidiformes | 154 | 632 | 368 |
| Total Abundance | **39156** | **25869** | **852** |

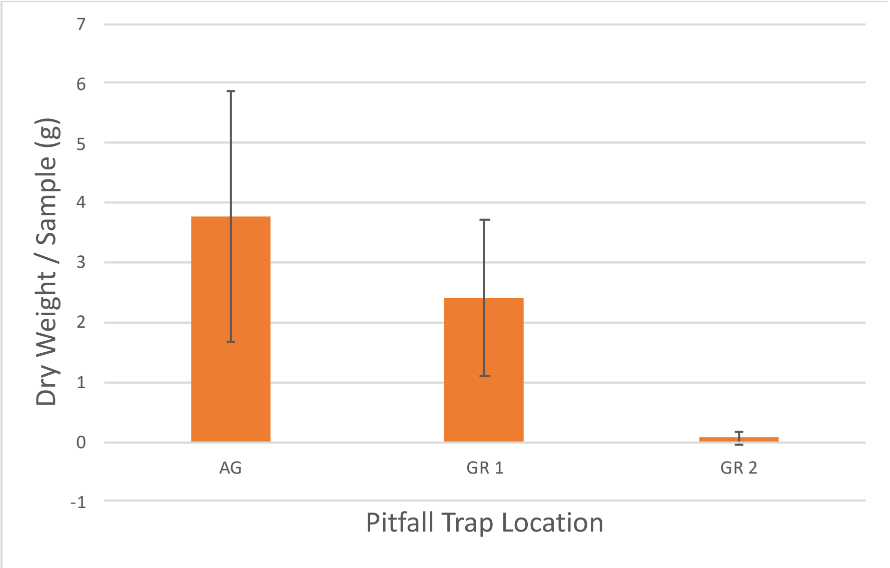

Figure 14. Dry weights of invertebrates per sample collected. Error bars represent the standard deviation among all samples at a given site. AG = Ground Level, GR = Green Roof).

Despite significantly higher richness values, the ground-level site has substantially lower diversity indices compared to the green roof sites. Interestingly the Shannon index and Simpson index were both higher for the extensive green roof (GR2) compared to the ground-level site and Green Roof 1 (H' = .64, 1.6, and 2.6 for the ground-level, GR1, and GR2 sites respectively). The Simpson index (1-D) revealed a similar pattern revealed a similar pattern (0.177, 0.602,0.837 for the ground-level, GR1, and GR2 sites respectively) demonstrating that despite having substantially lower richness, abundance, and biomass, the observed invertebrate community on the extensive green roof had higher species evenness (table 10). The high relative abundance of isopods at ground level (80.3%) and Green Roof 1 (57%), and low relative abundance on Green Roof 2 (4%) is largely responsible for the substantial differences in species evenness among the sites. Isopods are generally more sensitive to desiccation than other groups of invertebrates and prefer moist and shaded habitats and are particularly successful in urban gardens with organic mulches which provide an excellent sheltering habitat and food resource (Szlavecz et al., 2018). Low vegetation coverage, exposed media, and xeric conditions with minimal sheltering habitats on the extensive green roof is therefore unlikely to support a high abundance of this group. When isopods were excluded from the analyses, the intensive green roof (GR1) had a higher abundance of invertebrates than the ground level (AG), but both the Simpson Index and Shannon index were higher for ground level than either green roof location (Table 11).

Table 10. Invertebrate abundance, morphogroup richness, Shannon index (H’) and Simpson index (1-D) for the ground-level and green roof sites (AG = ground level, GR1 = Green Roof 1, GR2= Green Roof 2).

| | AG | GR1 | GR2 |
|---|---|---|---|
| **Abundance** | 39156 | 25869 | 852 |
| **Richness** | 253 | 242 | 59 |
| **Shannon Index (H’)** | 0.644 | 1.606 | 2.577 |
| **Simpson Index (1-D)** | 0.177 | 0.602 | 0.837 |

Table 11. Invertebrate abundance, morphogroup richness, Shannon index (H’) and Simpson index (1-D) for the ground-level and green roof sites excluding Isopoda (AG = ground level, GR1 = Green Roof 1, GR2= Green Roof 2).

| | AG | GR1 | GR2 |
|---|---|---|---|
| **Abundance** | 3102 | 10198 | 711 |
| **Richness** | 252 | 241 | 58 |
| **Shannon Index (H’)** | 3.57 | 1.291 | 2.423 |
| **Simpson Index (1-D)** | 0.999 | 0.939 | 0.840 |

At the order level, Polyxenidae and Trombidiformes were the only groups with higher abundance on the green roofs compared to ground level. The Polyxenidae are a group of small soft-bodied millipedes (known as pin-cushion millipedes) that inhabit crevices, the undersides of rocks, and the upper layers of soil. They are notably more tolerant of dry conditions than other Diplopoda taxa (Golovatch & Kime, 2009) suggesting an environmental explanation for their higher abundance on the green roofs compared to ground level. Trombidiformes, however, are extremely diverse in their feeding preferences (algivores, bacterivores, fungivores, herbivores, predators, and parasites) (Seniczak et al., 2022), and precise identification of this group was challenging due to their small size and numerous juvenile specimens which had delicate structures that easily degraded during sample storage.

The abundance of invertebrates varied considerably over the course of the study period, peaking on July 10 for all locations, but Green Roof 2 had relatively little variation in abundance compared to the other two sites (figure 15). Invertebrate abundance was higher for traps that were located in areas with higher vegetation coverage and plant species richness on the green roofs (figure 16), but this pattern was not observed among traps at ground-level. This may be because the areas surrounding ground-level pitfall traps were highly heterogenous, with significant variation in habitat characteristics over short distances whereas the green roof environments were generally more homogenous.

Still, in aggregate, the ground level pitfall traps produced a substantially greater number of invertebrates and were located in areas with higher average vegetation coverage, plant species richness, and vegetation complexity. The general pattern observed in this case study, wherein invertebrate species richness was positively associated with invertebrate abundance and species richness is in agreement with the preponderance of evidence that suggests these factors positively affect invertebrate diversity in urban gardens, parks, and other green space (Delahay et al., 2023).

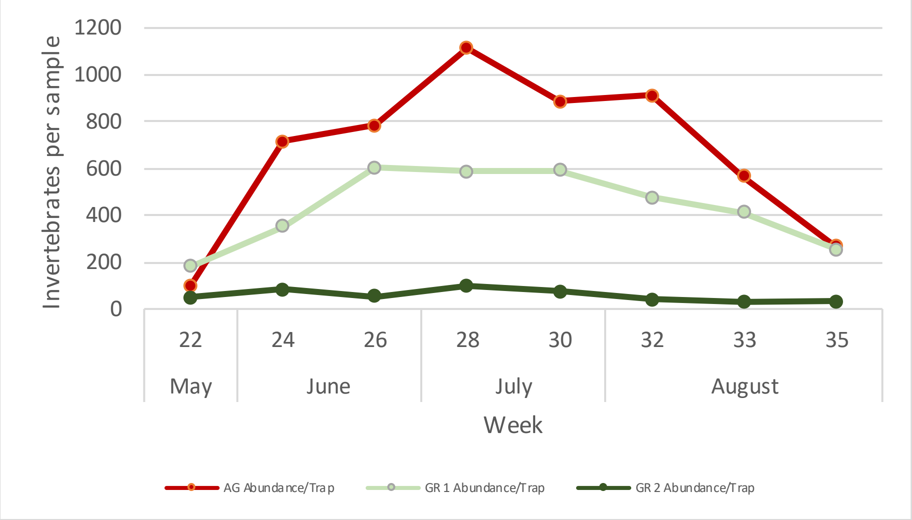

Figure 15. The abundance of trapped invertebrates over the course of the study for each location (AG = ground level, GR1 = Green Roof 1, GR2= Green Roof 2).

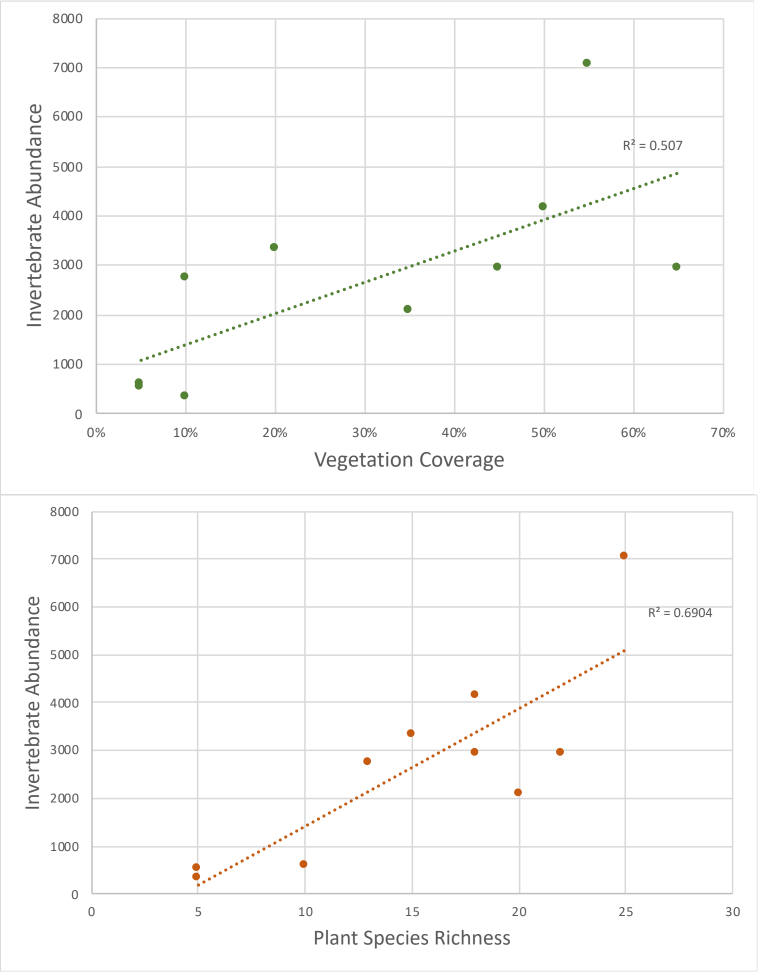

Figure 16. Relationship between percent vegetation coverage (top), and plant species richness (bottom) on invertebrate abundance on the Green Roofs.

Importantly, over the course of the study, a parasitoid wasp from the genus Cynipidae was captured in a pitfall trap at ground level and fit no existing descriptions. Further examination by entomologists at Colorado State University suggests that this collection represents an undescribed species and it is currently pending further examination by staff at the Denver Museum of Nature and Science.

## 2.4 Conclusions

Invertebrate abundance, richness, and biomass were higher at ground-level compared to either green roof site. The intensive green roof supported a similar species richness and abundance of invertebrates as ground-level, but the extensive green roof was relatively depauperate compared to the other two locations. However, we observed particular invertebrate orders in higher numbers on the green roofs, namely Polyxenidae and Trombidiformes, suggesting that the green roofs may support differential groups of invertebrates compared to ground-level habitats.

The results from this study corroborate other findings that show green space with higher vegetation coverage, plant species richness, and vegetation complexity will support a wider array of invertebrates. We also show that it is possible for densely planted intensive green roofs, in particular, to support comparable invertebrate diversity and abundance to ground-level green space in urban areas and therefore validates the idea that green roofs can meaningfully support biodiversity. The potential identification and description of a new species of parasitoid wasp similarly underscores the importance of biodiversity research in urban areas.

# CHAPTER 3. A COMPARISON OF FLORAL VISITORS AMONG ORNAMENTAL FLOWERING PLANTS USING A CITIZEN SCIENCE DATASET

## 3.1 Introduction

### *3.1.1 Value of Urban Environments and Ornamental Horticultural Landscapes to Floral Visitors*

Some scientists have characterized urban green space, gardens, and other horticultural installations as mere "facades" that fail to make meaningful contributions to ecosystem function. Quigley (2011), suggests that the burgeoning movement of urban biodiversity conservation through green infrastructure, ecological gardening, and environmentally-conscious horticulture may be misguided. There are, of course, many possible mechanisms through which urban gardens might contribute to ecosystem function, but one of the most studied is plant-pollinator interactions. Plant-pollinator interactions are of particular interest due to the calls for conservation action in response to globally declining pollinator populations (Potts et al., 2016). In apparent disagreement with Quigley's (2011) view, is an emerging body of work that demonstrates that urban areas can effectively provision nectar, pollen, and habitat for pollinators.

