Floral Enhancement of Turfgrass Lawns Benefits Wild Bees and Honey Bees (*Apis Mellifera*)

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Abstract

The turfgrass lawn is a common feature of urban and suburban communities, often accounting for the largest green spaces by area in these landscapes. Flowering species within turfgrass lawns have the potential to serve as a source of forage for bee pollinators in urban and suburban areas. We intentionally introduced low-growing flowers to turfgrass lawns to promote bee diversity and reduce inputs, while maintaining the traditional aesthetics and recreational uses associated with lawns. We compared bee communities on lawns with naturally-occurring blooms of *Trifolium repens* to bee communities on florally-enhanced lawns that contained *Prunella vulgaris* ssp. *lanceolata* and *Thymus serpyllum* in addition to *T. repens*. *Trifolium repens* provided forage for both wild bee communities and *Apis mellifera*, with *A. mellifera* being the most common of the 56 species of bees observed on *T. repens*. We found that florally-enhanced lawns supported more diverse bee communities than lawns with just *T. repens*. Furthermore, the bee communities supported by florally-enhanced lawns were significantly different from the bee communities supported by lawns containing just *T. repens* based on presence-absence (Jaccard's dissimilarity index). Our research indicates that *A. mellifera* colonies and wild bee communities can be supported by allowing *T. repens* to bloom in turfgrass lawns, and that land managers can support more diverse bee communities by intentionally introducing low-growing flowers to lawns.

Introduction

Human land-use changes that result in the loss or degradation of natural habitat are a leading contributor to the decline of wild bee populations and of *Apis mellifera* health (Winfree et al. 2009; Potts et al. 2010; Otto et al. 2016). Urbanization, the conversion of lands for urban needs, is one of the leading forms of land conversion in the United States. As of 2005, nearly 80% of the United States population lived in or near urban areas, with developed land accounting for over 100 million acres of land (McKinney 2005; USDA 2012). Urban lands are becoming more prominent, as an average of 1.5 million acres of natural and semi-natural lands, like forests and pastures, were converted to developed land annually between 2002 and 2007 (USDA 2012). There is a clear need to consider pollinator conservation within these greatly expanding land areas.

Urban bees are important pollinators of gardens, parks, urban cultivated lands, remnants of natural areas, and various other green spaces (Frankie et al. 2005; McFrederick and LeBuhn 2006; Fetridge et al. 2008; Matteson et al. 2008; Tonietto et al. 2011; Larson et al. 2014). To support bees in urban landscapes, there must be available sources of forage for pollen and nectar, as well as suitable nesting sites (Westrich 1996; Wojcik and McBride 2012). Bees can naturally occur in unmanaged urban greenspaces (Gardiner et al. 2013; Sivakoff et al. 2018) but increasing efforts have been made to redesign aspects of urban development to create habitat and forage for pollinators.

Poorly managed and high-input lawns can be associated with environmental issues including water consumption, pollution, pesticide application and exposure, and fossil fuel use (McPherson et al. 1989; Davis and Truett 2004). Furthermore, lawns under traditional management protocols in urban areas provide limited habitat for wildlife, including pollinators (Stier et al. 2013). When turfgrass landscapes are managed sustainably, they can provide ecosystem and cultural benefits, including controlling water runoff, carbon sequestration, benefits to mental health, and reduction of noise pollution, among others (Krenitsky et al. 1998; Qian and Follett 2002; Stier et al. 2013; Beard and Green 1994). Current efforts in turfgrass science seek to improve the sustainability of the turf lawn, primarily through reduction of inputs. Research on turfgrass species selection has indicated that low-input grass species, specifically the fine fescue grasses (*Festuca* spp.) can perform well in a lawn setting when irrigation, fertilizer, and mowing inputs are greatly reduced (Dernoeden et al. 1994; Watkins et al. 2011; Braun et al. 2020). While great strides have been made to improve the sustainability of turf lawns by reducing inputs, managing lawns to intentionally benefit pollinators is a more novel concept.

Creating an effective pollinator-friendly lawn requires balancing potentially competing aims of growing pollinator forage while maintaining aesthetically-pleasing spaces that allow for recreation. In order to balance these aims, we used flowering species that are both able to compete with turfgrass for resources and can bloom at 6.5 cm or lower, a height that is amenable with standard mowing practices. This height restriction greatly limits the plant palette that may be utilized within a lawn setting. The species utilized in our bee lawn seed mix followed recommendations by Lane et al. (2019), who found that *Trifolium repens, Prunella vulgaris* ssp. *lanceolata*, and *Thymus serpyllum* were able to establish with turfgrass under typical mowing conditions. Further work on flowering species suggests and that *Symphyotrichum lateriflorum* and *Coreopsis lanceolata* were able to bloom under mowing pressure, and thus potentially able to establish within turfgrass depending on environmental conditions (Lane, unpublished data).

Human perceptions of lawns are often dictated by cultural and neighborhood norms for landscape appearance, as lawns that strongly differ from what is commonplace are not well received by the public. Traditionally, flowering plants within the lawn were viewed as a nuisance, with consumers spending $450 million on lawn herbicides and plant growth regulators in 2012 (Atwood and Paisley-Jones 2017). There is evidence to suggest that public perceptions of lawn flowers may be changing (Nassauer et al. 2009). For example, while a survey of lawn preferences in April, 2010 suggested that Minnesota homeowners preferred lawns that were free of weed infestation (Hugie et al. 2012), a more recent survey of park visitors in Minneapolis, Minnesota revealed that 95.4% of respondents supported the planting of flowering bee lawns within community parks; consumers felt these lawns were aesthetically pleasing and beneficial to bees (Ramer et al. 2019).

With a growing body of literature suggesting that lawn flowers may support diverse communities of pollinators, it is essential to provide effective ways to support pollinators within turf lawns. While studies have demonstrated the value that naturally-occurring flowers may hold for pollinators (Shwartz et al. 2013; Larson et al. 2014; Lerman and Milam 2016), and have suggested strategies to enhance the number of flowers observed in a turf lawn (McCurdy et al. 2013; Sparks et al. 2015; Lane et al. 2016), none have implemented and studied the impact of a seed-mix designed specifically to provide forage for pollinators. In this study, we aimed to compare bee communities on florally-enhanced (seed-mix treatment) lawns to bee communities on lawns with naturally-occurring populations of *Trifolium repens*

(Dutch white clover). First, we documented the bee community visiting naturally occurring populations of *T. repens* in lawns at sixteen public parks within Minneapolis, MN to establish the bee community present prior to floral enhancement; eight parks of these parks were then selected for further sampling, with four receiving the seed-mix. Next, we measured the establishment and persistence of the seeded forage plants included in our seed-mix. Finally, we tested whether florally-enhanced lawns increased bee diversity and supported different bee communities than lawns with only *T. repens*. We hypothesized that florally-enhanced lawns would support more diverse communities of bees compared to naturally-occurring clover-only lawns. The quantification of the bee communities that forage in florally-enhanced turfgrass lawns highlights the ecological value of a land management strategy that is easy to implement and maintain.

