



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 data (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 species of flowers to lawns.

Keywords Bee lawn · Bee · Pollinator · Turfgrass · Urban ecology

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 *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 and Ascher 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 provisions, 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.

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Turf lawns, which account for nearly 2% of the continental United States (Milesi et al. 2005), are a common greenspace in urban communities that have untapped potential for conserving pollinators and natural resources. 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 the 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. A study by Dahmus and Nelson (2014) of yard perceptions among urban and suburban Minnesotans found that lawns were often viewed as the most important feature in residential yards, however, these lawns were rarely associated with ecosystem services. Instead, many residents associated lawns with environmental harm due to the inputs (mowing, fertilizer, water, etc.) required to maintain a healthy lawn. Despite this, research has shown that lawns can be managed to reduce inputs and provide forage for pollinators. Selhorst and Lal (2012) analyzed carbon emissions from home lawns and found that low-input lawns produce ~ 1/3 the carbon emissions as compared to high management lawns and other studies (Shwartz et al. 2013; Larson et al. 2014; Lerman and Milam 2016) have documented the pollinator communities within common lawn flowers. Lerman et al. (2018) found that lawns that are allowed to grow taller tend to have more flowers present for pollinators. While taller lawns with abundant flowers may be perceived as beneficial by eco-conscious community members, we recognize that many community members may be reluctant to accept taller and florally diverse lawns.

The goal of our study was to measure the diversity of bees on lawns enhanced with low-growing wildflowers. We aimed to use flowering species that are able to establish and bloom within

a lawn 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 lawn seed mix for floral enhancement 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 that *Symphytotrichum lateriflorum* and *Coreopsis lanceolata* are able to bloom under mowing pressure, and thus potentially able to establish within turfgrass lawns depending on environmental conditions (Lane, unpublished data). 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 2016), none have implemented and studied the impact of a seed-mix designed specifically to provide forage for pollinators, specifically bees.

In this study, we aimed to (1) demonstrate the value of *T. repens* to wild and managed bees within the context of a lawn, and (2) compare bee communities on florally-enhanced (seed-mix treatment) lawns to bee communities on lawns with naturally-occurring populations of *T. repens*. First, we documented the bee community visiting naturally occurring populations of *T. repens* in evenly-sized plots within lawn areas at sixteen public parks in Minneapolis, MN to establish the bee community present prior to floral enhancement; eight of these sixteen parks were then selected for further sampling, with plots within four parks 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 observed greater bee diversity and supported different bee communities compared to 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. Describing the diversity of bees that visit *T. repens* demonstrates the ecological value of allowing this flower to persist within a lawn setting. Furthermore, 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.

A subset of 8 parks out of the original 16 parks were selected to compare bee communities at clover-only parks and florally-enhanced parks (Fig. 1). The eight chosen park sites were split into pairs so that a plot within four of the sites with greater *T. repens* abundance was left untreated, and a plot 800 m² (40 m x 20 m) within each of the other four sites with fewer *T. repens* blooms was seeded to be florally enhanced (see below). Parks were paired based on spatial proximity to one another, with paired parks being no further than 4 km apart. This experimental design allowed us to compare bee diversity at florally-enhanced plots and clover-only plots, and also compare bee diversity within individual parks before and after floral enhancement.

Five floral species were selected for floral enhancement based on Lane (2016) and Lane et al. (2019) (Fig. 2): *Trifolium repens* (Dutch white clover), *Prunella vulgaris* ssp. *lanceolata* (self-heal), *Thymus serpyllum* (creeping thyme), *Symphotrichum lateriflorum* (calico aster), and *Coreopsis lanceolata*. 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 m²; seeds were mixed with Sustane 4 N-1.76P-3.32 K starter fertilizer and the mixture 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 in the plots at each of the four florally-enhanced parks as it was already established before seeding. *Prunella vulgaris* bloomed in 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 within the plots at each site, for a total of 128 plug plants per site per park evenly distributed across the 800 m² plots, 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 within each enhanced plot. Flowers failed to establish at one site (Matthews Park) where floral enhancement was attempted. Because of this, Matthews Park and its paired park (Longfellow Park) were not included in analyses comparing florally-enhanced and clover-only paired parks.

Vegetation surveys

Vegetation surveys were conducted to measure floral abundance at all 16 parks. In parks containing only *T. repens* (Fig. 1, yellow and blue pins), vegetation surveys were performed to assess the density of *T. repens* blooms

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	Treatment
Audubon	2.3	28	Florally-enhanced
Bancroft	1.8	6	Clover-only
Brackett	4.2	3	Clover-only
Farview	8.5	10	Clover-only
Hall	2.4	6	Clover-only
Kenwood	13.3	25	Florally-enhanced
Linden Hills	3.2	4	Clover-only
Logan	4.2	11	Clover-only
Longfellow	3.3	27	Clover-only
Matthews	4	26	Florally-enhanced ^a
North Commons	10.3	20	Clover-only
Painter	1.2	28	Clover-only
Powderhorn	26.7	9	Clover-only
Washburn Fair oaks	3.1	10	Clover-only
Willard	0.5	23	Florally-enhanced
Windom	3.3	28	Clover-only