Relative to surrounding nature preserves and agricultural landscapes, urban areas have been shown to offer similar nectar resource volumes, but a higher degree of nectar diversity, primarily from the diversity of plants represented in gardens (Tew et al., 2021). Similarly, urban green spaces tend to have high plant species diversity and nectar resource stability over the course of the growing season, especially compared to surrounding peri-urban vegetation, characteristics that can support higher pollinator density (Tew et al., 2022). Although uneven spatial distribution of pollinator-friendly vegetation remains common in cities, large-scale multi-city analyses have revealed that gardens and allotments are pollinator diversity hotspots within the generalized urban environment and therefore represent a key strategy for pollinator conservation (Baldock et al., 2019).

A variety of metrics influence the ability of urban areas and gardens to support pollinators. Vegetation composition, including habitat type, vegetation height, and taxonomic diversity are associated with variability in pollinator communities in urban areas (Dylewski et al., 2020). Plant growth form and species-specific characteristics also influence the volume of nectar provided to pollinators. In urban areas, nectar-rich shrubs and trees contribute highly to nectar production (Tew et al., 2021). Perennial vegetation, especially diverse naturalistic plantings, have been shown to provide high nectar and pollen volumes over longer periods, compared to plants with annual life cycles (Hicks et al., 2016). Quistberg et al. (2016) found that bees were generally more plentiful and exhibited greater species richness in larger gardens with increased floral abundance, reduced mulch cover, and greater exposure of bare ground. Others have shown that floral abundance positively affects wild bee species richness, but only when surrounding landscape-scale factors like local habitat size and urban land cover area are accounted for (Egerer et al., 2020).

A preponderance of evidence supports the positive effects of biodiversity and multiple aspects of ecosystem functionality (Hooper et al., 2005; Cardinale et al., 2012) as well as human health and economies (Clark et al., 2014; Velarde et al., 2007), suggesting broad benefits of urban green space, gardens, and horticultural plantings that extend beyond pollinator health. A recent study analyzing native-plant policy scenarios found that increasing pollinator-friendly plant coverage in Denver, CO, USA could prevent premature deaths attributed to environmental factors (Garber et al., 2023).

### *3.1.2 Plant Selection, Nativity, and Cultivated Origin*

Plant selection is critical to the value and success of pollinator habitat in garden settings, but there is little consistency in pollinator planting recommendations and often minimal empirical data to support plant choice. Non-peer-reviewed pollinator plant lists are widely available and are often specific to geographic regions. However, these lists are typically based on anecdotal information rather than empirical data and are lacking in specificity with regard to pollinator species that benefit from the recommended plants. Likewise, there are few publications, especially those that are regionally specific, that offer practical information on plant traits, taxonomic groups, or other plant characteristics that benefit pollinators.

Plant nativity is a commonly cited criterion for pollinator plant selection in urban areas, but direct comparisons of native and nonnative plants often report nominal differences in pollinator abundance and diversity (Erickson et al., 2021; Kalaman et al., 2022; Seitz et al., 2020). Floral area and resource value may be a larger driver of pollinator abundance than nativity per se, but areas with native plants are also more likely to support specialized pollinator groups (Seitz et al., 2020; Salisbury et al., 2015). For example, Fukase (2016) reports that urban gardens with a higher coverage area of native plants have greater pollinator activity, but only for bumblebees and the trend is not generalizable for pollinators overall. Bumble bee preferences in urban gardens in the United Kingdom were shown to depend on the plant species and bumble bee species considered, suggesting that floral attractiveness varies among both native and non-native flowers, as do floral preferences among different pollinator species (Hanley et al., 2014). Some studies, however, are more unequivocal; Corbet et al. (2001), in a study comparing insect visits and nectar production in four British native plants and four non-native plants, found that all native species were nectar-rich and frequently visited by pollinators. Conversely, non-native species received fewer pollinator visits, and in cases where nectar was available, it often remained inaccessible.

Many studies note that nonnative plants have higher pollinator visitation later in the growing season and therefore may represent important additions to urban landscapes for pollinators in autumn as native plant floral resources wane (Salisbury et al., 2011; Staab et al., 2020). Even studies that report that native plants attract, on average, greater numbers of pollinators, observe that certain nonnative species (including nonnative weeds) experience high pollinator visitation (Lowenstein et al., 2019) suggesting that species-specific plant characteristics, rather than nativity per se should be employed to design pollinator-friendly landscapes.

Few standardized definitions of native plants exist and often rely on contemporary geopolitical borders, rather than biogeographical boundaries, to define plant nativity. For example, Colorado native plants are often defined as “a plant existing in Colorado prior to European settlement" (Shonle et al., n.d.). or, more generally, any plant species "that occurs naturally in a particular region, state, ecosystem, and habitat without direct or indirect human actions" (Federal Native Plant Conservation, n.d.). For the purposes of this study, we define plants native to the United States as those found in the continental United States before European settlement, while plants native to Colorado are defined as those found within the current state boundaries of Colorado before European settlement.

The cultivated origin of cultivated plants may also impact their attractiveness to floral visitors due to human selection for aesthetic plant traits and the breeding of sterile cultivars (White, 2016). For instance, double-flowering varieties of plants have been shown to secrete little to no nectar and therefore attract few pollinators (Corbet et al. 2001). Likewise, while no evidence was found for differential flower visitation between cultivars and straight species, Mach and Potter (2018) also demonstrated that double-flowered and sterile shrub cultivars attract significantly fewer visitors. Cultivars, where floral morphology is similar to the straight species, have been shown to have no significant difference in native bee foraging compared to wild-type plants (Baker et al., 2020). Other experimental systems (Erickson et al., 2021; Ippolito et al., 2004; Nabors et al., 2022) and large-scale observation studies (Garbuzov & Ratnieks, 2014) find no preference among flower visitors between wild-type plants and cultivars. Together, results from this line of inquiry suggest that ornamental cultivars are not universally more or less attractive to flower visitors and should be evaluated on a case-by-case basis (Ricker et al., 2019).

The phrase “nativar” is increasingly used in the scientific literature related to the pollinator value of ornamental crops, however, we avoid this term as it generally communicates little biological value. For example, a seed-propagated selection of native species and a sterile interspecific hybrid may both be considered nativars (White, 2016). We consider any plant selection, cultivar, or hybrid with parentage that occurs wholly within the geographical bounds of our nativity definitions as a native plant.

### *3.1.3 Study Aims*

In this study we analyze four years of citizen science data to evaluate the differences in pollinator visitation among a diverse set of ornamental horticultural plant varieties. Citizen science is increasingly used by ecologists and the scientific community to answer complex questions that require large datasets that might otherwise be infeasible to produce. However, some scientists suggest that citizen science data is problematic and question adherence to standardized protocols by citizen scientists and overall data quality (Lukyanenko et al., 2016). Systematic reviews of citizen-science-based publications have supported this view citing a concerning lack of agreement on reanalyzed citizen science-based results (Aceves-Bueno et al., 2017). Despite this, a growing body of publications demonstrates that citizen science projects are capable of generating data of accuracy on par with or exceeding that of professionals, especially when processes to train and test volunteers and validate data are part of the process (Kosmala et al., 2016). Mason and Seshadri (2019) demonstrated that citizen scientists using the Native Bee Watch protocol, the same protocol used in this study, collected accurate data comparable to a professional researcher.

Specifically, we ask if plant nativity and cultivated origin is related to native bee visitation; in other words, do native ornamental plants ostensibly provision more pollinator resources than non-native plants and do horticultural selections and/or hybrids differ from straight species that are cultivated? Further, we seek to determine whether particular plant families and genera investigated are more likely to be associated with pollinator visitation, especially among Colorado native bees. Finally, this study provides practical information for urban planners, horticulturists, and ecologists, in the form of a taxon-specific pollinator visitation dataset for an array of ornamental plants in the commercial nursery industry. This information is critical to the quality and success of pollinator habitat in garden settings given the paucity of empirical information available for landscape practitioners and consumers.

## 3.2 Materials and Methods

### *3.2.1 Data Set*

This study leverages a large pollinator visitation data set following the protocol from Mason et al. (2018) collected at Denver Botanic Gardens in Denver, Colorado. Observations were performed at various locations of the 24-acre urban campus of ornamental gardens (39.732072, -104.960823) between 2017 and 2020 and at the peri-urban Chatfield Farms location (39.551012, -105.099248) during the 2018 and 2019 growing seasons.

4059 individual observation events of 232 plant taxa, encompassing 7529 pollinator observations are contained in the analysis. The pollinator observations include 4700 (62% of total) honeybees (*Apis mellifera*) and 1886 (25% of total) native bees. Flies (509), moths and butterflies (136), wasps (94), beetles (75), ants (18) and birds (30) comprised the remainder of the observations (Table 11). We supplemented the citizen science data to include additional taxon-specific plant information, not originally recorded in the dataset. Plants were each assigned a plant taxonomic family, growth form (herbaceous annual, herbaceous perennial, shrub, or vine), and nativity status for both the state of Colorado and the continental United States.

Table 12. Summary of pollinator observations by year, including the total number of pollinator observation events, number of observed plant families, genera, number of individual native and nonnative plants, number of honeybees, native bees, and total pollinators observed.

| | | **PLANT SUMMARY** | | | | **POLLINATOR SUMMARY** | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | **Number of Observations** | **Plant Families** | **Genera** | **Native Plants (US)** | **Nonnative Plants (US)** | **Honeybees** | **Native Bees** | **Total Pollinators** |
| **2017** | 1038 | 42 | 143 | 515 | 523 | 1937 | 538 | 2685 |
| **2018** | 1179 | 40 | 115 | 496 | 683 | 1116 | 546 | 1842 |
| **2019** | 668 | 23 | 56 | 315 | 353 | 776 | 585 | 1761 |
| **2020** | 1173 | 18 | 16 | 661 | 512 | 871 | 217 | 1241 |
| **Total** | **4058** | **43** | **143** | **1987** | **2071** | **4700** | **1886** | **7529** |

An origin classifier for each plant taxon, which specifies if it is a straight species, ornamental horticultural selection, or hybrid (either intraspecific or interspecific) was also included in the dataset. Species with fewer than 3 observation events were eliminated as singular, or even duplicate observation events have a greater chance of being nonrepresentative samples.

### *3.2.2 Citizen Science Protocol*

Pollinator observations followed the protocol as outlined by Mason et al. (2018) in “Native Bee Watch: A Colorado Citizen Science Field Guide”. Data collection consisted of two-minute timed observations of each plant and counting the number of bees observed within specific morpho-species categories focused on native bee taxa (Table 12). Observations of non-bee pollinators incorporating flies, butterflies, moths, beetles, wasps, ants, and birds were also included. During the two-minute observational window, only visiting pollinators that made contact with the floral reproductive structures were counted, according to Mason et al. (2018). If the reproductive structures of a plant were inactive or damaged, no observation was recorded. Observations took place between 9:00 am and 11:30 am, and the weather conditions including temperature, cloud conditions, and wind were recorded. Data collection began in May each year through the first major freeze, typically in late September or early October. All citizen scientists who contributed to the dataset were trained by extension agents and scientists from Colorado State University who were familiar with the protocol or by the authors of this study.

| Bee Group | Bee Subgroup | Common Name | Scientific Name | Family |
|---|---|---|---|---|
| Honey bee | NA | Honey bee | *Apis mellifera* | Apidae |
| Hairy leg bee | NA | Digger bee<br>Flower bee<br>Long-horned bee<br>Sunflower bee | *Anthophora* sp.<br>*Diadasia* sp.<br>*Melissodes* sp.<br>*Svastra* sp. | Apidae<br>Apidae<br>Apidae<br>Apidae |
| Hairy belly bee | Wasp-like | Wool carder bee<br>Resin bee | *Anthidium* sp.<br>*Megachile* sp. | Megachilidae<br>Megachilidae |
| | White-striped | Leafcutter bee | *Megachile* sp. | Megachilidae |
| | Other hairy belly bees | Mason bee | *Megachile* sp.<br>*Osmia* sp.<br>*Hoplitis* sp. | Megachilidae<br>Megachilidae<br>Megachilidae |
| Bumble bee | Orange band | Hunt's bumble bee<br>Central bumble bee | *Bombus huntii*<br>*Bombus centralis* | Apidae<br>Apidae |
| | Yellow and black | Brown belted bumble bee<br>Morrison's bumble bee<br>Nevada bumble bee | *Bombus griseocollis*<br>*Bombus morrisoni*<br>*Bombus nevadensis* | Apidae<br>Apidae<br>Apidae |
| | White or yellow tip | Western bumble bee | *Bombus occidentalis* | Apidae |
| | Mostly black | Cuckoo bumble bee | *Bombus insularis* | Apidae |
| | Mostly yellow | Golden northern bumble bee | *Bombus fervidus* | Apidae |
| Green metallic bee | NA | Sweat bee | *Agapostemon* sp.<br>*Augochlorella* sp. | Halictidae<br>Halictidae |
| Tiny dark bee | NA | Small carpenter bee<br>Small carpenter bee<br>Yellow-faced bee | *Ceratina neomexicanum*<br>*Ceratina* sp.<br>*Hylaeus* sp.<br>*Lasioglossum* sp. | Apidae<br>Apidae<br>Colletidae<br>Halictidae |
| Striped sweat bee | Small | Sweat bee<br>Sweat bee, other | *Halictus* sp.<br>*Lasioglossum* sp. | Halictidae<br>Halictidae |
| | Medium | Sweat bee<br>Sweat bee, other | *Halictus* sp.<br>*Lasioglossum* sp. | Halictidae<br>Halictidae |
| Cuckoo bee | Red abdomen | Cuckoo bee<br>Cuckoo bee | *Nomada* sp.<br>*Sphecodes* sp. | Apidae<br>Halictidae |
| | Small | Cuckoo bee<br>Cuckoo bee<br>Cuckoo bee | *Epeolus* sp.<br>*Nomada* sp.<br>*Sphecodes* sp. | Apidae<br>Apidae<br>Halictidae |
| | Large | Cuckoo bee<br>Cuckoo bee<br>Cuckoo bee | *Epeolus* sp.<br>*Nomada* sp.<br>*Sphecodes* sp. | Apidae<br>Apidae<br>Halictidae |

*Note: This is not an inclusive list of all bees found in these categories or in Colorado. These are some of the more common bees observed.*

Figure 17. Bee Morpho-Groups and Scientific Classifications from Mason et al (2018).