General Methods

Study Area

Sixteen public parks were selected to document the bee community on *T. repens* (Table 1) in urban areas within Hennepin county, Minnesota (Fig. 1) between Spring of 2016 and Summer of 2018. The Minneapolis Parks and Recreation Board provided a list of parks from which to choose for bee sampling, ranging in size from 0.5 hectares to 26.7 hectares. Each park contained pre-existing stands of *T. repens* within *Poa pratensis* (Kentucky bluegrass) or *Festuca* spp. (fine fescue) turf lawns that were mowed every 10–14 days from early summer through the fall of each year and did not receive irrigation or fertilizer. Eight of these parks were then selected for further study. The eight sites were split into pairs, where the site with greater *T. repens* abundance was untreated, and the site with fewer *T. repens* blooms was florally enhanced. We then compared bee communities on lawns with just *T. repens* to bee communities on lawns that were florally-enhanced.

In the fall of 2016, 800 m^2 (40 m x 20 m) areas within four of the eight parks were seeded to create florally-enhanced plots. Each florally-enhanced park was paired with a park that did not receive such a seeding. Parks were paired based on spatial proximity to one another, with paired parks being no further than 4 km apart. Five floral species were selected for floral enhancement based on Lane et al. (2016; 2019) (Fig. 2): *Trifolium repens*, *Prunella vulgaris* ssp. *lanceolata* (self-heal), *Thymus serpyllum* (creeping thyme), *Symphiotrichum lateriflorum* (calico aster), and *Coreopsis lanceolate*. The seed mix contained three species native to the north central U.S. (*P. vulgaris, S. lateriflorum, C. lanceolata)* as well as two non-native species (*T. repens, Th. serpyllum)*. Plots within four parks were florally-enhanced by seeding the floral mixture into existing stands of turfgrass and *T. repens*, following a dormant seeding protocol to ensure that flowering plants had the best chance of germinating the following spring. Kentucky bluegrass and fine fescues are preferred companion grasses for these plantings due to the slow rate of growth of these species (Lane et al. 2019).

Site preparation

Plots were dormant seeded in November 2016 after two forms of pre-seeding disruption to existing turf, scalping and aeration, following recommendations from Lane (2016). Directly after pre-seeding disruption, all plants were seeded at the rate of 241 seeds per m^2; seeds were mixed with Sustane 4N-1.76P-3.32K starter fertilizer and was applied at a rate of 47.7 kg ha^{-1} to assist in root establishment following recommendations on the fertilizer bag. The mixture was seeded using a drop spreader.

Floral establishment

Out of the five flower species planted in the fall of 2016, only *T. repens* and *P. vulgaris* bloomed in 2017. *Trifolium repens* bloomed at each of the four enhanced parks as it was already established before seeding. *Prunella vulgaris* bloomed at only Kenwood Park and Audubon Park in spring of 2017. To ensure blooms were observed for each species, plug plants of *Th. serpyllum*, *P. vulgaris, S. lateriflorum*, and *C. lanceolata* were installed in early summer 2017 at each of the four enhanced parks. Thirty-two plugs of each species were installed at each site, for a total of 128 plug plants per site per park evenly distributed across the 800 m^2 sites, with 16 rows of 8 plants each. Plant species alternated by row, with a 2.5 m border between each plant. Plugs were watered 2–3 times each week for the first 30 days after planting to ensure successful establishment. In early spring of 2018, an additional 55 plugs of *P. vulgaris* were planted at each site.

Vegetation Surveys

In parks containing only *T. repens*, vegetation surveys were performed to assess the density of *T. repens* blooms along a 30 m transect. A 1 m^2 quadrat was dropped once every 5 m on each side of the transect from the 0 m to 25 m, for a total of 12 measurements per survey. To obtain an estimate of total *T. repens* abundance, the observed number of blooms (flower heads) was multiplied by 5, as only one-fifth of the total area of the transect was sampled. In 2016 and 2017, the abundance of *T. repens* was counted, and the presence or absence of additional non-target flora (Table 2) was identified to species when possible. In 2018, turfgrass and forb coverage were also recorded by visually estimating turfgrass coverage and forb coverage within the quadrat each time the quadrat was dropped, and then calculating a grand average for the entire 30 m transect. Similarly, at florally-enhanced parks, the abundance of each floral species was counted following 30 m fixed transect walks. Additionally, in 2018, meandering transect surveys were performed once per week at florally-enhanced parks to survey patches of flowers for species that did not bloom in great densities throughout the area that was originally surveyed.

Bee surveys on T. repens

We sampled bees foraging on *T. repens* at 16 parks in 2016. In 2017 and 2018, we measured bee diversity and community composition at eight “paired” parks: four were florally-enhanced and four were clover-only. The paired parks were within 4 km of each other to facilitate the comparison of bee communities.

For bees foraging in parks with *T. repens* only, we conducted a total of 264 bee surveys over three years, beginning as early as May 26, and as ending late as September 7 each year. Sampling was restricted to central areas of parks where *T. repens* flowered in coexistence with turfgrass. Bees were sampled along a 30 m transect through these areas for 20 min on each survey date between 10 am and 3 pm on days without precipitation, severe winds or heavy cloud cover, and when daytime high temperatures were over 60°F. Transect locations within a park varied in response to *T. repens* density and were not always the same for each survey. Bees were collected continuously over the 20 min using a Bioquip 18-volt, cordless insect vacuum (SKIL 2810). All bees observed actively foraging on *T. repens* within 1 m on either side of the transect line were collected, stored in collection tubes and placed on ice before they were taken back to the University of Minnesota Bee Research Facility for identification, curation, and databasing.

Bee surveys on clover-only vs. florally-enhanced plots

In 2017 and 2018, the eight paired parks (four clover-only and four florally-enhanced) included in our subsample were visited once per week starting in May, until blooms were no longer present. Each park was sampled at least ten times in 2017, and eight times in 2018. Surveys at parks with only *T. repens* concluded in August, as flower blooms subsided at this point. Sampling at florally-enhanced parks concluded in September in 2018, due to the presence of late-blooming *Th. serpyllum*.

Fixed transect walks were used to sample for bees at paired parks in 2017 and 2018. At florally-enhanced parks sampling was restricted to the 800 m^2 where enhancement flowers were seeded. In 2018 while conducting fixed transect surveys, host plant identifications were recorded for each bee collected. Bees were placed in separate containers for each flowering species present during a sampling event, and when an observer had to alternate containers the timer was stopped for the duration of the transition. In addition to fixed transect walks, a minimum of five meandering transect walks were carried out at each florally-enhanced site. Observers walked at a consistent pace for 20 min, targeting patches of enhancement flora, when in bloom, with all bees observed collected via bee-vacuum. Bees were stored in separate containers based on the floral species they were collected off of to ensure proper host-plant identifications were recorded. The timer was paused when containers were switched during meandering transect surveys.

Bee Identification

Bees were identified to species or morphospecies by ZMP using a combination of published revisions and comparisons to previously identified specimens in the University of Minnesota Insect Collection (Baker 1975; Bouseman and LaBerge 1978; Coelho 2004; Gibbs 2010; Gibbs 2011; Gibbs et al. 2013; LaBerge 1971; LaBerge 1989; LaBerge and Bouseman 1970; Laverty and Harder 1988; Miller et al. 2002; Mitchell 1960; Roberts 1972; Roberts 1973; Sheffield et al. 2011; Shinn 1967; Williams et al. 2014). Specimens are deposited in the collection of the Cariveau Native Bee Lab and the University of Minnesota Insect Collection.