^aAlthough Matthews Park was seeded with flowers included in floral enhancement, flowers failed to establish at this site

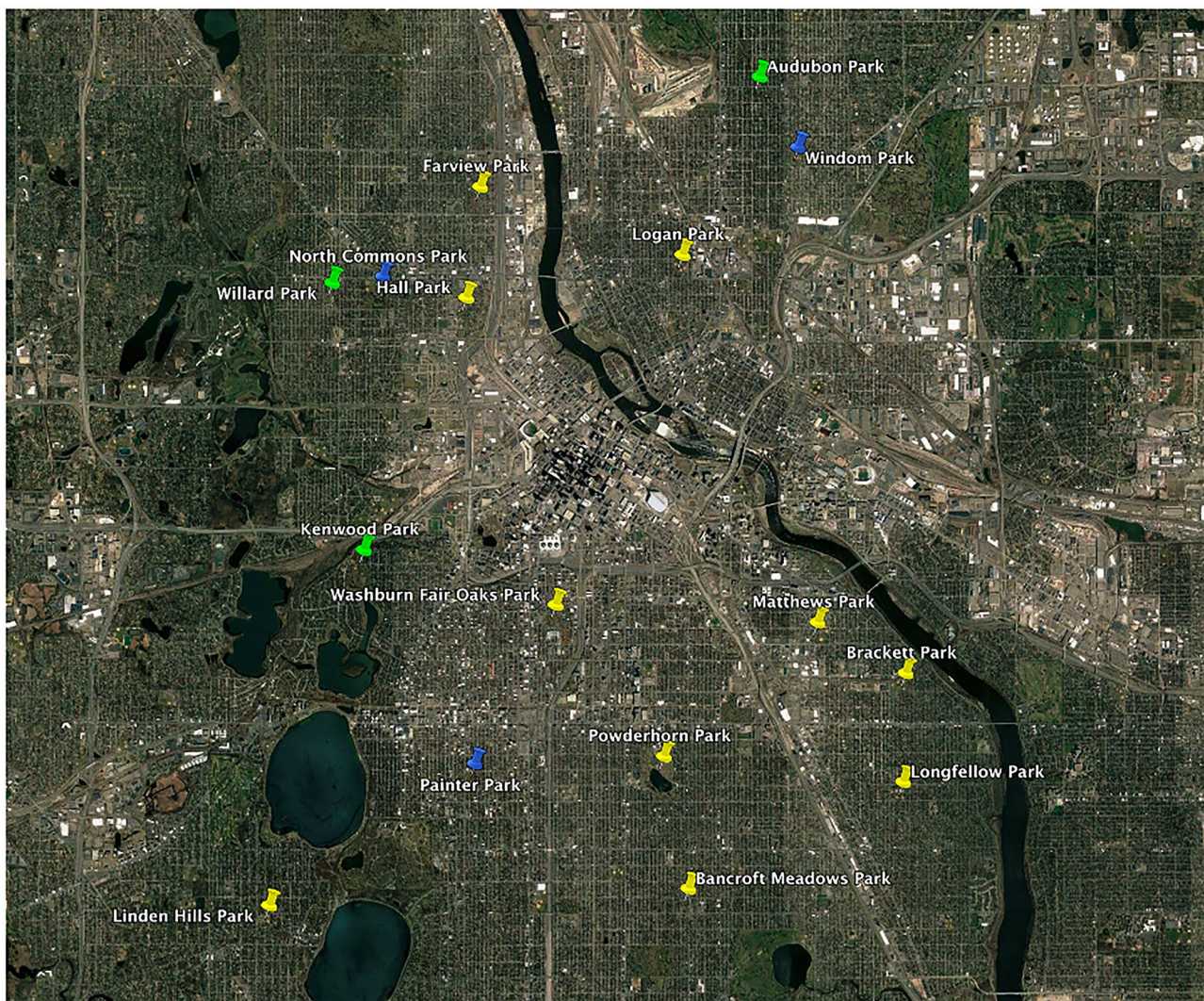


Fig. 1 Map of Minneapolis, Minnesota and surrounding areas depicting 16 parks with pre-existing stands of *Trifolium repens* growing in turf. In 2016 transects within all 16 parks were sampled approximately once every two weeks to measure bee diversity on *T. repens*. In 2017 and 2018 bee diversity within florally-enhanced plots within the parks (green pins) was compared to bee diversity in clover-only

plots within paired parks (blue pins) through weekly surveys. Yellow pins indicate the remaining clover-only parks that were surveyed for bees approximately once per month in 2017 and 2018. Floral establishment did not occur at Matthews Park and was not included in paired comparison with clover-only Longfellow park. Map created using ArcGIS software

along a 30 m transect. In 2016, all parks were surveyed approximately once every two weeks. In 2017 and 2018, paired parks with only *T. repens* (paired parks not florally enhanced; blue pins) were sampled on a transect once per week, while parks with only *T. repens* that were not a part of the paired park surveys (yellow pins) were sampled once per month. A 1 m² quadrat was dropped once every 5 m on each side of the transect from 0 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 (Supporting Information Table 1) 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.