### *3.2.3 Data analysis*

We performed a chi-squared test and a nominal logistical regression with multinomial binary categorical response was used to determine associations between pollinator nativity as a function of plant nativity. A Poisson distribution was assumed for the count data, but Poisson models showed significant dispersion, so a negative binomial regression model was used instead. Negative binomial regression models were run separately for counts of each pollinator grouping (honeybees, native bees, other pollinators, and total pollinators) with plant nativity, plant origin, plant growth form, observation location, year, and taxonomic order (as family and genus level resulted in too many predictors for the model). A separate model, using the same parameters, but including flower number as a predictor was used for the subset of observations which included flower count estimates (n=3123). Model selection was based on AIC scores and an evaluation of data dispersion metrics. All statistical analysis were performed in R (R Core Team 2022) .

## **3.3 Results and Discussion**

We found no association between plant and pollinator nativity regardless of whether plant nativity was defined at the level of the continental United States (X-squared = 0.0071444, p=.9326) or State of Colorado (X-squared = 0.0059761, p=.94333) (Figure 18D).

Plant origin was significantly associated with pollinator visitation. Selections were more likely to be visited by all pollinators (p<0.001), honeybees (p<0.001), and other pollinators (p<0.001) compared to hybrids, but there was no statistical difference for native bees (Figure 18 C, Table 12). Straight species, however, had significantly higher visitation for all pollinator groups, including native bees (p<0.001) (Figure 18C, Table 12). These results corroborate other work that demonstrates that ornamental horticultural hybrids are less attractive to pollinators (Mach & Potter, 2018; White, 2016). While our dataset includes a wide range of hybrid plants, the observational nature of the data precludes a trait-based explanation for lower pollinator visitation rates on hybrid plants. Ornamental plant breeding, however, is often focused on flower morphology (Botelho et al., 2015) and evidence suggests that traits desired by consumers like double flowering (Mach & Potter, 2018; Corbet et al 2001) and sterile flowers (White, 2016) provision fewer resources to pollinators.

Herbaceous perennials (p<0.0001) and shrubs (p<0.0001) experienced more visitation from all pollinators compared to herbaceous annuals and vines (Figure 18B, Table 12). Shrubs are usually larger in size and have more abundant flowers per individual and pollinators are often attracted to larger masses of floral resources (Fowler et al., 2016).

Native bees were observed significantly less often at the urban location compared to the peri-urban location (p<0.0001) and honeybees were observed significantly more often at the urban site (p<0.0001) (Figure 18A, Table 12). This corroborates work done by others that have found that surrounding landscape characteristics and proximity to surrounding rural land is positively associated with native and solitary bee abundance (Birdshire et al., 2020; Geslin et al., 2013)

We found no significant relationship between plant family and any pollinator group, but found that several genera were significantly related to higher pollinator visitation. Among those, *Seseli* (p<.0001), *Hesperaloe* (p<0.00001) *, Hepaticodium* (p<.0001), and *Chamaebatiaria* (p<.0001) reported significantly higher total pollinator visitation rates.

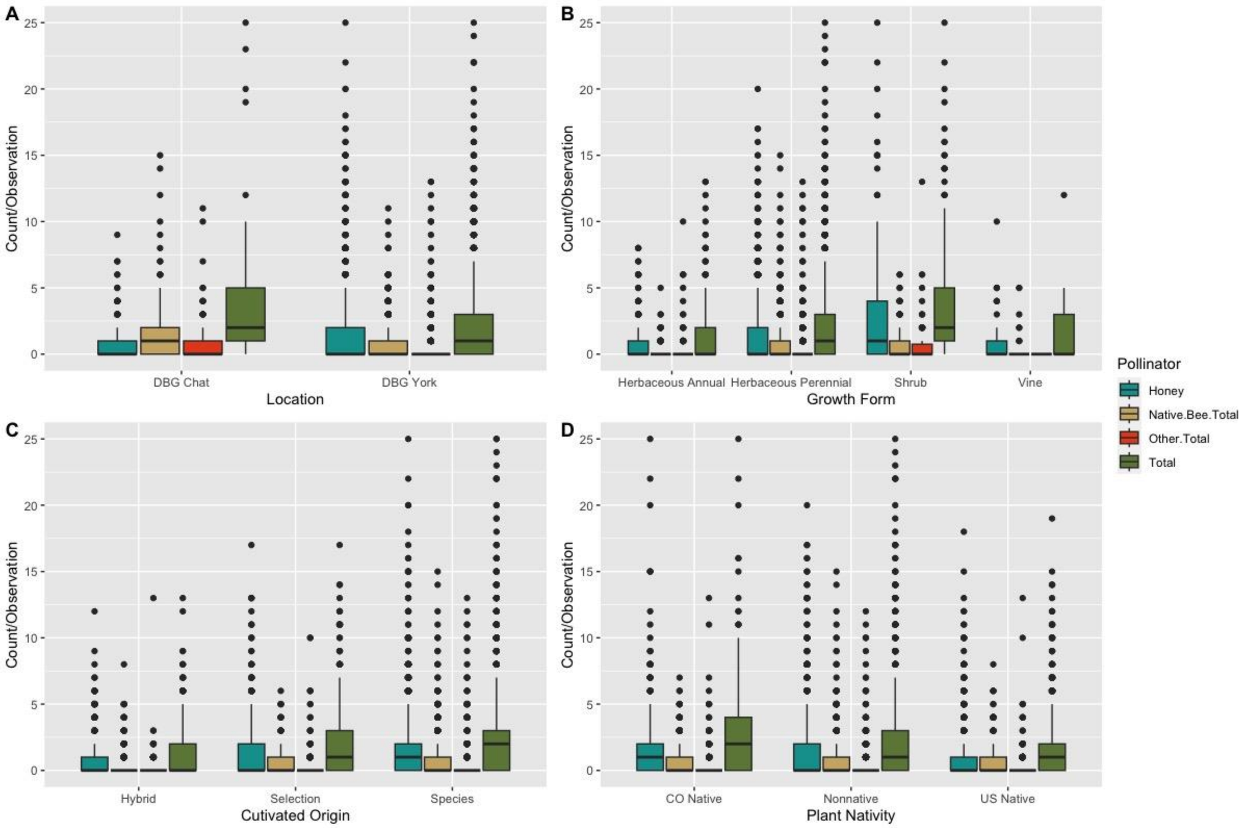

Figure 18. Counts per observation of honeybees, native bees, other pollinators, and total pollinators A) at the peri-urban (DBG Chat) and urban (DBG York) site, B) by growth form, C) cultivated origin, and D) plant nativity.

Table 13. Output from negative binomial regression models.

| | *Dependent variable:* | | | |
|---|---|---|---|---|
| | Total | Honey Bees | Native Bee Total | Other Pollinator Total |
| Origin: Selection | 0.514$^{***}$ | 0.603$^{***}$ | 0.216$^{*}$ | 0.511$^{***}$ |
| | (0.074) | (0.096) | (0.124) | (0.196) |
| Origin: Species | 0.669$^{***}$ | 0.641$^{***}$ | 0.738$^{***}$ | 0.717$^{***}$ |
| | (0.066) | (0.086) | (0.108) | (0.175) |
| Nativity: Nonnative | 0.021 | 0.129 | -0.136 | -0.328$^{**}$ |
| | (0.060) | (0.078) | (0.094) | (0.143) |
| Nativity: US Native | -0.257$^{***}$ | -0.194$^{**}$ | -0.208$^{*}$ | -0.601$^{***}$ |

| | | | | |
|---|---|---|---|---|
| | (0.069) | (0.090) | (0.108) | (0.169) |
| Growth Form: Herbaceous Perennial | 0.364$^{***}$ | 0.377$^{***}$ | 0.812$^{***}$ | -0.520$^{***}$ |
| | (0.088) | (0.113) | (0.165) | (0.198) |
| Growth Form: Shrub | 0.849$^{***}$ | 1.098$^{***}$ | 0.713$^{***}$ | -0.081 |
| | (0.110) | (0.141) | (0.201) | (0.253) |
| Growth Form: Vine | 0.092 | 0.132 | 0.886$^{**}$ | -23.799 |
| | (0.218) | (0.282) | (0.345) | (24,934.840) |
| Location: DBG York | -0.291$^{***}$ | 0.714$^{***}$ | -1.198$^{***}$ | -0.621$^{***}$ |
| | (0.103) | (0.149) | (0.151) | (0.225) |
| Year2018 | -0.537$^{***}$ | -0.735$^{***}$ | -0.096 | -0.344$^{**}$ |
| | (0.055) | (0.071) | (0.089) | (0.144) |
| Year2019 | -0.131$^{*}$ | -0.305$^{***}$ | -0.059 | 0.652$^{***}$ |
| | (0.073) | (0.095) | (0.119) | (0.173) |
| Year2020 | -0.329$^{***}$ | -0.313$^{***}$ | -0.512$^{***}$ | -0.046 |
| | (0.066) | (0.085) | (0.114) | (0.167) |
| Constant | 0.399$^{**}$ | -1.056$^{***}$ | -0.577$^{**}$ | -0.741$^{**}$ |
| | (0.156) | (0.213) | (0.257) | (0.357) |
| Observations | 3,400 | 3,398 | 3,400 | 3,400 |
| Log Likelihood | -6,539.466 | -5,182.324 | -3,214.998 | -1,860.174 |
| theta | 0.919$^{***}$ (0.038) | 0.537$^{***}$ (0.024) | 0.482$^{***}$ (0.033) | 0.200$^{***}$ (0.017) |
| Akaike Inf. Crit. | 13,102.930 | 10,388.650 | 6,453.995 | 3,744.348 |
| *Note:* | | | | *p<0.1; >**p<0.05; >***p<0.01 |

Table 14. The top 25 plants in the study ranked by average total pollinator visitation per observation event.