Data analysis

All statistical analysis were performed in the R statistical program (v 4.0.2). To determine how many bee species utilize *T. repens* as a source of forage within our study locations, we utilized the “specaccum” function within the package “vegan” (Oksanen et al. 2019) to generate species accumulation curves. We then used the “specpool” function to extrapolate the total number of species (i.e. additional unobserved species) visiting *T. repens* from the species accumulation curves.

To compare bee communities at florally-enhanced and clover-only sites, we calculated the local diversity (α-diversity) of bees at each site in our paired design in 2017 and 2018. Local bee diversity was calculated as Exponential Shannon’s index of entropy (Shannon’s entropy) using the “diversity” function in the R package “diverse” (Guevara et al. 2016). Bee diversity was measured using the exponential index of Shannon’s entropy, a metric that incorporates both species abundance and community evenness, without disproportionately favoring either rare or common species (Jost 2006). Park pairs were only included in this analysis if the florally-enhanced park had at least one *P. vulgaris* or *Th. serpyllum* bloom in a given year between 2017 and 2018. As such, we were able to include data from the Audubon-Windom pair in 2017 and 2018, the Kenwood-Painter pair in 2017 and 2018, and the Willard-North Commons pair in 2018 in this analysis. A student’s t-test was used to determine if florally-enhanced parks had a greater mean bee diversity than clover-only parks. Finally, to determine if bee diversity increased at florally-enhanced parks in response to floral enhancement, we calculated the change in local bee diversity for each park by subtracting the local bee diversity measured in 2016 from that measured in 2018. The average change in bee diversity at enhanced and at clover-only parks was then compared using a student’s t-test.

Finally, to compare bee community composition based on enhancement status (florally-enhanced or clover-only) and host flora (*T. repens* or *P. vulgaris* + *Th. serpyllum*), we first calculated the community dissimilarity matrix utilizing the Morisita-Horn and the Jaccard’s dissimilarity index. This was done using the vegdist function in the R package “vegan” (Oksanen et al. 2019). The Morisita-Horn index was used to provide an abundance-based metric for comparing bee communities, and the Jaccard’s dissimilarity index was used to provide a presence-absence metric for comparing bee communities. A permanova was then performed using the “Adonis” function in “vegan” to determine if there were statistically significant differences between bee communities. We then used Non-metric multidimensional scaling (NMDS) ordination to visualize our results using the “ordiplot” function in the R package “vegan”. Bee diversity on individual floral species (*T. repens, P. vulgaris, and Th. serpyllum*) at florally-enhanced parks was summarized by looking at bee abundance and bee species richness on each species.

Results

Floral abundance in Minneapolis public parks

The average abundance of *T. repens* across all parks was 769 (± 47, SE) inflorescences per 1 m quadrat across the 234 vegetation surveys conducted between 2016 and 2018. Nine additional naturally-occurring forbs were observed blooming alongside *T. repens* in turfgrass lawns throughout the sixteen parks sampled (Table 2).

Trifolium repens bloomed naturally at all paired parks, in all years of data collection, between May 26th and August 23nd. *Prunella vulgaris* established and bloomed at two sites in 2017, and three sites in 2018. *Thymus serpyllum* established and bloomed at one site in 2018. At paired parks, the most abundant floral species was *T. repens* ($\mu = 581 \pm 57$) followed by *P. vulgaris* ($\mu = 117 \pm 32$), and *Th. serpyllum* ($\mu = 10 \pm 4$) (Fig. 3). *C. lanceolata* and *S. lateriflorum* failed to bloom at all sites. In 2018, turfgrass accounted for 54.8% of the land coverage along transects at paired parks, and *T. repens, P. vulgaris*, and *Th. serpyllum* combined to account for 5.8% of land coverage. The remaining land coverage (39.4%) within lawns was comprised of a combination of weedy vegetation and bare ground.

Bee communities on T. repens

A total of 5038 bees were collected off of *T. repens* at the 16 parks sampled between 2016 and 2018 (Table 3). Overall, 56 species from five families and 20 genera were collected off of *T. repens*. Species curve extrapolations estimated a total visitation of 64 bee species. By group, 2230 individuals (44.2%) were *A. mellifera*, 765 individuals (15.1%) were *Bombus*, 1148 individuals (22.8%) were native bees not including *Bombus*, and 895 individuals (17.7%) were non-*Apis* exotic bees. Between 2016 and 2018, the number of bee species observed at a site on *T. repens* ranged from 5 to 17 within a given year. On average (± SD) a single lawn with *T. repens* hosted 11 bee species (± 3.79) within a year.

Exotic bees represented 62.0% (3125 specimens) of the total bee specimen collected off of *T. repens*, and 8.9% (5 species) of the species richness observed. The most abundant exotic bee species collected were *A. mellifera* and *Andrena wilkella* (59.8% of all specimens observed). The three other exotic bee species observed on *T. repens* were *Megachile rotundata*, *Anthidium oblongatum*, and *Hylaeus leptocephalus*.

Bee species composition at paired parks

A total of 2780 bees were collected on *T. repens*, *P. vulgaris*, and *Th. serpyllum*, at the three sets of paired parks included in the comparison of florally-enhanced and clover-only parks (Table 4). The fourth set of paired parks was not included in this analysis as seeded flowers never established and bloomed in the enhanced park. Overall, 53 bee species, representing 18 genera and 5 families were collected off of the three plant species at paired parks. Bootstrapping was used to predict that 61 wild bee species were present at the 6 paired parks. The same five exotic bee species were observed at these parks: *Apis mellifera, Andrena wilkella, Megachile rotundata, Anthidium oblongatum*, and *Hylaeus leptocephalus*, which represented 53.6% (1490 specimens) of the total bee specimens collected at paired parks (Table 4).

Comparing bee communities on enhanced vs clover-only parks

In 2017 and 2018, a total of 1826 bee specimens were collected off of *T. repens* from clover-only sites within the paired parks, including thirty-four wild bee species from 14 genera. Exotic bees represented 51.8% of the total bee specimens collected at clover-only parks, despite observing just five such species foraging at these parks. *Apis mellifera* accounted for 71.3% of the non-native bees observed at clover-only parks between 2017 and 2018. A total of 477 bee specimens, including 38 species representing 15 genera, were collected at florally-enhanced parks in 2017 and 2018; ten of these species were unique to enhanced parks (Table 4). *Apis mellifera* accounted for 47.1%, of the exotic bees observed at florally-enhanced parks.

We measured the impact of floral enhancement in two ways: first, by comparing enhanced sites to clover only parks, and second, by comparing their diversity to their pre-enhancement baseline. Florally-enhanced parks exhibited greater α-diversity of bees than clover-only parks ($p = 0.046$) (Fig. 4). Mean Shannon's entropy was 8.41 at florally-enhanced sites, and 6.98 at clover-only sites. Mean bee diversity at florally-enhanced parks increased significantly from their initial estimate in 2016 when compared to clover-only parks ($p = 0.038$) (Fig. 5). Bee community composition at enhanced and clover-only parks was not statistically different when considering species abundance ($F = 2.89$, $p = 0.092$ Morisita-Horn index) (Fig. 6a); however, they were significantly different from one another based on presence-absence ($p = 0.006$; Jaccard's dissimilarity index) (Fig. 6b).