In 2017 and 2018 we also recorded the abundance of *T. repens*, *P. vulgaris*, and *T. serpyllum* following 30 m fixed transect walks performed weekly within the florally-enhanced plots within the four parks (Fig. 1, green pins). Additionally, in 2018 meandering transect surveys were performed once per week only at florally-enhanced plots to survey patches of flowers for species that did not bloom in

Fig. 2 Flowering species included in the floral-enhancement seed mix. Top row (left to right) *Trifolium repens*, *Prunella vulgaris*, *Thymus serpyllum*. Bottom row (left to right) *Coreopsis lanceolata*, *Symphiotrichum lateriflorum*. *C. lanceolata* and *S. lateriflorum* did not establish during our floral enhancement trials



great densities throughout the 800 m² area that was originally surveyed.

Bee surveys

In 2016, we sampled bees foraging on *T. repens* along transects in 16 parks once every two weeks to allow for the comparison of individual parks before and after floral enhancement. In 2017 and 2018, we continued to sample all 16 parks, with the eight “paired” parks sampled weekly, and the remaining parks sampled once per month. We measured bee diversity and community composition at the three pairs of parks where seeded flowers were able to establish within florally enhanced parks; these paired parks were within 4 km of each other. A paired design ensured that observed differences in bee diversity were due to treatments rather than regional/local environmental factors (surrounding green space, proximity to managed honey bee colonies, etc.).

For bees foraging in the parks with *T. repens* only, we conducted a total of 264 bee surveys over three years, beginning as early as May 26, and ending as late as September 7 each year. Sampling was restricted to 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. Bees that moved through the transect without stopping on a *T. repens* flower were not collected.

In 2017 and 2018 the paired parks were visited once per week starting in May until blooms were no longer present. Each plot within the paired parks was sampled at least ten times in 2017, and eight times in 2018. Sampling at florally-enhanced plots concluded in September in 2018, due to the presence of late-blooming *Th. serpyllum*, whereas sampling at plots with only *T. repens* concluded in August, as flower blooms subsided at this point.

Bee community composition relative to floral composition

In 2018 while conducting the 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 the fixed transect

walks, a minimum of five meandering transect walks were conducted within each florally-enhanced plot. 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, 2011; Gibbs et al. 2013; LaBerge 1971, 1989; LaBerge and Bouseman 1970; Laverty and Harder 1988; Miller et al. 2002; Mitchell 1960; Roberts 1972, 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. All non-*Apis* bees were grouped as “wild” bees. This distinction was made to clearly separate managed honey bees from all other bees observed and collected in our surveys. Bees were also classified as either “native” or “exotic” to differentiate bees that have a longstanding relationship with the local ecosystem (native), from introduced species that have greater potential to disrupt ecological relationships (exotic).

Data analysis

All statistical analyses were performed in the R statistical program (v 4.0.2).

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 the exponential of Shannon entropy using the “diversity” function in the R package “diverse” (Guevara et al. 2016). This metric 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. Matthews and its clover-only paired park, Longfellow, were excluded from this analysis in both years as floral-establishment did not occur at Matthews. We included 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.

We measured differences in bee diversity in two ways. First, we compared bee diversity at florally-enhanced parks with their paired clover-only parks across the same time frame using a paired comparison. We then compared bee diversity at paired parks before and after floral enhancement. A student’s t-test was used to determine if observed differences were significant in each instance.

We also compared bee community composition based on enhancement status (florally-enhanced or clover-only) and host flora (*T. repens* or *P. vulgaris* + *Th. serpyllum*) by calculating 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 “`ordplot`” 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 30 m² quadrat across the 234 vegetation surveys conducted from 2016 to 2018. Nine additional naturally-occurring forbs were observed blooming alongside *T. repens* in turfgrass lawns throughout the sixteen parks sampled (Supporting Information Table 1). *Trifolium repens* bloomed naturally at all paired parks, in all years of data collection, between May 26th and August 23rd. *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 florally-enhanced 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* along transects at all 16 parks (yellow, blue, and green pins in Fig. 1) sampled between 2016 and 2018 (Table 2). 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. The number of bee species observed at a site on *T. repens* ranged from 5 to 17 within a given year. On average ($\pm$ SD) a single lawn with *T. repens* hosted 11 bee species ($\pm$ 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*.

Comparing bee communities at florally-enhanced parks and clover-only parks

A total of 2780 bees were collected on *T. repens*, *P. vulgaris*, and *Th. serpyllum*, within plots at the three sets of paired

parks (blue and green pins) included in the comparison of florally-enhanced and clover-only parks (Table 3). Overall, 53 bee species, representing 18 genera and 5 families were collected off of the three plant species at the 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 within plots at paired parks (Table 3).