| **Genus** | **Species** | **Cultivar** | **Growth Form** | **Origin** | **US Native** | **CO Native** | **Honey** | **Native Bees** | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| *Echinops* | *tjanschanicus* | | Herbaceous Perennial | Species | No | No | 10.0 | 1.0 | 11.3 |
| *Seseli* | *gummiferum* | | Herbaceous Perennial | Species | No | No | 4.1 | 4.5 | 10.9 |
| *Chamaebatiaria* | *millefolium* | | Shrub | Species | Yes | No | 6.8 | 1.1 | 9.1 |
| *Heptacodium* | *miconioides* | | Shrub | Species | No | No | 7.3 | 0.1 | 7.8 |
| *Delosperma* | | ‘Lavender Ice' | Herbaceous Perennial | Selection | No | No | 7.0 | 0.3 | 7.3 |
| *Fallugia* | *paradoxa* | | Shrub | Species | Yes | Yes | 4.3 | 1.1 | 6.6 |
| *Centaurea* | *macrocephala* | | Herbaceous Perennial | Species | No | No | 3.7 | 3.6 | 6.2 |
| *Anchusa* | *capensis* | | Herbaceous Perennial | Species | No | No | 5.4 | 0.7 | 6.1 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Eutrochium* | *maculatum* | 'Gateway' | Herbaceous Perennial | Selection | Yes | No | 5.4 | 1.1 | 6.0 |
| *Sedum* | *sediforme* | | Herbaceous Perennial | Species | No | No | 3.6 | 2.2 | 5.6 |
| *Ammi* | *visnaga* | | Herbaceous Annual | Species | No | No | 4.0 | 0.6 | 5.5 |
| *Rudbeckia* | *laciniata* | | Herbaceous Perennial | Species | Yes | Yes | 5.9 | 0.7 | 5.4 |
| *Eriogonum* | *wrightii* var. *wrightii* | | Herbaceous Perennial | Species | Yes | No | 4.7 | 0.5 | 5.3 |
| *Penstemon* | *x mexicali* | Pikes Peak Purple' | Herbaceous Perennial | Hybrid | Yes | No | 5.0 | 0.0 | 5.0 |
| *Lonicera* | *reticulata* | Kintzley's Ghost' | Vine | Selection | No | No | 4.0 | 1.6 | 4.9 |
| *Rubus* | *deliciosus* | | Shrub | Species | Yes | Yes | 2.9 | 2.2 | 4.8 |
| *Anethum* | *graveolens* | | Herbaceous Annual | Species | No | No | 1.7 | 2.0 | 4.8 |
| *Satureja* | *montana* var. *illyrica* | v. | Herbaceous Perennial | Species | No | No | 3.3 | 1.8 | 4.8 |
| *Zauschneria* | *garrettii* | | Herbaceous Perennial | Species | Yes | No | 5.5 | 0.1 | 4.7 |
| *Delosperma* | *dyeri* | 'Psdold' | Herbaceous Perennial | Selection | No | No | 0.0 | 4.0 | 4.5 |
| *Pseudolysimachion* | *longifolia* | | Herbaceous Perennial | Species | No | No | 6.3 | 0.9 | 4.4 |
| *Ericameria* | *nauseosus* var.*nauseosus* | | Shrub | Species | Yes | Yes | 6.2 | 0.0 | 4.3 |
| *Anthemis* | *marschalliana* | | Herbaceous Perennial | Species | No | No | 0.0 | 3.2 | 4.2 |
| *Engelmannia* | *peristenia* | | Herbaceous Perennial | Species | Yes | Yes | 2.6 | 1.3 | 4.1 |
| *Origanum* | *libanoticum* | | Herbaceous Perennial | Species | No | No | 2.0 | 3.0 | 3.9 |

Table 15. The top 25 plants in the study ranked by average native bee pollinator visitation per observation event.

| **Genus** | **Species** | **Cultivar** | **Growth Form** | **Origin** | **US Native** | **CO Native** | **Honey** | **Total** | **Native Bees** |
|---|---|---|---|---|---|---|---|---|---|
| *Seseli* | *gummiferum* | | Herbaceous Perennial | Species | No | No | 4.14 | 10.94 | 4.51 |
| *Delosperma* | *dyeri* | 'Psdold' | Herbaceous Perennial | Selection | No | No | 0.00 | 4.50 | 4.00 |
| *Centaurea* | *macrocephala* | | Herbaceous Perennial | Species | No | No | 3.67 | 6.22 | 3.56 |
| *Anthemis* | *marschalliana* | | Herbaceous Perennial | Species | No | No | 0.00 | 4.20 | 3.20 |
| *Origanum* | *libanoticum* | | Herbaceous Perennial | Species | No | No | 2.00 | 3.92 | 3.00 |
| *Veronica* | *liwanensis* | | Herbaceous Perennial | Species | No | No | 3.00 | 3.50 | 2.75 |
| *Rubus* | *deliciosus* | | Shrub | Species | Yes | Yes | 2.94 | 4.83 | 2.22 |
| *Sedum* | *sediforme* | | Herbaceous Perennial | Species | No | No | 3.61 | 5.64 | 2.18 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Penstemon* | *linarioides* var. *coloradoensis* | | Herbaceous Perennial | Species | Yes | Yes | 3.00 | 3.00 | 2.10 |
| *Anethum* | *graveolens* | | Herbaeous Annual | Species | No | No | 1.67 | 4.80 | 2.00 |
| *Veronica* | *x* | 'P108S' | Herbaceous Perennial | Hybrid | No | No | 2.00 | 2.33 | 1.92 |
| *Crambe* | *maritima* | | Herbaceous Perennial | Species | No | No | 0.00 | 2.57 | 1.86 |
| *Solidago* | *simplex* var. *nana* | | Herbaceous Perennial | Species | Yes | No | 2.33 | 2.53 | 1.80 |
| *Satureja* | *montana var. illyrica* | | Herbaceous Perennial | Species | No | No | 3.27 | 4.75 | 1.79 |
| *Phlomis* | *cashmeriana* | | Herbaceous Perennial | Species | No | No | 1.75 | 3.08 | 1.69 |
| *Penstemon* | *mensarum* | | Herbaceous Perennial | Species | Yes | Yes | 0.00 | 1.60 | 1.60 |
| *Lonicera* | *reticulata* | Kintzley's Ghost' | Vine | Selection | No | No | 4.00 | 4.92 | 1.58 |
| *Tanacetum* | *cinerariifolium* | | Herbaceous Perennial | Species | No | No | 1.00 | 2.58 | 1.50 |
| *Veronica* | *'Reavis'* | | Herbaceous Perennial | Selection | No | No | 1.00 | 1.75 | 1.50 |
| *Rudbeckia* | *hirta* | Denver Daisy' | Herbaceous Perennial | Selection | Yes | Yes | 1.80 | 2.93 | 1.48 |
| *Veronicastrum* | *virginicum* | | Herbaceous Perennial | Species | No | No | 1.00 | 1.80 | 1.40 |
| *Allium* | *christophii* | | Herbaceous Perennial | Species | No | No | 1.00 | 2.00 | 1.33 |
| *Tanacetum* | *densum* ssp. *amani* | | Herbaceous Perennial | Species | No | No | 0.00 | 2.00 | 1.29 |
| *Engelmannia* | *peristenia* | | Herbaceous Perennial | Species | Yes | Yes | 2.65 | 4.11 | 1.28 |
| *Scutellaria* | *scordiifolia* | Pat Hayward' | Herbaceous Perennial | Selection | No | No | 1.50 | 1.53 | 1.27 |

## 3.4 Conclusions

Plant nativity, both at the regional and continental scale has little impact on pollinator visitation among the observed plant taxa included in this study and had no association with the nativity of pollinators. We found that there were differences in pollinator visitation as a function of plant growth form and origin with shrubs and herbaceous perennials visited at the highest rates and higher visitation on horticultural selections and straight species compared to hybrids. Native bees were also more likely to be observed at the peri-urban location compared to the urban site. Particular plant families, including the *Apiaceae, Crassulacea,* and *Onograceae* showed the highest rates of total pollinator visitation, however, there was significant variability between individual species. Generalizations about the pollinator value of horticultural ornamental crops based on nativity are not supported by this analysis, but our analysis supports growing evidence that horticultural hybridization hinders pollinator visitation.

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APPENDIX

## Chapter 1 Supplementary Data

Supplementary Table 1. substrate temperature Data (substrate monthly mean temperature(°C), annual mean temperature(°C), maximum annual temperature(°C), and minimum annual temperature(°C) ) for all Data Loggers operating in 2019.

| | **April** | **May** | **June** | **July** | **August** | **September** | **October** | **Average Temp** | **Max Temp** | **Min Temp** |
|---|---|---|---|---|---|---|---|---|---|---|
| **AG1** | 15.58 | 13.69 | 21.92 | 24.75 | 23.85 | 21.05 | 10.81 | **15.08** | **34.02** | **2.92** |
| **AG2** | 21.46 | 21.59 | 20.85 | 22.59 | 23.80 | 22.25 | 12.37 | **18.99** | **30.16** | **2.62** |
| **AG3** | 13.97 | 12.93 | 18.16 | 22.58 | 22.51 | 19.69 | 10.04 | **17.13** | **30.93** | **3.04** |
| **AG4** | 12.31 | 11.80 | 17.60 | 21.45 | 21.04 | 17.92 | 9.32 | **15.92** | **25.82** | **6.65** |
| **AG5** | 14.90 | 13.32 | 19.01 | 22.52 | 21.95 | 18.35 | 8.74 | **16.97** | **29.21** | **3.04** |
| **GR1** | 19.53 | 15.66 | 22.99 | 27.53 | 25.86 | 23.30 | 10.39 | **20.75** | **43.88** | **-0.22** |
| **GR2** | 19.24 | 14.78 | 22.31 | 27.41 | 26.01 | 21.42 | 9.47 | **20.09** | **38.09** | **0.60** |
| **AG AVG** | 15.65 | 14.67 | 19.51 | 22.78 | 22.63 | 19.85 | 10.26 | **16.82** | **30.03** | **3.65** |
| **GR AVG** | 19.39 | 15.22 | 22.65 | 27.47 | 25.93 | 22.36 | 9.93 | **20.42** | **40.99** | **0.19** |

Supplementary Table 2. Substrate temperature data (substrate monthly mean temperature(°C), annual mean temperature(°C), maximum annual temperature(°C), and minimum annual temperature(°C) ) for all Data Loggers operating in 2020

| | **April** | **May** | **June** | **July** | **August** | **September** | **October** | **Average Temp** | **Max Temp** | **Min Temp** |
|---|---|---|---|---|---|---|---|---|---|---|
| **AG1** | 13.30 | 20.62 | 22.46 | 24.05 | 24.59 | 19.54 | 15.85 | 20.06 | 33.29 | 2.53 |
| **AG2** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| **AG3** | 10.47 | 15.82 | 18.75 | 20.61 | 21.16 | 17.41 | 11.50 | 16.53 | 25.87 | 3.17 |
| **AG4** | 9.11 | 12.97 | 17.84 | 21.08 | 20.80 | 17.81 | 9.32 | 15.56 | 27.54 | 3.30 |
| **AG5** | 10.90 | 16.30 | 18.23 | 22.27 | 22.01 | 16.95 | 9.38 | 16.58 | 26.81 | 2.01 |
| **AG6** | 9.69 | 15.01 | 18.49 | 20.99 | 21.25 | 16.55 | 10.72 | 16.10 | 25.69 | 3.30 |
| **GR1** | 15.20 | 21.58 | 23.60 | 25.22 | 25.86 | 18.90 | N/A | 21.73 | 35.09 | 0.94 |
| **GR2** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| **GR3** | 15.69 | 20.54 | 23.82 | 26.41 | 26.63 | 18.77 | 11.33 | 20.46 | 36.72 | 0.51 |
| **GR4** | 15.98 | 20.73 | 24.08 | 25.99 | 25.36 | 17.30 | 9.11 | 19.79 | 35.86 | 0.38 |
| **GR5** | 12.62 | 20.78 | 23.83 | 25.62 | 24.92 | 18.21 | 11.13 | 19.59 | 39.51 | 0.86 |
| **GR6** | N/A | -17.78 | 22.42 | 23.01 | 22.18 | 17.64 | 12.58 | 19.57 | 37.36 | 2.92 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **AG AVG** | 10.69 | 16.15 | 19.15 | 21.80 | 21.96 | 17.65 | 11.35 | 16.97 | 27.84 | 2.86 |
| **GR AVG** | 14.87 | 20.91 | 23.55 | 25.25 | 24.99 | 18.17 | 11.04 | 20.23 | 36.91 | 1.12 |

## Chapter 2 Supplementary Data

Supplementary Table 1. All invertebrates identified over the course of the study and the locations where they were found (AG, GR1, GR2).