Bees collected based on host plant

In 2018, the host plants of the bees were recorded. At florally-enhanced parks, a total of 223 bee specimens from 21 wild bee species were collected while visiting *T. repens* and a total of 103 bee specimens from 20 wild bee species were collected off of *P. vulgaris* and *Th. serpyllum* (76 and 27, respectively). Exotic bees represented just 2.9% (3 specimens) of the specimens collected off of *P. vulgaris* and *Th. serpyllum* at enhanced parks in 2018. No honey bees were collected off of either of these two flowers species.

The analysis of bees collected only on host plants in 2018 revealed no statistically significant differences between bee communities on *T. repens* and bee communities on *P. vulgaris* and *Th. serpyllum* according to the abundance metric ($F = 9.18$, $p = 0.1$; Morisita-Horn index) or the presence-absence metric ($F = 1.38$, $p = 0.2$; Jaccard's dissimilarity index). The data suggests that host-plant accounted for 69.7 of the variation between bee communities.

Discussion

We found that while lawns in parks with *Trifolium repens* supported a diverse community of bees, enhancing lawns with two additional floral species, *Prunella vulgaris* and *Thymus serpyllum*, supported significantly greater bee diversity and with different bee community compositions. These results demonstrate the ecological value to pollinators of a relatively easy land management strategy: intentionally enhancing turf lawns with low-growing flowers.

Bee diversity on T. repens

We found 55 species of wild bees (56 species total including *A. mellifera*) that foraged on *T. repens* over three years, which accounts for greater than 17% of the currently recorded bee species in the state of Minnesota; this is more than twice the number of bee species observed on *T. repens* within urban and suburban lawns of Lexington, Kentucky (Larson et al 2014). As our study was restricted to a narrow geographic range within Minnesota, it is likely that *T. repens* may provide forage to additional species outside the surveyed areas.

Non-native (exotic) bees were more abundant than native bees on clover, making up 62% of the total foragers, however, diverse native bees were also found. *Apis mellifera* was the most abundant species utilizing *T. repens*, accounting for 44% of visitors, which was similar to Larson et al. (2014) who also found that *A. mellifera* accounted for 44% of all individuals observed on *T. repens* in Lexington, Kentucky. *Apis mellifera* abundance increased at a greater rate than wild bee abundance with increasing abundance of *T. repens* blooms, likely due to the ability of honey bees to recruit nestmates to abundant patches of flowers; honey bee visitation rates have been shown to increase with increasing floral abundance (Essenberg 2014; Hung et al. 2019). Nearly 93% (51/55) of the non-*Apis* bee species observed on *T. repens* are native to the U.S, demonstrating its nutritional value to many bees. Seven-hundred and sixty-five bumblebee specimens from 7 species were collected on *T. repens*, including *Bombus fervidus*, a species of conservation concern (Colla et al. 2012); this species was also collected on *T. repens* in Kentucky (Larson et al 2014).

Florally-enhanced parks

Florally-enhanced lawns had significantly greater bee diversity than clover-only lawns according to transect surveys conducted between 2017 and 2018. Lawns that were florally-enhanced after the first year of sampling also experienced a greater increase in bee diversity than lawns that contained only *T. repens* throughout the course of the study.

Florally-enhanced lawns supported significantly different bee community composition than clover-only lawns according to Jaccard's dissimilarity index, and marginally different bee communities according to the Morisita-horn index. Species that were highly abundant in both florally-enhanced and clover-only lawns likely reduced differences observed between bee communities according to the Morisita-horn index, an abundance-based metric. Conversely, the Jaccard's dissimilarity index weights all bees equally regardless of abundance, which placed a greater emphasis on species that were unique to a community, especially those that were low in abundance.

When bee communities were compared based on host plant in 2018, the bee community observed on *T. repens* was not significantly different from bee community observed on *P. vulgaris* and *Th. serpyllum* by either index. The sample size of bees collected off *P. vulgaris* and *Th. serpyllum* was likely too small to detect differences in bee communities based on host plant records. We believe that we would have observed differences in bee community composition based on host plant records with a greater sample size of bees collected off of *P. vulgaris* and *Th. serpyllum*. Also, as 2018 was the first year *Th. serpyllum* bloomed, it is likely that more time was required for this plant to be fully established within lawns. Despite the low abundance of the *P. vulgaris* and *Th. serpyllum*, five bee species were observed on these species that were not present on *T. repens.* Three of these bee species (*Lasioglossum ephialtum, L. leucocomum, L. pilosum*) were singletons and doubletons, and their presence or absence may have been due to chance.

Ninety-seven percent of the bees (100/103 specimens) observed foraging on *P. vulgaris* and *Th. serpyllum* were native species compared to 38% native bees on clover. *Apis mellifera* was not observed on either *P. vulgaris* or *Th. serpyllum*. *Prunella vulgaris* flower has a whorled bloom with a deep corolla, which may have restricted visitation to very large bees with long tongues and very small bees that were observed crawling into the flowers. If *A. mellifera* is unable to forage on *P. vulgaris*, including this floral species in lawn seed mixes could serve as a source of resource partitioning among bee species. Although bee records on *Th. serpyllum* were limited due to the low abundance of blooms observed, this plant holds great value to bees, in part due to its phenology. *Thymus serpyllum* blooms between July and September in Minnesota, and may serve as a source of forage for bees active late in the season when other plants have stopped blooming.

Floral establishment

We observed significantly greater bee diversity in florally-enhanced lawns as compared to clover-only lawns, even though only two flowers (*P. vulgaris* and *Th. serpyllum*) established successfully in addition to *T. repens* at florally-enhanced parks. *Prunella vulgaris* established in the first summer after planting at two sites 2017, and in the second summer after planting at one additional site in 2018; delayed blooming for this species is not uncommon (Lane 2016). Furthermore, both *P. vulgaris* and *Th. serpyllum* were abundant in low numbers relative to *T. repens* through our surveys. The greater bee diversity at florally-enhanced sites relative to clover-only sites demonstrates that even small increases in floral diversity can benefit bee communities. Improved floral establishment of intentionally seeded flowers may offer further benefits to bee communities, as significant relationships have been shown between floral abundance and bee abundance (Banaszak 1996) and floral abundance and bee species composition (Potts et al. 2003).

Taking further measures to improve floral establishment may result in increased success when seeding flowers in a lawn area. We suspect that flora had difficulty establishing at some parks due to soil compaction and wear damage, especially at one site that was located at the bottom of a popular sledding hill. In non-dormant seeding situations, utilizing germination blankets and applying irrigation after seeding to help plants retain moisture may promote floral establishment. Furthermore, taking measures to reduce competition from weeds and foot traffic during plant establishment could aid in the establishment of *P. vulgaris* and *Th. serpyllum*. We were unable to minimize weed pressure through the use of herbicides as herbicide use is restricted within public parks in Minneapolis, Minnesota. We also believe that using greater seeding rates for *P. vulgaris and Th. serpyllum* may result in increased floral abundance. Two floral species, *C. lanceolata* and *S. lateriflorum* failed to establish at any of the enhanced sites. These flowers were likely outcompeted for resources by the turfgrass and naturally-occurring weedy species. Both *C. lanceolata* and *S. lateriflorum* are generally maintained at taller heights and are not often found in lawn settings.