In 2017 and 2018, a total of 1826 bee specimens were collected off of *T. repens* from clover-only plots within the paired parks (blue pins), including 34 wild bee species from 14 genera. Exotic bees represented 51.8% of the total bee specimens collected in plots within 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 in 2017 and 2018. A total of 477 bee specimens, including 38 species representing 15 genera, were collected at florally-enhanced parks (green pins) in 2017 and 2018; ten of these species were unique to enhanced parks (Table 3). *Apis mellifera* accounted for 47.1% of the exotic bees observed at florally-enhanced parks.

In the comparison between bee communities at florally-enhanced plots within parks (green pins) and clover-only plots within parks (blue pins), we found that florally-enhanced plots exhibited greater α -diversity of bees than clover-only plots ($p=0.046$) (Fig. 4). Mean exponential of Shannon entropy was 8.41 at florally-enhanced sites, and 6.98 at clover-only sites. When comparing bee communities at florally-enhanced parks and clover-only parks to their pre-enhancement baseline we found that florally-enhanced plots experienced a significantly greater increase in diversity ($p=0.038$) than plots that remained clover-only (Fig. 5). Bee

Fig. 3 Mean abundance of lawn inflorescences observed within florally-enhanced lawns in Minneapolis, Minnesota in 2018. Flowers were counted along a 30 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

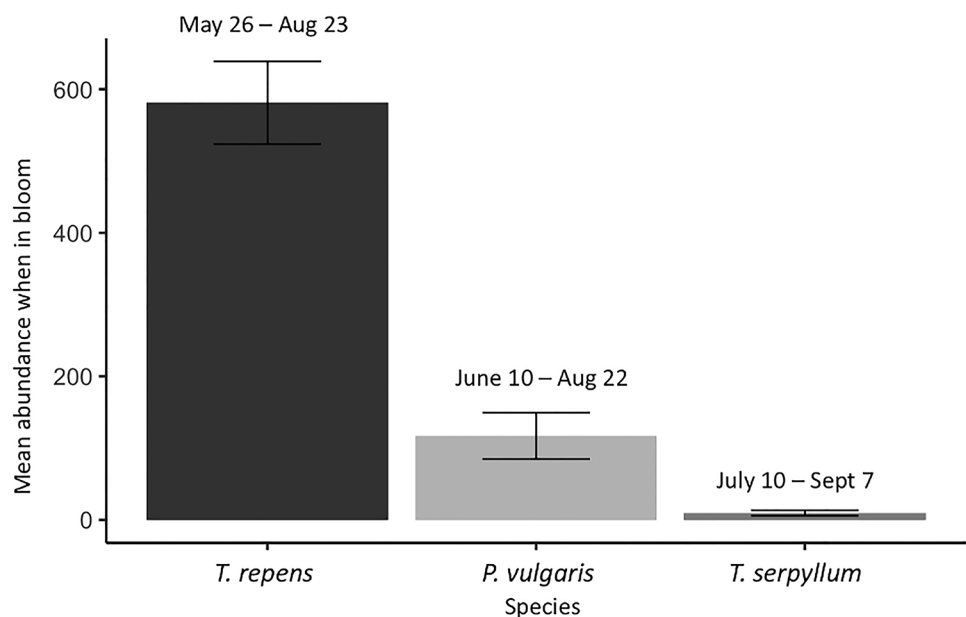


Table 2 Species list of bee specimen collected off of *T. repens* blooms in 16 turfgrass lawns of parks in Minneapolis, Minnesota

Family	Species	Abundance
Andrenidae	<i>Andrena carlini</i>	1
	<i>Andrena commoda</i>	4
	<i>Andrena dunningi</i>	5
	<i>Andrena vicina</i>	6
	<i>Andrena wilkella</i>	781
	<i>Andrena wilmattae</i>	25
	<i>Calliopsis andreniformis</i>	425
Apidae	<i>Apis mellifera</i>	2230
	<i>Bombus auricomus</i>	1
	<i>Bombus bimaculatus</i>	73
	<i>Bombus fervidus</i>	26
	<i>Bombus griseocollis</i>	23
	<i>Bombus impatiens</i>	461
	<i>Bombus rufocinctus</i>	180
	<i>Bombus vagans</i>	1
	<i>Melissodes subillatus</i>	3
	<i>Nomada species 1</i>	2
	<i>Nomada species 2</i>	3
	<i>Nomada species 3</i>	1
Colletidae	<i>Colletes kincaidii</i>	2
	<i>Colletes robertsonii</i>	1
Halictidae	<i>Hylaeus leptocephalus</i>	1
	<i>Agapostemon sericeus</i>	59
	<i>Agapostemon texanus</i>	8
	<i>Agapostemon virescens</i>	6
	<i>Anthidium oblongatum</i>	36
	<i>Augochlorella aurata</i>	36
	<i>Halictus confusus</i>	230
	<i>Halictus ligatus</i>	2
	<i>Halictus rubicundus</i>	268
	<i>Lasioglossum admirandum</i>	1
	<i>Lasioglossum anomalum</i>	2
	<i>Lasioglossum cinctipes</i>	1
	<i>Lasioglossum heterognathum</i>	1
	<i>Lasioglossum hitchensi</i>	5
	<i>Lasioglossum imitatum</i>	1
	<i>Lasioglossum lineatulum</i>	4
	<i>Lasioglossum paradmirandum</i>	11
	<i>Lasioglossum platyparium</i>	1
	<i>Lasioglossum pruinosum</i>	1
	<i>Lasioglossum “tegulare group”</i>	1
	<i>Lasioglossum viridatum</i>	1
	<i>Lasioglossum weemsi</i>	2
	<i>Lasioglossum zephyrus</i>	1
	<i>Sphecodes sp.1</i>	1
Megachilidae	<i>Coelioxys rufitarsis</i>	1
	<i>Heriades carinata</i>	1
	<i>Hoplitis producta</i>	3
	<i>Hoplitis truncata</i>	1