| Order | Genus | AG | GR1 | GR2 |
|---|---|---|---|---|
| Araneae | Attinella | X | X | X |
| Araneae | Dysdera | X | X | X |
| Araneae | Neon | X | X | |
| Araneae | Pelegrina | X | X | |
| Araneae | Phidippus | X | X | |
| Araneae | Philodromus | X | X | X |
| Araneae | Tenuiphantes | X | X | X |
| Araneae | Ebo | | X | |
| Araneae | Habronattus | | X | |
| Araneae | Mecaphesa | | X | |
| Araneae | Misumenops | | X | |
| Coleoptera | Aeolus | X | X | |
| Coleoptera | Barypeithes | X | X | |
| Coleoptera | FAM: Carabidae | X | X | |
| Coleoptera | FAM: Carabidae Morpho-species 1 | X | X | X |
| Coleoptera | FAM: Carabidae Morpho-species 11 | X | X | |
| Coleoptera | FAM: Carabidae Morpho-species 12 | X | X | |
| Coleoptera | FAM: Carabidae Morpho-species 2 | X | X | X |
| Coleoptera | FAM: Carabidae Morpho-species 3 | X | X | |
| Coleoptera | FAM: Carabidae Morpho-species 4 | X | X | X |
| Coleoptera | FAM: Carabidae Morpho-species 6 | X | X | |
| Coleoptera | FAM: Carabidae Morpho-species 7 | X | X | |
| Coleoptera | FAM: Carabidae Morpho-species 8 | X | X | |
| Coleoptera | FAM: Chrysomelidae morpho-species 1 | X | X | |
| Coleoptera | FAM: Chrysomelidae morpho-species 2 | X | X | |
| Coleoptera | FAM: Chrysomelidae morpho-species 3 | X | X | |
| Coleoptera | FAM: Chrysomelidae morpho-species 4 | X | X | |
| Coleoptera | FAM: Chrysomelidae morpho-species 5 | X | X | |
| Coleoptera | FAM: Chrysomelidae morpho-species 8 | X | X | |

| | | | | |
|---|---|---|---|---|
| Coleoptera | FAM: Coccinellidae morpho-species 2 | X | X | |
| Coleoptera | FAM: Curculionidae morpho-species 1 | X | X | |
| Coleoptera | FAM: Curculionidae morpho-species 3 | X | X | |
| Coleoptera | FAM: Curculionidae morpho-species 4 | X | X | |
| Coleoptera | FAM: Curculionidae morpho-species 5 | X | X | |
| Coleoptera | FAM: Curculionidae morpho-species 6 | X | X | |
| Coleoptera | FAM: Curculionidae morpho-species 7 | X | X | |
| Coleoptera | FAM: Curculionidae morpho-species 8 | X | X | X |
| Coleoptera | FAM: Staphylinidae morpho species 1 | X | X | X |
| Coleoptera | FAM: Staphylinidae morpho species 2 | X | X | |
| Coleoptera | FAM: Staphylinidae morpho-species 2 | X | X | |
| Coleoptera | Hippodamia | X | X | |
| Coleoptera | monocesta | X | X | |
| Coleoptera | Popillia | X | X | |
| Coleoptera | Pyropyga | X | X | |
| Coleoptera | Saprinus | X | X | |
| Coleoptera | SubFam: Rutelinae | X | X | |
| Coleoptera | Teuchestes | X | X | |
| Coleoptera | Xenochodaeus | X | X | |
| Coleoptera | Apterodela | | X | |
| Coleoptera | FAM: Carabidae Morpho-species 10 | | X | |
| Coleoptera | FAM: Carabidae Morpho-species 5 | | X | |
| Coleoptera | FAM: Carabidae Morpho-species 9 | | X | |
| Coleoptera | FAM: Chrysomelidae morpho-species 6 | | X | |
| Coleoptera | FAM: Coccinellidae | | X | |
| Coleoptera | FAM: Coccinellidae morpho-species 1 | | X | |
| Coleoptera | FAM: Curculionidae morpho-species 2 | | X | |
| Coleoptera | FAM: Elateridae | | X | |
| Coleoptera | FAM: Histerridae morpho-species 1 | | X | |
| Coleoptera | FAM: Staphylinidae morpho species 3 | | X | X |
| Coleoptera | Kuschelina | | X | |
| Coleoptera | Metaparia | | X | |
| Coleoptera | Ortona | | X | |
| Coleoptera | Sup.Fam: Coccoidae | | X | |
| Coleoptera | SubFam.: Rutelinae morpho-species 1 | | | X |
| Dermaptera | FAM: Foriculidae | X | X | |
| Dermaptera | Forficula | X | X | X |
| Diptera | Achalcus | X | X | |
| Diptera | Acoenonia | X | X | |

|  |  |  |  |  |
|---|---|---|---|---|
| Diptera | Aenigmatias | X | X |  |
| Diptera | Angioneura | X | X |  |
| Diptera | Anthomyiinae | X | X |  |
| Diptera | Apotropina | X | X |  |
| Diptera | Beckerina | X | X |  |
| Diptera | Bellardia | X | X |  |
| Diptera | Blaesoxipha | X | X |  |
| Diptera | Bombyliomyia | X | X |  |
| Diptera | Bradysia | X | X | X |
| Diptera | Camptops | X | X |  |
| Diptera | Chaetopleurophora | X | X |  |
| Diptera | Chamaemyiidae | X | X |  |
| Diptera | Chlorops | X | X |  |
| Diptera | Chonocephalus | X | X |  |
| Diptera | Clogmia | X | X |  |
| Diptera | Cordilura | X | X |  |
| Diptera | Corynoptera | X | X |  |
| Diptera | Cricotopus | X | X |  |
| Diptera | Dohrniphora | X | X |  |
| Diptera | Enlinia | X | X | X |
| Diptera | Eremomyioides | X | X | X |
| Diptera | Euryomma | X | X |  |
| Diptera | FAM: Ceratopogonidae | X | X |  |
| Diptera | FAM: Chironomidae | X | X |  |
| Diptera | FAM: Chloropidae | X | X |  |
| Diptera | FAM: Drosophilidae | X | X |  |
| Diptera | FAM: Milichiidae | X | X |  |
| Diptera | FAM: Nymphomyiidae morpho-species 1 | X | X | X |
| Diptera | FAM: Phorinae | X | X |  |
| Diptera | FAM: Sarcophagidae | X | X |  |
| Diptera | FAM: Sciaridae | X | X |  |
| Diptera | FAM: Sphaeroceridae morpho-species 1 | X | X |  |
| Diptera | Fannia | X | X | X |
| Diptera | Fucellia | X | X |  |
| Diptera | Gymnophora | X | X |  |
| Diptera | Homaluroides | X | X |  |
| Diptera | Hydrophoria | X | X |  |
| Diptera | Kellymyia | X | X |  |
| Diptera | Leia | X | X |  |

| | | | | |
|---|---|---|---|---|
| Diptera | Lydina | X | X | |
| Diptera | Meromyza | X | X | |
| Diptera | Metangela | X | X | |
| Diptera | Microcerella | X | X | |
| Diptera | Nearcticorpus | X | X | |
| Diptera | Nymphomyiidae | X | X | |
| Diptera | Oestrophasia | X | X | |
| Diptera | Orthacheta | X | X | |
| Diptera | Paraelomma | X | X | |
| Diptera | Paragus | X | X | |
| Diptera | Parallelomma | X | X | |
| Diptera | Paralucilia | X | X | |
| Diptera | Peletia | X | X | |
| Diptera | Pentaneurini | X | X | |
| Diptera | Phlebothrix | X | X | |
| Diptera | Pnyxia | X | X | X |
| Diptera | Pollenia | X | X | |
| Diptera | Porricondylinae | X | X | |
| Diptera | Procladiini | X | X | |
| Diptera | Procladius | X | X | |
| Diptera | Protocalliphora | X | X | |
| Diptera | Pseudocalliope | X | X | |
| Diptera | Puliciphora | X | X | |
| Diptera | Sarcofahrtiopsis | X | X | |
| Diptera | Scaptomyza | X | X | X |
| Diptera | Scathophaga | X | X | X |
| Diptera | Scatopsciara | X | X | |
| Diptera | Scatopse | X | X | |
| Diptera | Schwenkfeldina | X | X | |
| Diptera | Sciara | X | X | X |
| Diptera | Senotainia | X | X | |
| Diptera | Spelobia | X | X | |
| Diptera | Sphaeroceridae | X | X | |
| Diptera | SubFam: Metopininae morpho-species 1 | X | X | X |
| Diptera | SubFam: Metopininae morpho-species 2 | X | X | X |
| Diptera | SUbFam.: Ceratopogoninae | X | X | |
| Diptera | Tephritis | X | X | |
| Diptera | Thaumatomyia | X | X | X |
| Diptera | Thricops | X | X | |

|  |  |  |  |
|---|---|---|---|
| Diptera | Boettcheria | X |  |
| Diptera | Chaetochlorops | X |  |
| Diptera | Chalarus | X |  |
| Diptera | Chironomidae | X |  |
| Diptera | Condylostylus | X |  |
| Diptera | Curtonotum | X |  |
| Diptera | Delia | X |  |
| Diptera | delina | X |  |
| Diptera | Diplotoxa | X |  |
| Diptera | Distichona | X |  |
| Diptera | Drymeia | X |  |
| Diptera | Epichlorops | X |  |
| Diptera | Epidapus | X |  |
| Diptera | FAM: Periscelididae | X |  |
| Diptera | Harmstonia | X |  |
| Diptera | Hippelates | X |  |
| Diptera | Johnsonia | X |  |
| Diptera | Leptocera | X |  |
| Diptera | Leucophora | X |  |
| Diptera | Lispe | X |  |
| Diptera | Medetera | X | X |
| Diptera | Melanodexia | X |  |
| Diptera | Micrempis | X |  |
| Diptera | Musca | X |  |
| Diptera | Opsodexia | X |  |
| Diptera | Oseinellinae | X |  |
| Diptera | Phethochaeta | X |  |
| Diptera | Phytosciara | X |  |
| Diptera | Proctacanthus | X |  |
| Diptera | Protophormia | X |  |
| Diptera | Pseudacteon | X |  |
| Diptera | Ravinia | X |  |
| Diptera | Sarothromyia | X |  |
| Diptera | Sciapus | X |  |
| Diptera | SubFam: Limoniidae mopho-species 1 | X |  |
| Diptera | SubFam.: Dolichopodidae | X |  |
| Diptera | Tachyempis | X |  |
| Diptera | TRIBE: Tanytarsini | X |  |
| Diptera | triphlepa | X |  |

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|---|---|---|---|---|
| Diptera | Xylomya | | X | |
| Diptera | Diaphorus | | | X |
| Diptera | Sepedon | | | X |
| Diptera | Xanthochlorus | | | X |
| Haplotaxida | Diplocardia | X | X | |
| Hemiptera | Agallia | X | X | |
| Hemiptera | Amnestus | X | X | |
| Hemiptera | Atrazonotus | X | X | |
| Hemiptera | Balclutha | X | X | |
| Hemiptera | Ceratagallia | X | X | X |
| Hemiptera | Chlorochroa | X | X | |
| Hemiptera | Corimelaena | X | X | |
| Hemiptera | Euschistus | X | X | |
| Hemiptera | FAM: Aphididae morpho-species 2 | X | X | |
| Hemiptera | FAM: Lygaeidae | X | X | |
| Hemiptera | FAM.: Aphididae morpho-species 1 | X | X | |
| Hemiptera | FAM.: Aphididae morpho-species 2 | X | X | |
| Hemiptera | FAM.: Aphididae morpho-species 3 | X | X | |
| Hemiptera | FAM.: Aphididae morpho-species 4 | X | X | |
| Hemiptera | Gyponana | X | X | |
| Hemiptera | Idiocerus | X | X | X |
| Hemiptera | Irbiasia | X | X | |
| Hemiptera | Irbisia | X | X | |
| Hemiptera | Liorhyssus | X | X | X |
| Hemiptera | Microporus | X | X | |
| Hemiptera | Neocoelidiini | X | X | |
| Hemiptera | Neophilaenus | X | X | |
| Hemiptera | Neortholomus | X | X | X |
| Hemiptera | Ophiderma | X | X | |
| Hemiptera | Orius | X | X | |
| Hemiptera | Pangaeus | X | X | |
| Hemiptera | Pediopsoides | X | X | |
| Hemiptera | Philaenarcys | X | X | |
| Hemiptera | phytocoris | X | X | |
| Hemiptera | Planaphrodes | X | X | |
| Hemiptera | Reduvius | X | X | |
| Hemiptera | SuperFAM: Lygaeoidae morpho-species 1 | X | X | |
| Hemiptera | Tribe: Cicadellini | X | X | |
| Hemiptera | Aphrophora | | X | |