Conclusions

These results demonstrate how flowering lawns can support diverse communities of bees while still maintaining the recreational function of the conventional turf lawn. Floral cover accounted for just under 6% of total land cover within flowering lawns, with turfgrass occupying the majority of lawn coverage, which allows homeowners and land managers to maintain the aesthetics and recreational value traditionally associated with lawns while still providing valuable forage to pollinators. Furthermore, flowering lawns are sustainable, utilizing low-input grass and flower species. Clover-only lawns can provide forage for both wild bee and *A. mellifera* communities. Homeowners and land managers should allow *T. repens* to persist in lawns due to its value to bees, in addition to the value nitrogen fixation provides for maintaining the health of a lawn. Land managers who are open to ecologically innovative landscape designs may want to consider utilizing florally-enhanced lawns, which supported more diverse bee communities and greater visitation by native bees than clover-only lawns.

Declarations

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Conflicts of interest/Competing interests: James Wolfin is currently employed by Metro Blooms, a non-profit organization in Minneapolis, Minnesota that partners with communities to create resilient landscapes and foster clean watersheds, embracing the value of equity and inclusion to solve environmental challenges.

Ethics approval: Not applicable

Consent to participate: Not applicable

Consent for publication: Not applicable

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Code availability: Not applicable

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Tables

Table 1

List of sites where bee specimens were collected off of *T. repens* blooms within turfgrass lawns of Minneapolis public parks

Site	Park Area (ha)	Number of Surveys
Audubon	2.3	28
Bancroft	1.8	6
Brackett	4.2	3
Farview	8.5	10
Hall	2.4	6
Kenwood	13.3	25
Linden Hills	3.2	4
Logan	4.2	11
Longfellow	3.3	27
Matthews	4	26
North Commons	10.3	20
Painter	1.2	28
Powderhorn	26.7	9
Washburn Fair oaks	3.1	10
Willard	0.5	23
Windom	3.3	28

Table 2
Naturally-occurring weedy species observed within flowering lawns. Bees were not collected off of these species as they were not observed in high abundance on these flowers

Species name	Common name	Origin	Bloom time (Zone 4–5)
Taraxacum officinale	Common dandelion	Exotic	Full season
Potentilla argentea	Silver cinquefoil	Exotic	Summer - early fall
Medicago lupulina	Black medic	Exotic	Full season
Stellaria media	Common chickweed	Exotic	Summer - early fall
Oxalis stricta	Yellow wood sorrel	Native	Summer - fall
Matricaria discoidea	Pineapple weed	Exotic	Full season
Plantago lanceolata	English plantain	Exotic	Summer - fall
Verbena bracteata	Big-bract verbena	Native	Full season
Lotus conriculatus	Birdsfoot trefoil	Exotic	Summer

Table 3

Species list of bee specimen collected off of *T. repens* blooms in 16 turfgrass lawns of parks in Minneapolis, Minnesota. Species in bold were only collected only at florally enhanced parks.

Family	Species	Abundance
Andrenidae	*Andrena carlini*	1
	Andrena commoda	4
	Andrena dunningi	5
	Andrena vicina	6
	Andrena wilkella	781
	Andrena wilmattae	25
	Calliopsis andreniformis	425
Apidae	*Apis mellifera*	2230
	Bombus auricomus	1
	Bombus bimaculatus	73
	Bombus fervidus	26
	Bombus griseocollis	23
	Bombus impatiens	461
	Bombus rufocinctus	180
	Bombus vagans	1
	Melissodes subillatus	3
	Nomada species 1	2
	Nomada species 2	3
	Nomada species 3	1
Colletidae	*Colletes kincaidii*	2
	Colletes robertsonii	1
	Hylaeus leptocephalus	1
Halictidae	*Agapostemon sericeus*	59
	Agapostemon texanus	8
	Agapostemon virescens	6
	Anthidium oblongatum	36

Family	Species	Abundance
	Augochlorella aurata	36
	Halictus confusus	230
	Halictus ligatus	2
	Halictus rubicundus	268
	Lasioglossum admirandum	1
	Lasioglossum anomalum	2
	Lasioglossum cinctipes	1
	Lasioglossum heterognathum	1
	Lasioglossum hitchensi	5
	Lasioglossum imitatum	1
	Lasioglossum lineatulum	4
	Lasioglossum paradmirandum	11
	Lasioglossum platyparium	1
	Lasioglossum pruinosum	1
	Lasioglossum "tegulare group"	1
	Lasioglossum viridatum	1
	Lasioglossum weemsi	2
	Lasioglossum zephyrus	1
	Sphecodes sp.1	1
Megachilidae	*Coelioxys rufitarsis*	1
	Heriades carinata	1
	Hoplitis producta	3
	Hoplitis truncata	1
	Megachile campanulae	1
	Megachile frigida	8
	Megachile latimanus	7
	Megachile rotundata	77
	Megachile texana	1

Family	Species	Abundance
	Osmia pumila	3

Table 4

Bee species collected off of flowering lawns at 3 sets of paired parks in Minneapolis, Minnesota between 2016 and 2018. Species in bold were only collected at florally-enhanced parks. An asterisk (*) indicates species that were collected only off of *P. vulgaris*, a carrot (^) indicates species that were collected only off of *Th. serpyllum*, and a plus sign (+) indicates species that were collected off of both *P. vulgaris* and *Th. serpyllum*, but not *T. repens*

Family	Species	Abundance
Andrenidae	*Andrena carlini*	1
	Andrena commoda	2
	Andrena dunningi	4
	Andrena vicina	1
	Andrena wilkella	381
	Andrena wilmattae	5
	Calliopsis andreniformis	213
Apidae	*Apis mellifera*	1040
	Bombus auricomus	1
	Bombus bimaculatus	44
	Bombus fervidus	20
	Bombus griseocollis	10
	Bombus impatiens	385
	Bombus rufocinctus	110
	Bombus ternarius	1
	Bombus vagans	2
	Melissodes bimaculatus	1
	Melissodes subillatus	2
	Nomada species 1	1
Colletidae	*Colletes kincaidii*	2
	Hylaeus leptocephalus	1
Halictidae	*Agapostemon sericeus*	33
	Agapostemon texanus	5

Family	Species	Abundance
	Agapostemon virescens	3
	Auguchlorella aurata	71
	Dufourea monardae*	4
	Halictus confusus	146
	Halictus ligatus	1
	Halictus rubicundus	142
	Lasioglossum admirandum	1
	Lasioglossum anomalum	21
	Lasioglossum (Dialictus) spp.+	3
	Lasioglossum ephialtum*	1
	Lasioglossum heterognathum	1
	Lasioglossum hitchensi	9
	Lasioglossum illinoense	1
	Lasioglossum leucocomum*	2
	Lasioglossum lineatulum	1
	Lasioglossum paradmirandum	10
	Lasioglossum pilosum^	1
	Lasioglossum pruinosum	3
	Lasioglossum “tegulare group”	6
	Lasioglossum weemsi	2
	Lasioglossum zephyrus	1
Megachilidae	*Anthidium oblongatum*	22
	Coelioxys rufitarsus	2
	Hoplitis producta	3
	Hoplitis truncata	1
	Megachile campanulae	1
	Megachile frigida	4