Table 2 (continued)

Family	Species	Abundance
	<i>Megachile campanulae</i>	1
	<i>Megachile frigida</i>	8
	<i>Megachile latimanus</i>	7
	<i>Megachile rotundata</i>	77
	<i>Megachile texana</i>	1
	<i>Osmia pumila</i>	3

community composition at florally-enhanced and clover-only plots was not statistically different when considering species abundance ($F = 2.89$, $p = 0.092$, $df = 9$ Morisita-Horn index) (Fig. 6a); however, they were significantly different from one another based on presence-absence ($p = 0.006$, $df = 9$; Jaccard's dissimilarity index) (Fig. 6b).

Bees collected based on host plant at florally-enhanced sites

At florally-enhanced plots within parks, a total of 223 bee specimens from 21 wild bee species were collected off of *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) in 2018. Exotic bees represented just 2.9% (3 specimens) of the specimens collected off of *P. vulgaris* and *Th. serpyllum* at enhanced parks. No honey bees were collected off of either of these two flower species.

The analysis of bees collected by host plant 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 ($F = 9.18$, $p = 0.1$, $df = 5$; Morisita-Horn index) or the presence-absence metric ($F = 1.38$, $p = 0.2$, $df = 5$; 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 different bee community compositions. These results demonstrate the ecological value to pollinators of a simple land management strategy: intentionally enhancing turf lawns with low-growing flowers. Our study supports the hypothesis that florally-enhanced lawns support more diverse communities of bees compared to naturally-occurring clover-only lawns.

Table 3 Bee species collected off of flowering lawns at 3 sets of paired parks in Minneapolis, Minnesota between 2016 and 2018

Family	Species	Abundance
Andrenidae	<i>Andrena carlini</i>	1
	<i>Andrena commoda</i>	2
	<i>Andrena dunningi</i>	4
	<i>Andrena vicina</i>	1
	<i>Andrena wilkella</i>	381
	<i>Andrena wilmattae</i>	5
	<i>Calliopsis andreniformis</i>	213
Apidae	<i>Apis mellifera</i>	1040
	<i>Bombus auricomus</i>	1
	<i>Bombus bimaculatus</i>	44
	<i>Bombus fervidus</i>	20
	<i>Bombus griseocollis</i>	10
	<i>Bombus impatiens</i>	385
	<i>Bombus rufocinctus</i>	110
	<i>Bombus ternarius</i>	1
	<i>Bombus vagans</i>	2
	<i>Melissodes bimaculatus</i>	1
	<i>Melissodes subillatus</i>	2
	<i>Nomada species 1</i>	1
Colletidae	<i>Colletes kincaidii</i>	2
	<i>Hylaeus leptocephalus</i>	1
Halictidae	<i>Agapostemon sericeus</i>	33
	<i>Agapostemon texanus</i>	5
	<i>Agapostemon virescens</i>	3
	<i>Augochlorella aurata</i>	71
	<i>Dufourea monardae</i>*	4
	<i>Halictus confusus</i>	146
	<i>Halictus ligatus</i>	1
	<i>Halictus rubicundus</i>	142
	<i>Lasioglossum admirandum</i>	1
	<i>Lasioglossum anomalum</i>	21
	<i>Lasioglossum (Dialictus) spp.</i>⁺	3
	<i>Lasioglossum ephialtum</i>*	1
	<i>Lasioglossum heterognathum</i>	1
	<i>Lasioglossum hitchensi</i>	9
	<i>Lasioglossum illinoense</i>	1
	<i>Lasioglossum leucocomum</i>*	2
	<i>Lasioglossum lineatulum</i>	1
	<i>Lasioglossum paradmirandum</i>	10
	<i>Lasioglossum pilosum</i>[^]	1
	<i>Lasioglossum pruinolum</i>	3
	<i>Lasioglossum “tegulare group”</i>	6
	<i>Lasioglossum weemsi</i>	2
	<i>Lasioglossum zephyrus</i>	1
Megachilidae	<i>Anthidium oblongatum</i>	22
	<i>Coelioxys rufitarsus</i>	2
	<i>Hoplitis producta</i>	3
	<i>Hoplitis truncata</i>	1
	<i>Megachile campanulae</i>	1