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|---|---|---|---|---|
| Hemiptera | Arhyssus | | X | |
| Hemiptera | Cacopsylla | | X | |
| Hemiptera | Populicerus | | X | |
| Hemiptera | Stictopleurus | | X | |
| Hemiptera | SubFAM: Emesinae | | X | |
| Hemiptera | FAM: Aphididae morpho-species 3 | | | X |
| Hemiptera | FAM: Aphididae morpho-species 5 | | | X |
| Hemiptera | Geocoris | | | X |
| Hemiptera | Heteropsylla | | | X |
| Hemiptera | Lopidae | | | X |
| Hymenoptera | Apis | X | X | X |
| Hymenoptera | Baeus | X | X | |
| Hymenoptera | Brachymyrmex | X | X | |
| Hymenoptera | Camponotus | X | X | X |
| Hymenoptera | Cerocephala | X | X | |
| Hymenoptera | Cryptopone | X | X | |
| Hymenoptera | Dorymyrmex | X | X | |
| Hymenoptera | Dufourea | X | X | |
| Hymenoptera | Eucoilidae | X | X | |
| Hymenoptera | FAM: Aphelinidae morpho-species 1 | X | X | |
| Hymenoptera | FAM: Aphelinidae morpho-species 2 | X | X | |
| Hymenoptera | FAM: Apidae | X | X | |
| Hymenoptera | FAM: Braconidae morpho-species 1 | X | X | |
| Hymenoptera | FAM: Braconidae morpho-species 2 | X | X | |
| Hymenoptera | FAM: Braconidae morpho-species 3 | X | X | |
| Hymenoptera | FAM: Braconidae morpho-species 6 | X | X | |
| Hymenoptera | FAM: Ceraphronidae morpho-species 1 | X | X | |
| Hymenoptera | FAM: Ceraphronidae morpho-species 2 | X | X | |
| Hymenoptera | FAM: Colletidae | X | X | |
| Hymenoptera | FAM: Diapriidae morpho-species 1 | X | X | |
| Hymenoptera | FAM: Diapriidae morpho-species 2 | X | X | |
| Hymenoptera | FAM: Diapriidae morpho-species 3 | X | X | |
| Hymenoptera | FAM: Diapriidae morpho-species 4 | X | X | |
| Hymenoptera | FAM: Encyrtidae morpho-species 1 | X | X | |
| Hymenoptera | FAM: Encyrtidae morpho-species 2 | X | X | |
| Hymenoptera | FAM: Encyrtidae morpho-species 4 | X | X | |
| Hymenoptera | FAM: Encyrtidae morpho-species 5 | X | X | X |
| Hymenoptera | FAM: Encyrtidae morpho-species 6 | X | X | |
| Hymenoptera | FAM: Encyrtidae morpho-species 7 | X | X | |

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|---|---|---|---|---|
| Hymenoptera | FAM: Eucoilidae morpho-species 1 | X | X | |
| Hymenoptera | FAM: Eulophidae morpho-species 1 | X | X | |
| Hymenoptera | FAM: Eulophidae morpho-species 2 | X | X | |
| Hymenoptera | FAM: Eulophidae morpho-species 3 | X | X | |
| Hymenoptera | FAM: figitidae | X | X | |
| Hymenoptera | FAM: figitidae morpho-species 1 | X | X | |
| Hymenoptera | FAM: Ichneumonidae morpho-species 2 | X | X | |
| Hymenoptera | FAM: Mymaridae morpho-species 1 | X | X | |
| Hymenoptera | FAM: Mymaridae morpho-species 2 | X | X | |
| Hymenoptera | FAM: Mymaridae morpho-species 3 | X | X | |
| Hymenoptera | FAM: Mymaridae morpho-species 4 | X | X | |
| Hymenoptera | FAM: Mymaridae morpho-species 5 | X | X | |
| Hymenoptera | FAM: Mymaridae morpho-species 8 | X | X | |
| Hymenoptera | Fam: Mymicinae | X | X | |
| Hymenoptera | FAM: Platygastridae | X | X | |
| Hymenoptera | FAM: Specidae | X | X | |
| Hymenoptera | Formica | X | X | |
| Hymenoptera | Hesperapis | X | X | |
| Hymenoptera | Holopyga | X | X | |
| Hymenoptera | Lagynodes | X | X | |
| Hymenoptera | Lasioglossum | X | X | |
| Hymenoptera | Myrmecocystus | X | X | |
| Hymenoptera | Platylabops | X | X | |
| Hymenoptera | Polistes | X | X | |
| Hymenoptera | Ponera | X | X | |
| Hymenoptera | Pseudomasaris | X | X | |
| Hymenoptera | Sphecodes | X | X | |
| Hymenoptera | SubFam.: Scelionidae morpho-species 1 | X | X | |
| Hymenoptera | SubFam.: Scelionidae morpho-species 10 | X | X | |
| Hymenoptera | SubFam.: Scelionidae morpho-species 11 | X | X | |
| Hymenoptera | SubFam.: Scelionidae morpho-species 12 | X | X | |
| Hymenoptera | SubFam.: Scelionidae morpho-species 2 | X | X | |
| Hymenoptera | SubFam.: Scelionidae morpho-species 3 | X | X | X |
| Hymenoptera | SubFam.: Scelionidae morpho-species 4 | X | X | X |
| Hymenoptera | SubFam.: Scelionidae morpho-species 5 | X | X | |
| Hymenoptera | SubFam.: Scelionidae morpho-species 6 | X | X | |
| Hymenoptera | SubFam.: Scelionidae morpho-species 7 | X | X | X |
| Hymenoptera | SubFam.: Scelionidae morpho-species 8 | X | X | |
| Hymenoptera | SubFam.: Scelionidae morpho-species 9 | X | X | X |

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|---|---|---|---|---|
| Hymenoptera | SupFam: Apoidae | X | X | |
| Hymenoptera | Tetramorium | X | X | X |
| Hymenoptera | Xeralictus | X | X | |
| Hymenoptera | Agapostemon | | X | |
| Hymenoptera | Anoplius | | X | |
| Hymenoptera | Aphaereta | | X | |
| Hymenoptera | Bombus | | X | |
| Hymenoptera | Colletes | | X | |
| Hymenoptera | Dialictus | | X | |
| Hymenoptera | FAM: Bethylidae mortho-species 1 | | X | X |
| Hymenoptera | FAM: Cynipidae morpho-species 1 | | X | |
| Hymenoptera | FAM: Dryinidae | | X | |
| Hymenoptera | FAM: Encyrtidae morpho-species 3 | | X | |
| Hymenoptera | FAM: Encyrtidae morpho-species 8 | | X | |
| Hymenoptera | FAM: Halictidae | | X | |
| Hymenoptera | FAM: Ichneumonidae morpho-species 1 | | X | |
| Hymenoptera | FAM: Mymaridae morpho-species 6 | | X | |
| Hymenoptera | FAM: Mymaridae morpho-species 7 | | X | |
| Hymenoptera | FAM: myrmicinae | | X | |
| Hymenoptera | FAM: Pteromalidae morpho-species 1 | | X | |
| Hymenoptera | FAM: Trichogrammatidae | | X | |
| Hymenoptera | Halictus | | X | X |
| Hymenoptera | Hypoponera | | X | |
| Hymenoptera | Perilampus | | X | |
| Hymenoptera | Pheidole | | X | |
| Hymenoptera | Ponerini | | X | |
| Hymenoptera | Sphex | | X | |
| Hymenoptera | Stenodynerus | | X | |
| Hymenoptera | SubFam: Epichrysomallinae morpho-species 1 | | X | |
| Hymenoptera | SupFam: Ceraphronidae Morpho-species 1 | | X | |
| Hymenoptera | Systropha | | X | |
| Hymenoptera | Temnothorax | | X | |
| Hymenoptera | Tribe: Formicini | | X | |
| Hymenoptera | Xylocopa | | X | |
| Hymenoptera | Coccophagoides | | | X |
| Isopoda | Armadillidium | X | X | X |
| Isopoda | Hyloniscus | X | X | |
| Julida | Aniulus | X | X | X |
| Julida | Cylindroiulus | | X | |

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|---|---|---|---|---|
| Lepidoptera | Crambus | X | X | |
| Lepidoptera | Euxoa | X | X | |
| lepidoptera | Cerealis | | X | |
| lepidoptera | Leptotes | | | X |
| Lithobiomorpha | Neolithobius | X | X | |
| Lithobiomorpha | Buethobius | | X | |
| Lithobiomorpha | Lamyctes | | X | |
| Odonata | Argia | X | X | |
| Opiliones | Liopilio | X | X | X |
| Orthoptera | Arphia | X | X | |
| Orthoptera | FAM: Acrididae | X | X | |
| Orthoptera | Hesperotittix | X | X | |
| Polydesmida | Tidesmus | X | X | X |
| Pseudoscorpiones | SubOrder: Iocheirata | | X | |
| Scutigeromorpha | FAM: Scutigeridae | X | X | |
| Spirostreptida | FAM: Camabalidae | | | X |
| SUBCLASS: Collembola | | X | X | |
| SUBCLASS: Collembola | | | X | |
| Thysanoptera | FAM: Phlaeothripidae | X | X | |
| Thysanoptera | SubFam: Phlaeothripinae | X | X | X |
| Thysanoptera | Phlaeothripidae | | X | |
| Trombidiformes | Erythracaridae | X | X | X |
| Trombidiformes | FAM: Bdellidae morpho-species 1 | X | X | |
| Trombidiformes | FAM: Bdellidae morpho-species 2 | X | X | X |
| Trombidiformes | FAM: Erythracaridae | X | X | X |
| Trombidiformes | Sup.Order: Acariformes morpho-species 1 | X | X | X |
| Trombidiformes | Sup.Order: Acariformes morpho-species 3 | X | X | |
| Trombidiformes | Sup.Order: Acariformes morpho-species 2 | | X | |
| Trombidiformes | Sup.Order: Acariformes morpho-species 4 | | X | |

## Chapter 3 Supplementary Data

Supplementary Table 1. Plant genera, species, growth form, and origin included in this study. Plants are organized by family. US Nativity: 0=Nonnative, 1=Native to the continental United States. CO Nativity: 0=Nonnative, 1=Native.

| Family | Genus | Species | Cultivar | Growth Form | Origin | US Nativity | CO Nativity |
|---|---|---|---|---|---|---|---|
| **Adoxaceae** | *Sambucus* | *nigra* | | Shrub | Species | 1 | 1 |
| **Aizoaceae** | *Delosperma* | *dyeri* | | Herbaceous Perennial | Selection | 0 | 0 |

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|---|---|---|---|---|---|---|---|
| **Aizoaceae** | *Delosperma* | *floribundum* | | Herbaceous Perennial | Species | 0 | 0 |
| **Aizoaceae** | *Delosperma* | | 'Kelaidis' | Herbaceous Perennial | Selection | 0 | 0 |
| **Aizoaceae** | *Delosperma* | | Alan's Apricot' | Herbaceous Perennial | Selection | 0 | 0 |
| **Aizoaceae** | *Delosperma* | | Fire Spinner' | Herbaceous Perennial | Selection | 0 | 0 |
| **Aizoaceae** | *Delosperma* | | John Proffitt' | Herbaceous Perennial | Selection | 0 | 0 |
| **Aizoaceae** | *Delosperma* | | Kelaidis' | Herbaceous Perennial | Selection | 0 | 0 |
| **Aizoaceae** | *Delosperma* | | Lavender Ice' | Herbaceous Perennial | Selection | 0 | 0 |
| **Aizoaceae** | *Delosperma* | | Lavender Ice' | Herbaceous Perennial | Selection | 0 | 0 |
| **Aizoaceae** | *Delosperma* | | Red Mountian Flame' | Herbaceous Perennial | Selection | 0 | 0 |
| **Amaryllidaceae** | *Allium* | *x* | Millennium' | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Apiaceae** | *Ammi* | *visnaga* | | Herbaceous Annual | Selection | 0 | 0 |
| **Apiaceae** | *Ammi* | *visnaga* | | Herbaceous Annual | Species | 0 | 0 |
| **Apiaceae** | *Anethum* | *graveolens* | | Herbaceous Annual | Species | 0 | 0 |
| **Apiaceae** | *Angelica* | *pachycarpa* | | Herbaceous Perennial | Species | 0 | 0 |
| **Apiaceae** | *Anthemis* | *marschalliana* | | Herbaceous Perennial | Species | 0 | 0 |
| **Apiaceae** | *Anthemis* | *tinctoria* | | Herbaceous Perennial | Species | 0 | 0 |
| **Apiaceae** | *Astrantia* | *major* | 'Roma' | Herbaceous Perennial | Selection | 0 | 0 |
| **Apiaceae** | *Eryngium* | *planum* | Blue Glitter' | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Apiaceae** | *Seseli* | *gummiferum* | | Herbaceous Perennial | Species | 0 | 0 |
| **Apocynaceae** | *Asclepias* | *incarnata* | | Herbaceous Perennial | Species | 1 | 1 |
| **Asparagaceae** | *Herperaloe* | *parviflora* | | Herbaceous Perennial | Species | 1 | 0 |
| **Asparagaceae** | *Ornithogalum* | *magnum* | | Herbaceous Perennial | Species | 0 | 0 |
| **Asteraceae** | *Achillea* | *filipendulina* | Cloth of Gold | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Asteraceae** | *Achillea* | | 'Moonshine' | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Asteraceae** | *Anaphalis* | *margaritacea subsp. japonica* | | Herbaceous Perennial | Species | 0 | 0 |
| **Asteraceae** | *Berlandiera* | *lyrata* | | Herbaceous Perennial | Species | 1 | 1 |
| **Asteraceae** | *Centaurea* | *macrocephala* | | Herbaceous Perennial | Species | 0 | 0 |
| **Asteraceae** | *Coreopsis* | *tinctoria* | | Herbaceous Annual | Species | 1 | 1 |
| **Asteraceae** | *Cosmos* | *bipinnatus* | | Herbaceous Annual | Selection | 0 | 0 |