Family	Species	Abundance
	Megachile latimanus	3
	Megachule rotundata	46
	Megachile texana	1
	Osmia pumila	2

Figures

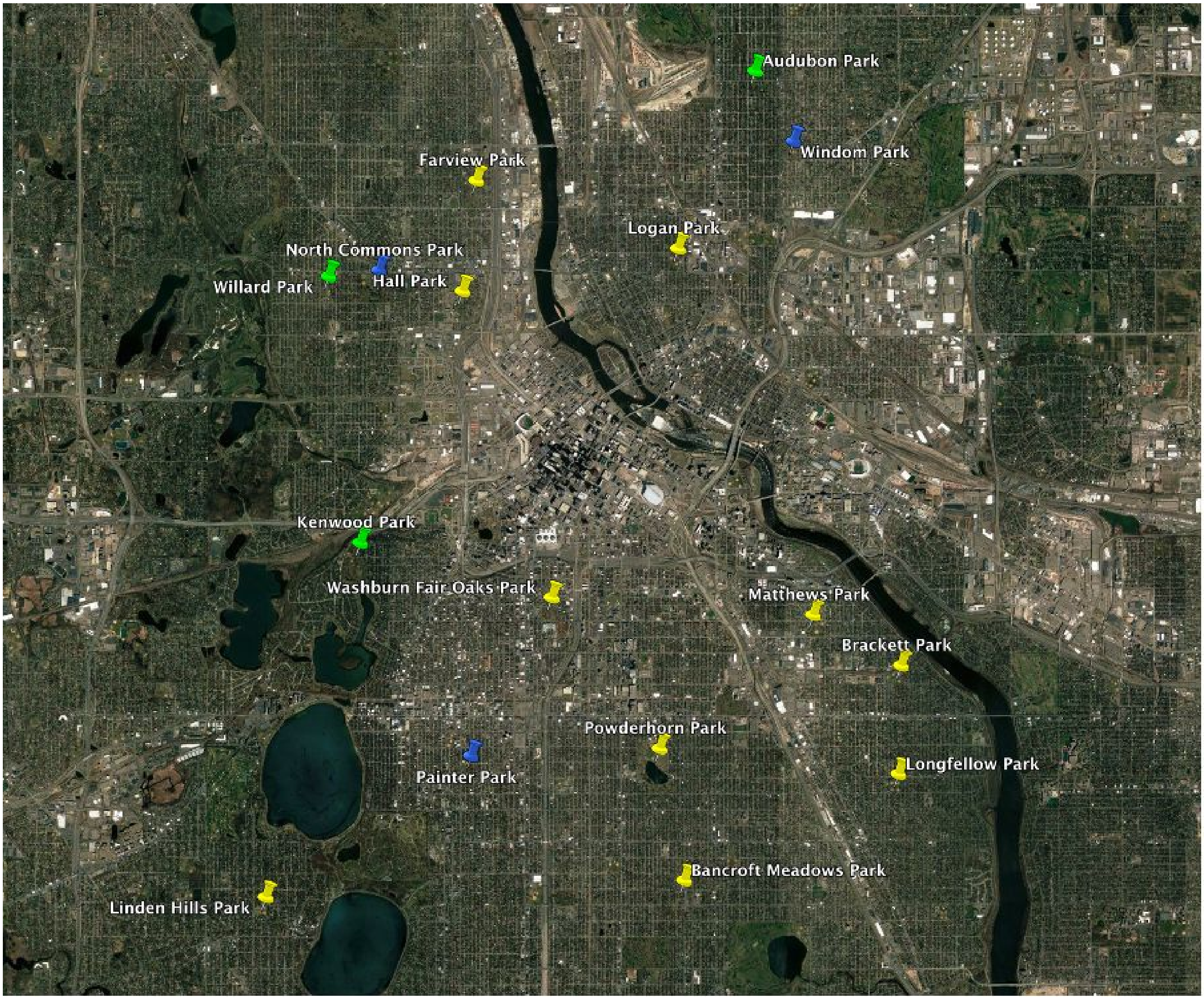


Figure 1

Map of Minneapolis, Minnesota and surrounding areas depicting site locations (thumbnails). Yellow thumbnails indicate clover-only parks, green thumbnails indicate florally-enhanced paired parks, and blue thumbnails indicate clover-only paired parks. Map created using ArcGIS software Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Candidates for floral enhancement for turfgrass lawns. Top row (left to right) Trifolium repens, Prunella vulgaris, Thymus serpyllum. Bottom row (left to right) Coreopsis lanceolata, Symphiotrichum lateriflorum