Table 3 (continued)

Family	Species	Abundance
	<i>Megachile frigida</i>	4
	<i>Megachile latimanus</i>	3
	<i>Megachile rotundata</i>	46
	<i>Megachile texana</i>	1
	<i>Osmia pumila</i>	2

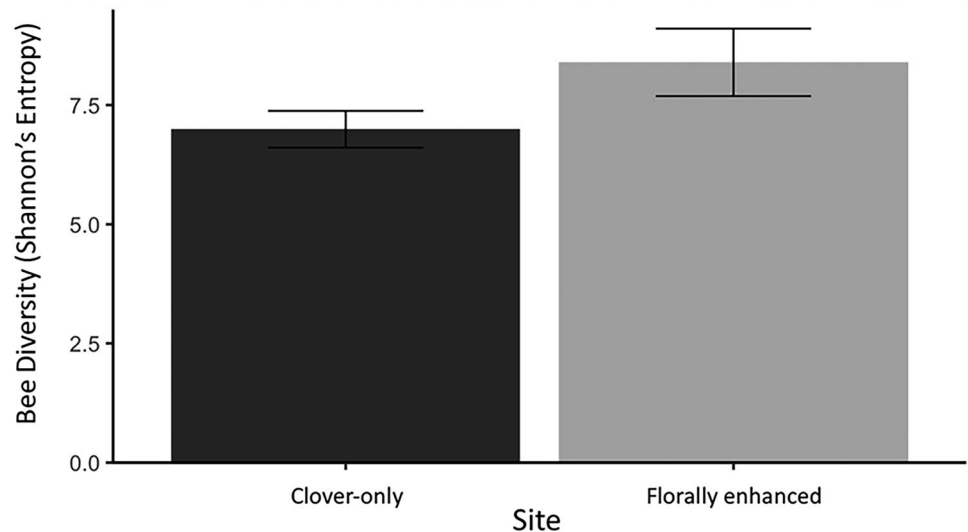
Species in bold were only collected at florally-enhanced parks. An asterisk (*) indicates species that were collected only off of *P. vulgaris*, a carrot (^) indicates species that were collected only off of *Th. serpyllum*, and a plus sign (+) indicates species that were collected off of both *P. vulgaris* and *Th. serpyllum*, but not *T. repens*

Our results on the bee diversity observed in florally enhanced lawns and lawns with just *T. repens* can contribute to the acceptance and adoption of alternative, eco-friendly lawns. Previous research has shown that 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 are often 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).

Floral establishment

Even though some floral species failed to establish, or established inconsistently, the increased bee diversity observed at florally-enhanced sites demonstrates the potential that exists for intentionally introducing flowers to lawns. While previous studies have explored the benefits of naturally-occurring lawn flowers (Larson et al. 2014; Lerman and Milam 2016) and altering typical lawn management strategies to promote the abundance of these naturally-occurring flowers (Lerman et al. 2018) our study is novel as we explore the possibility of intentionally introducing pollinator-friendly flowers into the lawn. We observed significantly greater bee diversity in florally-enhanced lawns as compared to lawns with naturally-occurring populations of *T. repens*, even though only two flowers (*P. vulgaris* and *Th. serpyllum*)

Fig. 4 Exponential of Shannon entropy at clover-only and florally-enhanced parks in Minneapolis, Minnesota, 2016–2018. Florally-enhanced parks exhibited a significantly greater diversity ($p=0.046$) than clover-only parks



established successfully in addition to *T. repens* at our florally-enhanced parks. These results build on the body of research that demonstrates that even small increases in floral diversity can benefit bee communities and local efforts to improve sustainability. 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). Improved floral establishment may be observed by removing highly competitive

weeds prior to overseeding. Florally-enhanced lawns may be able to contribute to sustainability efforts, as small conversions of turfgrass into floral cover have been found to increase pollination supply at urban farms and community gardens (Davis et al. 2017).

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. Soil compaction has been found to