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|---|---|---|---|---|---|---|---|
| **Asteraceae** | *Cosmos* | *bipinnatus* | | Herbaceous Annual | Selection | 0 | 0 |
| **Asteraceae** | *Dieteria* | *bigelovii* | | Herbaceous Perennial | Species | 1 | 1 |
| **Asteraceae** | *Echinacea* | *tennesseensis* | | Herbaceous Perennial | Species | 1 | 0 |
| **Asteraceae** | *Echinacea* | | Cheyenne Spirit' | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Asteraceae** | *Echinops* | *tjianschanicus* | | Herbaceous Perennial | Species | 0 | 0 |
| **Asteraceae** | *Engelmannia* | *peristenia* | | Herbaceous Perennial | Species | 1 | 1 |
| **Asteraceae** | *Englemannia* | *peristenia* | | Herbaceous Perennial | Species | 1 | 1 |
| **Asteraceae** | *Ericameria* | *nauseosa* | | Shrub | Species | 1 | 1 |
| **Asteraceae** | *Eutrochium* | *maculatum* | 'Gateway' | Herbaceous Perennial | Selection | 1 | 0 |
| **Asteraceae** | *Eutrochium* | *maculatum* | Bartered Bride' | Herbaceous Perennial | Selection | 1 | 0 |
| **Asteraceae** | *Gaillardia* | *aristata* | Amber Wheels' | Herbaceous Perennial | Selection | 1 | 1 |
| **Asteraceae** | *Helenium* | *amarum* | Dakota Gold' | Herbaceous Annual | Selection | 1 | 0 |
| **Asteraceae** | *Heterotheca* | *jonesii x villosa* | 'Goldhill' | Herbaceous Perennial | Hybrid | 1 | 1 |
| **Asteraceae** | *Inula* | *magnifica* | | Herbaceous Perennial | Species | 0 | 0 |
| **Asteraceae** | *Liatris* | *spicata* | 'Kobold' | Herbaceous Perennial | Selection | 1 | 0 |
| **Asteraceae** | *Liatris* | *spicata* | Floristan' | Herbaceous Perennial | Selection | 1 | 0 |
| **Asteraceae** | *Osteospermum* | *x* | 'Avalanche' | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Asteraceae** | *Rudbeckia* | *hirta* | Denver Daisy' | Herbaceous Perennial | Hybrid | 1 | 1 |
| **Asteraceae** | *Rudbeckia* | *laciniata* | | Herbaceous Perennial | Species | 1 | 1 |
| **Asteraceae** | *Rudbeckia* | *occidentalis* | Green Wizard' | Herbaceous Perennial | Selection | 1 | 0 |
| **Asteraceae** | *Rudbeckia* | *triloba* | | Herbaceous Perennial | Species | 1 | 0 |
| **Asteraceae** | *Solidago* | *simplex var. nana* | | Herbaceous Perennial | Species | 1 | 0 |
| **Asteraceae** | *Solidago* | *x* | Crown of Rays' | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Asteraceae** | *Symphyiotrichum* | *novae-angliae* | 'Purple | Herbaceous Perennial | Selection | 1 | 0 |
| **Asteraceae** | *Tanacetum* | *cinerariifolium* | | Herbaceous Perennial | Species | 0 | 0 |
| **Asteraceae** | *Tanacetum* | *densum ssp. amani* | | Herbaceous Perennial | Species | 0 | 0 |
| **Asteraceae** | *Tanacetum* | *parthenium* | 'Aureum' | Herbaceous Perennial | Selection | 0 | 0 |
| **Asteraceae** | *Tithonia* | *rotundifolia* | | Herbaceous Annual | Selection | 0 | 0 |
| **Asteraceae** | *Zinnia* | *grandiflora* | | Herbaceous Perennial | Selection | 1 | 1 |
| **Asteraceae** | *Zinnia* | | Profusion Fire' | Herbaceous Annual | Hybrid | 0 | 0 |

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|---|---|---|---|---|---|---|---|
| **Boraginaceae** | *Anchusa* | *azurea* | 'Dropmore' | Herbaceous Perennial | Selection | 0 | 0 |
| **Boraginaceae** | *Anchusa* | *capensis* | | Herbaceous Perennial | Species | 0 | 0 |
| **Boraginaceae** | *Brunnera* | *macrophylla* | | Herbaceous Perennial | Selection | 0 | 0 |
| **Boraginaceae** | *Echium* | *amoenum* | | Herbaceous Perennial | Species | 0 | 0 |
| **Brassicaceae** | *Crambe* | *maritima* | | Herbaceous Perennial | Species | 0 | 0 |
| **Campanulaceae** | *Campanula* | *garganica* | | Herbaceous Perennial | Species | 0 | 0 |
| **Campanulaceae** | *Lobelia* | *cardinalis* | | Herbaceous Perennial | Species | 1 | 1 |
| **Campanulaceae** | *Lobelia* | *cardinalis* | | Herbaceous Perennial | Selection | 1 | 0 |
| **Caprifoliaceae** | *Heptacodium* | *miconioides* | | Shrub | Species | 0 | 0 |
| **Caprifoliaceae** | *Knautia* | *macedonica* | | Herbaceous Perennial | Species | 0 | 0 |
| **Caprifoliaceae** | *Lonicera* | *korolkowii* | | Shrub | Selection | 0 | 0 |
| **Caprifoliaceae** | *Lonicera* | *reticulata* | Kintzley's Ghost' | Vine | Selection | 0 | 0 |
| **Caprifoliaceae** | *Pterocephalus* | *depressus* | | Herbaceous Perennial | Species | 0 | 0 |
| **Caprifoliaceae** | *Symphoricarpos* | *albus* | | Shrub | Species | 1 | 1 |
| **Caprifoliaceae** | *Valeriana* | *officianalis* | | Herbaceous Perennial | Species | 0 | 0 |
| **Caryophyllaceae** | *Dianthus* | *plumarius* | | Herbaceous Perennial | Species | 0 | 0 |
| **Caryophyllaceae** | *Dianthus* | | First Love' | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Caryophyllaceae** | *Silene* | *chalcedonica* | | Herbaceous Perennial | Species | 0 | 0 |
| **Cistaceae** | *Helianthemum* | *nummularium* | | Herbaceous Perennial | Selection | 0 | 0 |
| **Cleomaceae** | *Cleome* | | Sparkler Mix' | Herbaceous Annual | Hybrid | 0 | 0 |
| **Commelinaceae** | *Tradescantia* | *occidentalis* | | Herbaceous Perennial | Species | 1 | 1 |
| **Convolvulaceae** | *Ipomoea* | *x* | multifida | Vine | Hybrid | 0 | 0 |
| **Crassulaceae** | *Sedum* | *sediforme* | | Herbaceous Perennial | Species | 0 | 0 |
| **Fabaceae** | *Lablab* | *pupureus* | Ruby Moon' | Vine | Selection | 0 | 0 |
| **Fabaceae** | *Lupinus* | *x* | Gallery Blue' | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Gentianaceae** | *Eustoma* | *russellianum* | Reina Champagne' | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Geraniaceae** | *Erodium* | *chrysanthum* | | Herbaceous Perennial | Species | 0 | 0 |
| **Geraniaceae** | *Geranium* | *dalmaticum* | | Herbaceous Perennial | Species | 0 | 0 |
| **Geraniaceae** | *Geranium* | *magniflorium* | | Herbaceous Perennial | Species | 0 | 0 |
| **Geraniaceae** | *Geranium* | *sanguineum* | | Herbaceous Perennial | Species | 0 | 0 |
| **Hydrangeaceae** | *Hydrangea* | *arborescens* | 'Annabelle' | Shrub | Selection | 1 | 0 |
| **Hydrangeaceae** | *Jamesia* | *americana* | | Shrub | Species | 1 | 1 |

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|---|---|---|---|---|---|---|---|
| **Iridaceae** | *Sisyrinchium* | *angustifolium* | 'Lucerne' | Herbaceous Perennial | Selection | 1 | 0 |
| **Lamiaceae** | *Agastache* | *aurantiaca* | Coronado' | Herbaceous Perennial | Selection | 1 | 0 |
| **Lamiaceae** | *Agastache* | *cana* | Double Bubble Mint' | Herbaceous Perennial | Selection | 1 | 0 |
| **Lamiaceae** | *Agastache* | *cana* | Sinning' | Herbaceous Perennial | Selection | 1 | 0 |
| **Lamiaceae** | *Agastache* | *foeniculum* |  | Herbaceous Perennial | Species | 1 | 1 |
| **Lamiaceae** | *Agastache* | *pallidiflora var. neomexicana* |  | Herbaceous Perennial | Species | 1 | 0 |
| **Lamiaceae** | *Agastache* | *pallidiflora var. neomexicana* |  | Herbaceous Perennial | Species | 1 | 0 |
| **Lamiaceae** | *Agastache* | *rupestris* |  | Herbaceous Perennial | Species | 1 | 0 |
| **Lamiaceae** | *Agastache* |  | Blue Boa | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Lamiaceae** | *Caropteris* | *x clandonensis* |  | Shrub | Hybrid | 0 | 0 |
| **Lamiaceae** | *Lamium* | *maculatum* | ‘Orchid Frost' | Herbaceous Perennial | Selection | 0 | 0 |
| **Lamiaceae** | *Lavandula* | *angustifolia* | 'Munstead' | Shrub | Selection | 0 | 0 |
| **Lamiaceae** | *Lavandula* | *angustifolia* | Wee One' | Shrub | Selection | 0 | 0 |
| **Lamiaceae** | *Marribium* | *rotundifolium* |  | Herbaceous Perennial | Species | 0 | 0 |
| **Lamiaceae** | *Monarda* | *fistulosa* |  | Herbaceous Perennial | Species | 1 | 1 |
| **Lamiaceae** | *Monarda* | *x* | 'Fireball' | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Lamiaceae** | *Monardella* | *macrantha* | Marian Simpson' | Herbaceous Perennial | Selection | 1 | 0 |
| **Lamiaceae** | *Nepeta* | *x* | 'Psfike' | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Lamiaceae** | *Ocimum* | *basilicum* |  | Herbaceous Annual | Species | 0 | 0 |
| **Lamiaceae** | *Origanum* | *libanoticum* |  | Herbaceous Perennial | Species | 0 | 0 |
| **Lamiaceae** | *Origanum* | *vulgare* |  | Herbaceous Perennial | Selection | 0 | 0 |
| **Lamiaceae** | *Origonium* | *libanoticum* |  | Herbaceous Perennial | Selection | 0 | 0 |
| **Lamiaceae** | *Perovskia* | *atripicifolia* |  | Herbaceous Perennial | Species | 0 | 0 |
| **Lamiaceae** | *Phlomis* | *cashmeriana* |  | Herbaceous Perennial | Species | 0 | 0 |
| **Lamiaceae** | *Physostegia* | *virginiana* |  | Herbaceous Perennial | Species | 1 | 0 |
| **Lamiaceae** | *Plectranthus* | *argentatus* |  | Herbaceous Annual | Species | 0 | 0 |
| **Lamiaceae** | *Salvia* | *argentea* |  | Herbaceous Perennial | Species | 0 | 0 |
| **Lamiaceae** | *Salvia* | *azurea* | 'Nekan' | Herbaceous Perennial | Selection | 1 | 1 |
| **Lamiaceae** | *Salvia* | *coccinea* | Summer Jewel' | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Lamiaceae** | *Salvia* | *coccinea* | Summer Jewel' | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Lamiaceae** | *Salvia* | *cyanescens* |  | Herbaceous Perennial | Species | 0 | 0 |