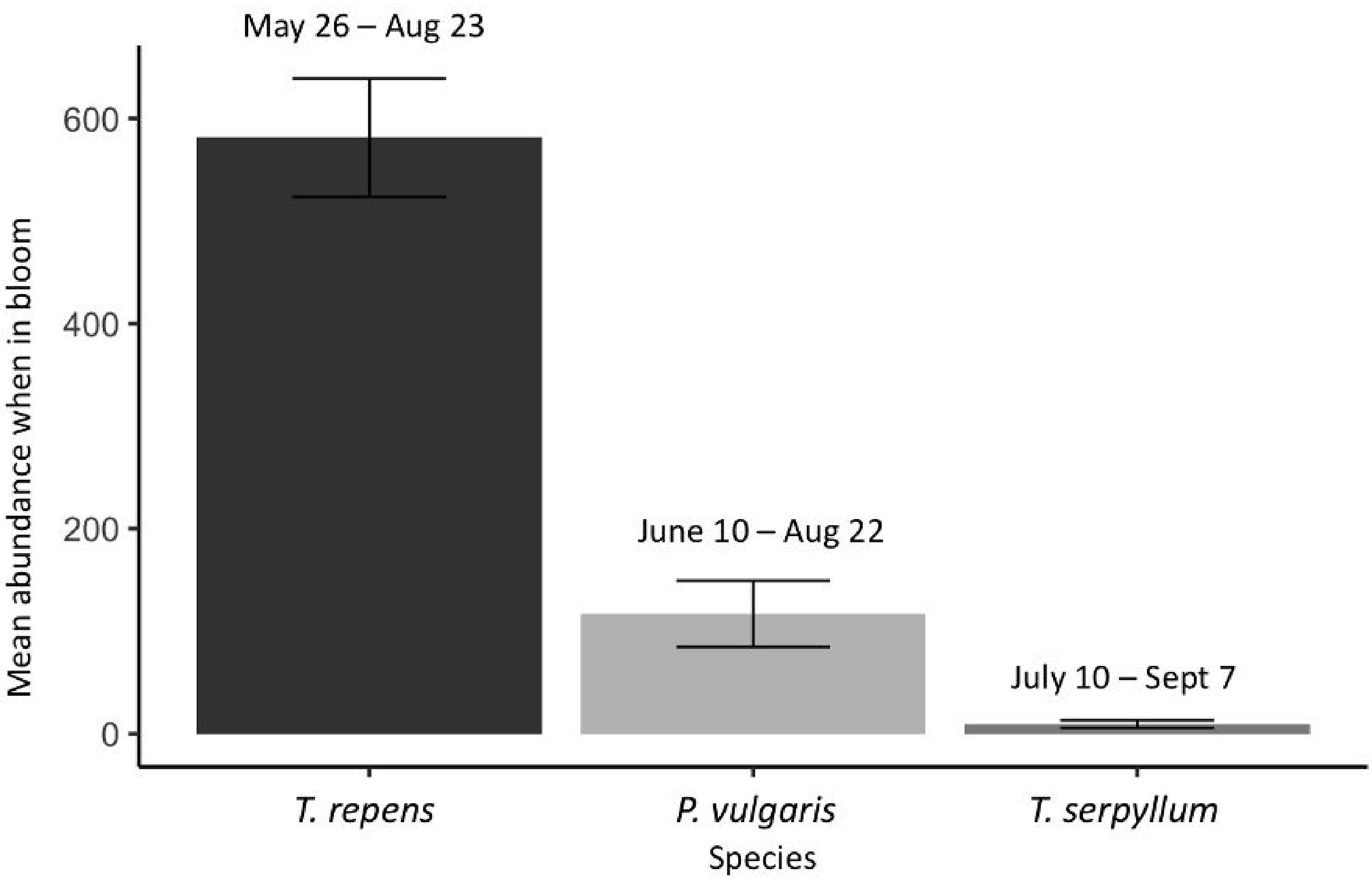


Figure 3

Mean abundance of lawn inflorescences observed within flowering lawns in Minneapolis, Minnesota in 2018. Flowers were counted along a thirty m, fixed transect, immediately following bee surveys along the same transect line. Vertical bars denote standard error. Dates above each bar indicate the bloom period for each species in 2018

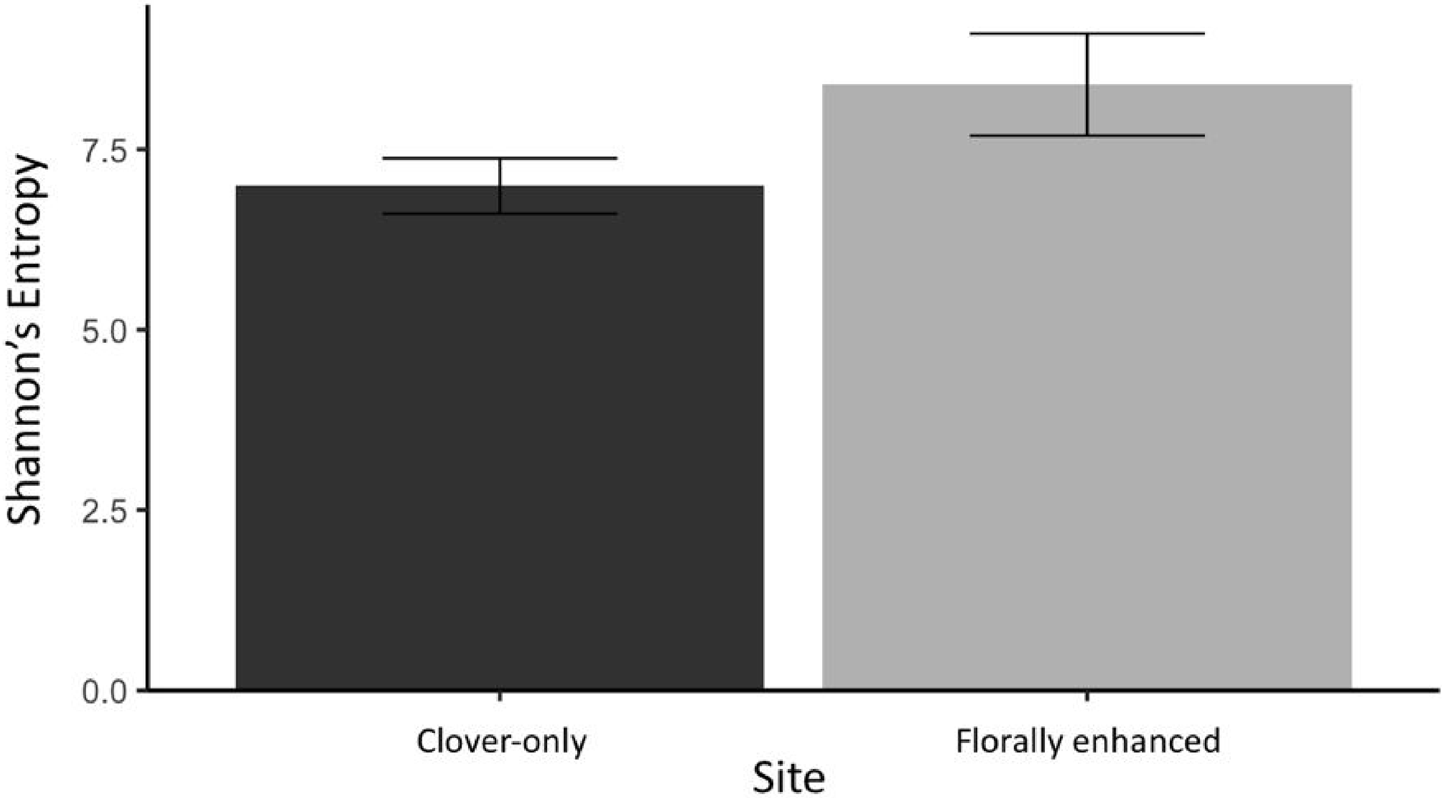


Figure 4

Exponential Shannon's index of entropy at clover-only and florally-enhanced parks in Minneapolis, Minnesota, 2016-2018. Florally-enhanced parks exhibited greater diversity ($p= 0.046$) than clover-only parks