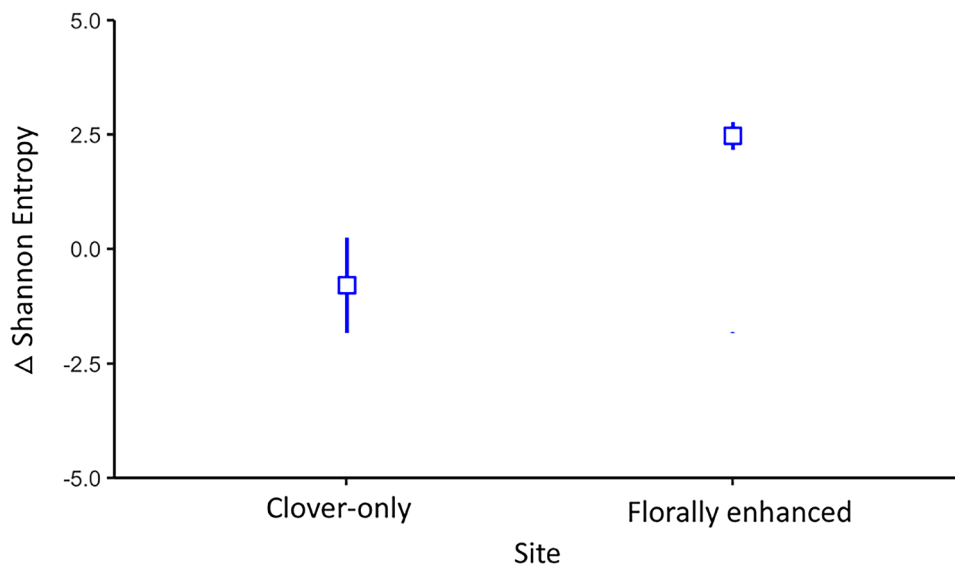
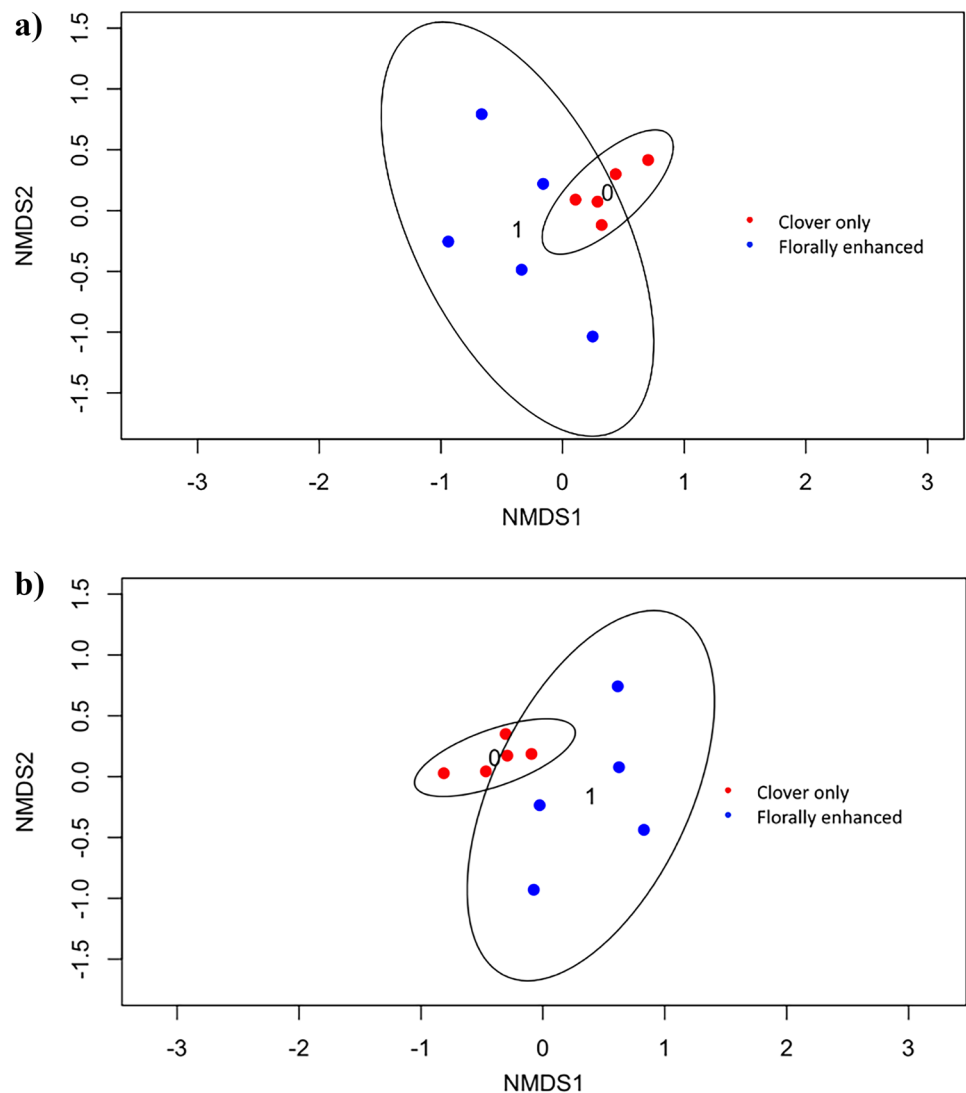


Fig. 5 Change in Bee Diversity (Exponential of Shannon entropy) at florally-enhanced and clover-only parks. Bee diversity was measured in 2016 at both florally-enhanced and clover-only parks, prior to the addition of wildflowers at florally-enhanced sites, to establish a 'baseline' for bee diversity. Bee diversity was measured again after floral enhancement at both florally-enhanced and clover-only sites. We then

compared the change in bee diversity at both florally-enhanced to the change in bee diversity at clover-only sites between 2016 and 2018. Plots within parks that were florally-enhanced exhibited a significantly greater increase in diversity ($p=0.038$) than plots within parks that remained clover-only during this time frame

Fig. 6 a-b Non-metric multi-dimensional scaling ordination of the community composition of bees collected at florally-enhanced and clover-only plots in Minneapolis, Minnesota, 2017–2018, according to the Morisita-horn index (a) and the Jaccard dissimilarity index (b)



reduce establishment and cause shallow root depth in plants (Hebblethwaite and McGowan 1980; Gilman et al. 1987). 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 with herbicides as herbicide use is restricted within public parks in Minneapolis, Minnesota. Using higher seeding rates for *P. vulgaris* and *Th. serpyllum* may have resulted 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.