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| **Lamiaceae** | *Salvia* | *daghestanica* | | Herbaceous Perennial | Species | 0 | 0 |
| **Lamiaceae** | *Salvia* | *darcyi* | 'Pscarl' | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Lamiaceae** | *Salvia* | *darcyi x microphylla* | Windwalker' | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Lamiaceae** | *Salvia* | *farinacea* | | Herbaceous Perennial | Selection | 1 | 0 |
| **Lamiaceae** | *Salvia* | *greggii* | Furman's Red' | Herbaceous Perennial | Selection | 1 | 0 |
| **Lamiaceae** | *Salvia* | *greggii* | Wild Thing' | Herbaceous Perennial | Selection | 1 | 0 |
| **Lamiaceae** | *Salvia* | *lemmonii* | 'PWIN04S' | Herbaceous Perennial | Selection | 1 | 0 |
| **Lamiaceae** | *Salvia* | *moorcroftiana x indica* | | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Lamiaceae** | *Salvia* | *nemorosa* | 'Lubecca' | Herbaceous Perennial | Selection | 0 | 0 |
| **Lamiaceae** | *Salvia* | *nemorosa* | 'Marcus' | Herbaceous Perennial | Selection | 0 | 0 |
| **Lamiaceae** | *Salvia* | *pachyphylla* | | Shrub | Species | 1 | 0 |
| **Lamiaceae** | *Salvia* | *reptens* | | Herbaceous Perennial | Selection | 1 | 0 |
| **Lamiaceae** | *Satureja* | *montana* | | Herbaceous Perennial | Species | 0 | 0 |
| **Lamiaceae** | *Scutellaria* | *resinosa* | Smoky Hills' | Herbaceous Perennial | Selection | 1 | 0 |
| **Lamiaceae** | *Scutellaria* | *scordifolia* | 'Pat | Herbaceous Perennial | Selection | 0 | 0 |
| **Lamiaceae** | *Scutellaria* | *scordiifolia* | 'Pat | Herbaceous Perennial | Selection | 0 | 0 |
| **Lamiaceae** | *Scutellaria* | *suffrutescens* | | Herbaceous Perennial | Species | 0 | 0 |
| **Lamiaceae** | *Teucrium* | *cossonii* | | Herbaceous Perennial | Species | 0 | 0 |
| **Lamiaceae** | *Thymus* | *serphyllum* | Pink Chintz' | Herbaceous Perennial | Selection | 0 | 0 |
| **Liliaceae** | *Allium* | *cernuum* | | Herbaceous Perennial | Species | 1 | 1 |
| **Liliaceae** | *Allium* | *christophii* | | Herbaceous Perennial | Species | 0 | 0 |
| **Liliaceae** | *Allium* | *unifolium* | | Herbaceous Perennial | Species | 1 | 0 |
| **Limnanthaceae** | *Limnanthes* | *douglasii* | | Herbaceous Annual | Species | 0 | 0 |
| **Linaceae** | *Linum* | *narbonense* | | Herbaceous Perennial | Species | 0 | 0 |
| **Malvaceae** | *Callirhoe* | *involucrata* | | Herbaceous Perennial | Species | 1 | 1 |
| **Onagraceae** | *Epilobium* | *canum* | | Herbaceous Perennial | Species | 1 | 0 |
| **Onagraceae** | *Epilobium* | *fleischeri* | | Herbaceous Perennial | Species | 0 | 0 |
| **Onograceae** | *Oenothera* | *macrocarpa ssp. incana* | | Herbaceous Perennial | Species | 1 | 0 |
| **Onograceae** | *Oenothera* | *macrocarpa ssp. incana* | | Herbaceous Perennial | Species | 1 | 0 |
| **Papaveraceae** | *Glaucium* | *flavum* | | Herbaceous Perennial | Species | 0 | 0 |

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| **Papaveraceae** | *Papaver* | *rupifragum* | Double Tangerine Gem' | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Papaveraceae** | *Papaver* | *somniferum* | | Herbaceous Perennial | Species | 0 | 0 |
| **Plantaginaceae** | *Antirrhinum* | *Chantilly Bronze'* | | Herbaceous Annual | Selection | 0 | 0 |
| **Plantaginaceae** | *Asarina* | *scandens* | Sky Blue' | Herbaceous Annual | Species | 0 | 0 |
| **Plantaginaceae** | *Digitalis* | *ferruginea* | Gelber Herold' | Herbaceous Perennial | Selection | 0 | 0 |
| **Plantaginaceae** | *Digitalis* | *grandiflora* | | Herbaceous Perennial | Species | 0 | 0 |
| **Plantaginaceae** | *Digitalis* | *obscura* | | Herbaceous Perennial | Species | 0 | 0 |
| **Plantaginaceae** | *Digitalis* | *purpurea* | | Herbaceous Perennial | Species | 0 | 0 |
| **Plantaginaceae** | *Digitalis* | *stewartii* | | Herbaceous Perennial | Species | 0 | 0 |
| **Plantaginaceae** | *Digitalis* | *thapsi* | | Herbaceous Perennial | Species | 0 | 0 |
| **Plantaginaceae** | *Penstemon* | *barbatus* | Coral Baby' | Herbaceous Perennial | Hybrid | 1 | 1 |
| **Plantaginaceae** | *Penstemon* | *grandiflorus* | | Herbaceous Perennial | | 1 | 1 |
| **Plantaginaceae** | *Penstemon* | *linariodes* | | Herbaceous Perennial | Species | 1 | 1 |
| **Plantaginaceae** | *Penstemon* | *linariodes* | | Herbaceous Perennial | Species | 1 | 1 |
| **Plantaginaceae** | *Penstemon* | *mensarum* | | Herbaceous Perennial | Species | 1 | 1 |
| **Plantaginaceae** | *Penstemon* | *pinifolius* | | Herbaceous Perennial | Selection | 1 | 0 |
| **Plantaginaceae** | *Penstemon* | *pinifolius* | | Herbaceous Perennial | Species | 1 | 0 |
| **Plantaginaceae** | *Penstemon* | *pseudospectabilis* | | Herbaceous Perennial | Species | 1 | 0 |
| **Plantaginaceae** | *Penstemon* | *rostriflorus* | | Herbaceous Perennial | Species | 1 | 1 |
| **Plantaginaceae** | *Penstemon* | *x barbatus* | Red Riding Hood' | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Plantaginaceae** | *Penstemon* | *x barbatus* | Red Riding Hood' | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Plantaginaceae** | *Penstemon* | *x mexicali* | Carolyn's Hope' | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Plantaginaceae** | *Penstemon* | *x mexicali* | Carolyn's Hope' | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Plantaginaceae** | *Penstemon* | *x mexicali* | Peak' | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Plantaginaceae** | *Penstemon* | *x mexicali* | Pikes Peak Purple' | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Plantaginaceae** | *Penstemon* | *x mexicali* | Pikes Peak Purple' | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Plantaginaceae** | *Penstemon* | *x mexicali* | Red Rocks' | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Plantaginaceae** | *Penstemon* | *x mexicali* | Windwalker' | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Plantaginaceae** | *Penstemon* | *strictus* | | Herbaceous Perennial | Species | 1 | 1 |

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| **Plantaginaceae** | *Veronica* | *liwanensis* | | Herbaceous Perennial | Species | 0 | 0 |
| **Plantaginaceae** | *Veronica* | *longifolia* | | Herbaceous Perennial | Species | 0 | 0 |
| **Plantaginaceae** | *Veronica* | *x* | 'Reavis' | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Plantaginaceae** | *Veronica* | *x* | Snowmass' | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Plantaginaceae** | *Veronicastrum* | *virginicum* | | Herbaceous Perennial | Species | 1 | 0 |
| **Plumbaginaceae** | *Ceratostigma* | *plumbaginoides* | | Herbaceous Perennial | Species | 0 | 0 |
| **Plumbaginaceae** | *Ceratostigma* | *plumbaginoides* | | Herbaceous Perennial | Species | 0 | 0 |
| **Poaceae** | *Bouteloua* | *gracilis* | Blonde Ambition' | Grass | Selection | 1 | 1 |
| **Polemoniaceae** | *Ipomopsis* | *rubra* | | Herbaceous Annual | Species | 1 | 0 |
| **Polemoniaceae** | *Phlox* | *paniculata* | 'Norah Leigh' | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Polygonaceae** | *Erigonium* | *umbellatum var. aureum* | | Herbaceous Perennial | Species | 1 | 1 |
| **Polygonaceae** | *Erigonum* | *wrightii var. wrightii* | | Herbaceous Perennial | Species | 1 | 0 |
| **Polygonaceae** | *Eriogonum* | *jamesii* | | Herbaceous Perennial | Species | 1 | 1 |
| **Ranunculaceae** | *Aconitum* | *napellus* | | Herbaceous Perennial | Species | 0 | 0 |
| **Ranunculaceae** | *Anemone* | *cylindrica* | | Herbaceous Perennial | Species | 1 | 1 |
| **Ranunculaceae** | *Aquilegia* | *chrysantha* | | Herbaceous Perennial | Species | 1 | 1 |
| **Ranunculaceae** | *Aquilegia* | *chrysantha* | | Herbaceous Perennial | Species | 1 | 1 |
| **Ranunculaceae** | *Clematis* | *integrifolia* | | Herbaceous Perennial | Species | 0 | 0 |
| **Ranunculaceae** | *Clematis* | *texensis* | | Herbaceous Vine | Species | 1 | 0 |
| **Ranunculaceae** | *Delphinium* | *grandiflorum* | Diamonds Blue' | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Ranunculaceae** | *Nigella* | *damascena* | | Herbaceous Annual | Species | 0 | 0 |
| **Ranunculaceae** | *Pulsatilla* | *vulgaris* | | Herbaceous Perennial | Species | 0 | 0 |
| **Rosaceae** | *Alchemilla* | *mollis* | | Herbaceous Perennial | Species | 0 | 0 |
| **Rosaceae** | *Chamaebatiaria* | *milefolium* | | Shrub | Species | 1 | 0 |
| **Rosaceae** | *Dasiphora* | *fruticosa* | | Shrub | Species | 1 | 1 |
| **Rosaceae** | *Fallugia* | *paradoxa* | | Shrub | Species | 1 | 1 |
| **Rosaceae** | *Filipendula* | *rubra* | 'Venusta' | Herbaceous Perennial | Selection | 0 | 0 |
| **Rosaceae** | *Geum* | *triflorum* | | Herbaceous Perennial | Species | 1 | 1 |
| **Rosaceae** | *Geum* | | Totally Tangerine' | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Rosaceae** | *Potentilla* | *astrosanguinea* | | Herbaceous Perennial | Species | 0 | 0 |
| **Rosaceae** | *Rosa* | *glauca* | | Shrub | Species | 0 | 0 |

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| **Rosaceae** | *Rubus* | *deliciosus* | | Shrub | Species | 1 | 1 |
| **Rosaceae** | *Sorbaria* | *sorbifolia* | | Shrub | Species | 0 | 0 |
| **Saxifragaceae** | *Heuchera* | *americana* | Dale's Strain' | Herbaceous Perennial | Selection | 1 | 0 |
| **Saxifragaceae** | *Heuchera* | *sanguinea* | ‘Snow Angel' | Herbaceous Perennial | Hybrid | 1 | 0 |
| **Scrophulariaceae** | *Buddleja* | *alternifolia* | 'Argentea' | Shrub | Selection | 0 | 0 |
| **Scrophulariaceae** | *Buddleja* | *davidii* | 'Nanho | Shrub | Selection | 0 | 0 |
| **Scrophulariaceae** | *Diascia* | *integerrima* | | Herbaceous Perennial | Species | 0 | 0 |
| **Scrophulariaceae** | *Scrophularia* | *macrantha* | | Herbaceous Perennial | Species | 1 | 0 |
| **Scrophulariaceae** | *Verbascum* | *chaixii* | | Herbaceous Perennial | Species | 0 | 0 |
| **Solanaceae** | *Nicotiana* | *x sanderae* | | Herbaceous Annual | Hybrid | 0 | 0 |
| **Verbenaceae** | *Glandularia* | *bipinnatifida* | | Herbaceous Perennial | Species | 1 | 0 |
| **Verbenaceae** | *Verbena* | *bonariensis* | | Herbaceous Annual | Species | 0 | 0 |
| **Verbenaceae** | *Verbena* | *hastata* | | Herbaceous Perennial | Species | 1 | 1 |
| **Verbenaceae** | *Verbena* | *speciosa* | Imagination' | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Verbenaceae** | *Verbena* | | Endurascape Red' | Herbaceous Perennial | Hybrid | 0 | 0 |
| **Violaceae** | *Viola* | *corsica* | | Herbaceous Perennial | Species | 0 | 0 |