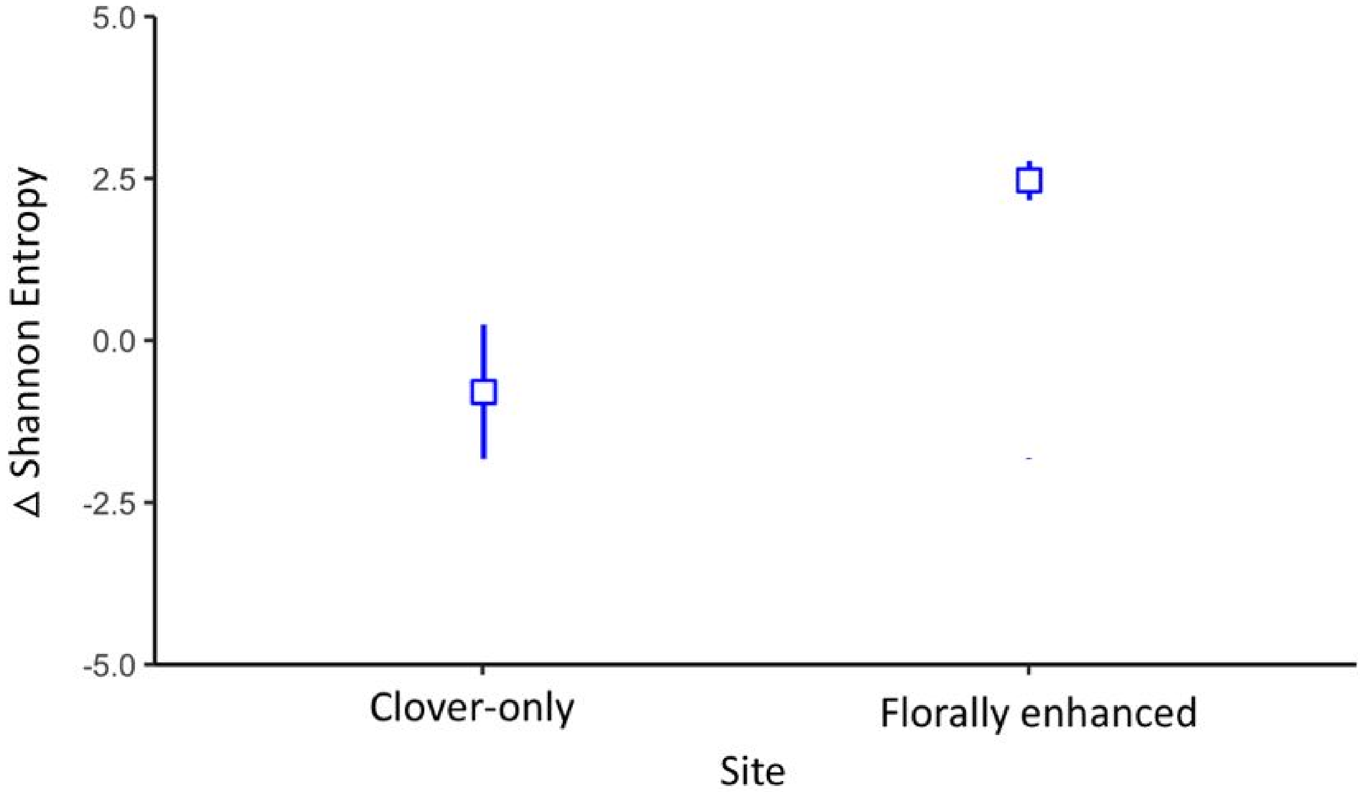
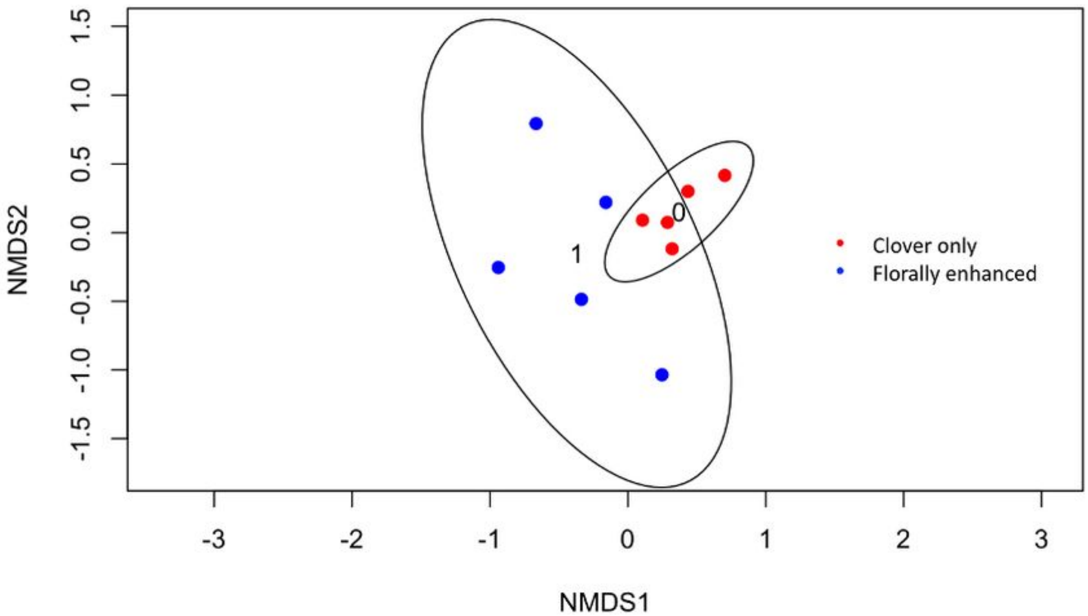
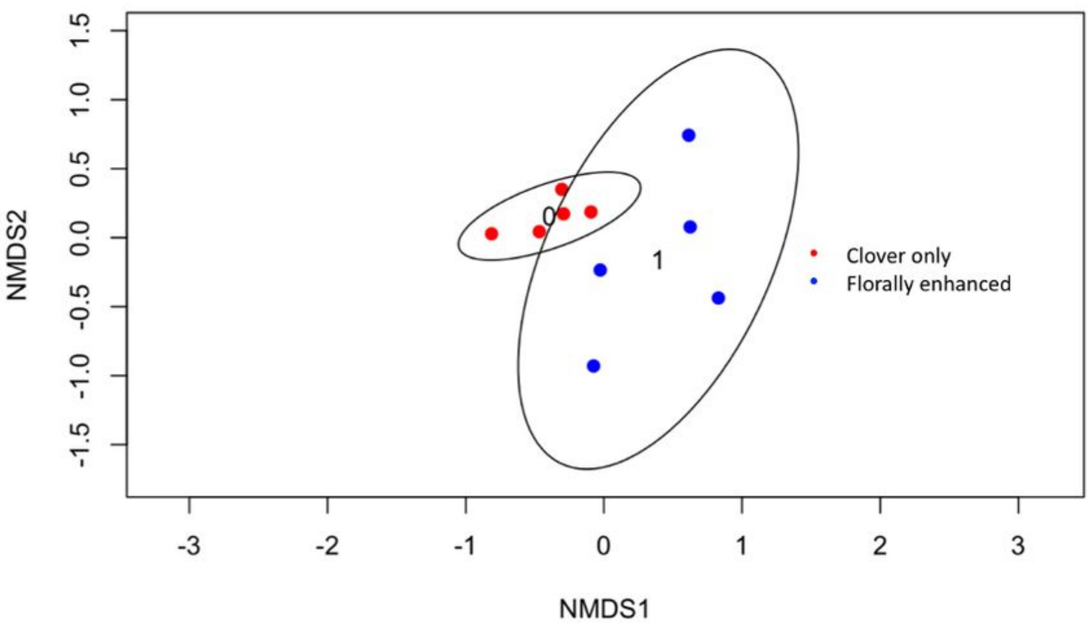


Figure 5

Change in the Exponential Shannon's index of entropy at enhanced and clover-only parks between 2016 and 2018. Parks that were florally-enhanced exhibited a greater increase in diversity (p=0.038) than parks that remained clover-only during this time frame



A)



B)

Figure 6

a-b Non-metric multidimensional scaling ordination of the community composition of bees collected at florally-enhanced and clover-only park in Minneapolis, Minnesota, 2017-2018, according to the Morisita-horn index (a) and the Jaccard dissimilarity index (b).