Bee diversity on *T. repens*

Trifolium repens provides high-quality forage for diverse bee communities, including both honey bees and wild bees. The 55 species of wild bees (56 species total including *A. mellifera*) observed on *T. repens* account for greater than 13% of the recorded bee species in the state of Minnesota. As our study was restricted to a narrow geographic range within Minnesota, it is likely that *T. repens* may provide forage to additional species that are not present in the surveyed areas. Furthermore, the 55 bee species we observed on *T. repens* is more than twice the number of bee species observed on *T. repens* within a similar study that took place in Lexington, Kentucky, indicating that this flower may provide greater conservation value than previously thought (Larson et al. 2014).

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. Nearly 93% (51/55) of the non-*Apis* bee species observed on *T. repens* are native to the U.S, demonstrating its value as a source of forage 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). In addition to being attractive to a diversity of bees, both the pollen and nectar of *T. repens* have been shown to provide high-quality forage for native and non-native bees (MacIvor et al. 2014; Tew et al. 2021; Roulston et al. 2000; Baude et al. 2016).

Florally-enhanced parks

Introducing additional floral species to lawns already containing *T. repens* can allow a lawn area to support more diverse bee communities. 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 experienced a greater increase in bee diversity than lawns that remained clover-only throughout the years of the study when compared to the pre-enhancement baseline. One limitation to this study was that sampling effort was not equal between florally-enhanced and clover-only parks. While fixed transects were conducted at both parks, we also conducted meandering transects at florally-enhanced enhanced sites to ensure that populations of *P. vulgaris* and *Th. serpyllum* were thoroughly sampled. We do not believe that the extra sampling conducted at florally-enhanced parks detracts from the results we observed. Although extra sampling that took place at florally-enhanced parks, we still observed greater species richness at florally-enhanced parks despite collecting more bee specimens at clover-only parks (Fig. 7).

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 (Horn 1966), an abundance-based metric. Conversely, the Jaccard's dissimilarity index (Jaccard 1902) 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. The Jaccard's dissimilarity index was included to compare communities while

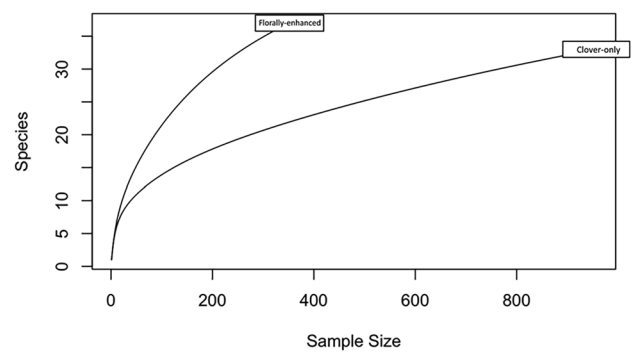


Fig. 7 Rarefaction curve showing the total number of bees collected and the number of bee species observed in florally-enhanced and untreated plots. Despite collecting more individual specimen at clover-only parks, more bee species were observed at florally-enhanced parks

focusing on species richness, while the Morisita-horn index was included to compare communities while considering the relative abundance of each species in each community.

When bee communities were compared based on host plant in 2018, the bee community observed on *T. repens* was not significantly different from bee communities 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. 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.

97% of the bees (100/103 specimens) observed foraging on *P. vulgaris* and *Th. serpyllum* were native species compared to 38% native bees on *T. repens*. *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 between honey bees and wild 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. *Trifolium repens* (May – August) and *P. vulgaris* (June – August) bloom early in the growing season when forage is abundant. *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.

Conclusion

Homeowners and land managers should consider allowing *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. Ultimately, the intentional introduction of flowers to lawns represents an effective and economical contribution to pollinator conservation. While florally-enhanced turfgrass lawns are not an alternative to gardens and native plantings, they are a significant improvement to the conventional turf lawn that can function as a food desert for pollinators. In areas where turfgrass is desired, enhancing the turfgrass with low-growing flowers could become the new norm for landscaping as part of a widespread effort to conserve natural resources and protect our at-risk pollinators.

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Data availability Data available upon request.

Code availability Not applicable.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflicts of interest/Competing interests James Wolfin is currently employed by Metro Blooms, a non-profit organization in Minneapolis, Minnesota.

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