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Research

The Bee Community of *Cannabis sativa* and Corresponding Effects of Landscape Composition

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Abstract

Industrial hemp, *Cannabis sativa* (Cannabaceae), is a newly introduced and rapidly expanding crop in the American agricultural landscape. As an exclusively wind-pollinated crop, hemp lacks nectar but produces an abundance of pollen during a period of floral dearth in agricultural landscapes. These pollen resources are attractive to a range of bee species but the diversity of floral visitors and their use of hemp across a range of agricultural contexts remains unclear. We made repeated sweep net collections of bees visiting hemp flowers on farms in New York, which varied in both landscape context and phenotypic traits of hemp varieties. We identified all bee visitors to the species level and found that hemp supported 16 different bee species. Landscape simplification negatively impacted the abundance of bees visiting hemp flowers but did not affect the species richness of the community. Plant height, on the other hand, was strongly correlated with bee species richness and abundance for hemp plots with taller varieties attracting a broader diversity of bee species. Because of its temporally unique flowering phenology, hemp has the potential to provide a critical nutritional resource to a diverse community of bees during a period of floral scarcity and thereby may help to sustain agroecosystem-wide pollination services for other crops in the landscape. As cultivation of hemp increases, growers, land managers, and policy makers should consider its value in supporting bee communities and take its attractiveness to bees into account when developing pest management strategies.

Key words: hemp, wild bees, honey bees, landscape simplification, plant traits

Bees provide essential pollination services in both natural and agricultural systems; yet, both wild and managed bees have been adversely impacted by numerous characteristics of large-scale, intensified agriculture, including the widespread use of chemical pesticides and insecticides, persistent pathogens and parasites, and the loss of seminatural nesting habitat and plant diversity (Goulson et al. 2015, Dicks et al. 2016). Landscape-scale loss of natural areas and plant diversity, a defining characteristic of intensive agriculture, occurs as a consequence of the increased size and connectivity of areas devoted to agricultural production (Meehan et al. 2011). Habitat loss associated with agricultural land-use change imposes nutritional stress on bee communities (Naug 2009) by reducing the diversity of floral resources and imposing temporal gaps in resource availability (Di Pasquale et al. 2016). Changing land use patterns, therefore, threaten the sustainability of the pollination services that our agricultural systems rely upon.

The recent federal legalization and agricultural expansion of industrial hemp, *Cannabis sativa* (Schluttenhofer and Yuan 2017), may influence the spatial and temporal distribution of pollen resources for bee communities in the United States. Industrial hemp offers a unique floral resource to bees in agricultural landscapes. Hemp flowers late in the summer releasing an abundance of pollen during a period of native and agricultural floral dearth (Dalio 2012, Koh et al. 2016). As a result, hemp pollen may offer a vital subsistence resource to bees at a point in the season when they are resource-limited (Dalio 2012), thereby helping to alleviate the pressures imposed by spatial and temporal variation in resource availability that is characteristic of simplified agricultural landscapes (Schellhorn et al. 2015).

Recent studies have documented the importance of hemp pollen in supporting a diverse community of bees during periods of floral resource scarcity (O'Brien and Arathi 2019). Hemp visitor communities may vary across the season (O'Brien and Arathi 2019) potentially reflecting changes in landscape-level floral resources over time. Specifically, hemp's pollinator community may vary temporally as bees respond to local declines in the availability of floral resources when the flowers of other late-season crops in the landscape senesce (Grab et al. 2017). Additionally, we know little about the effects of varietal traits, like plant height, which have been previously shown to alter visitor preference in other systems (Parsche et al. 2011). Plant height in hemp is highly variable and determined by both genetic and environmental factors (Campbell et al. 2019). Furthermore, flower visitors may respond to land use change not only in terms of

abundance and species richness but also in community composition (Rollin et al. 2015). By exploring changes in composition, we can detect more subtle changes in community structure including species turnover whereby the identity of the species and their relative abundances change across the landscape gradient. However, prior studies have been limited in both their spatial and taxonomic resolution. Therefore, hemp's ability to support a diverse bee community across a variety of contexts remains unresolved.

While it is apparent that hemp, as a widely expanding, pollen-abundant crop, can provide resources for bees, the bee community visiting hemp has not yet been identified in the northeastern U.S. agricultural landscape. In this study, we characterize the bee community visiting hemp along a landscape gradient to determine how shift in landscape composition affects hemp's bee community. Furthermore, we investigate the effects of plant height and sampling date on the abundance and species richness of the hemp bee community.

Methods

Study System

Hemp is a dioecious, wind-pollinated crop. It lacks brightly colored flowers, extrafloral nectaries, and sweet aromas, adaptations characteristic of most insect-pollinated crops (Small and Marcus 2002). Male plants grow taller than females and release mass quantities of pollen for several weeks until they senesce. Bees visit male flowers to collect pollen; however, bees do not visit female flowers because they lack floral nectar and, therefore, they do not contribute to hemp pollination.

Data were collected at 11 hemp farms in the summer of 2018 in the Finger Lakes region of New York. This region is characterized by a wide array of agricultural and natural land uses, including dairy, field crop, fruit, and vegetable production as well as deciduous forests, woodlots, and old field pastures. In the Finger Lakes region, industrial hemp is produced for grain, fiber, and cannabidiol (CBD) extraction. Cannabidiol is a nonpsychoactive phytocannabinoid produced by female hemp plants that is used in the manufacturing of Epidiolex, a pure concentrate of CBD used to treat severe forms of Epilepsy, as well as in the herbal supplements industry (Hilderbrand 2018). However, because CBD production only utilizes female plants, all bee sampling was conducted on plots producing hemp for grain and fiber, which offer both male and female plants.

The hemp fields involved in this study varied in size, with the smallest plot being ~317 m^2 (<0.1 acres) and the largest operation cultivating roughly 42,262 m^2 (>11 acres). Hemp cultivars varied across sites, depending upon whether the plot was being cultivated for fiber, grain, or dual-purpose production. Fields generally contained a single variety; however, when multiple varieties were present, they were grown in separate areas and we focused our sampling efforts on the variety with the greatest bee activity. The average height of hemp plants was estimated as tall (≥2 m), medium (1–2 m), or short (≤1 m).

Landscape Analysis

Measures of landscape composition were used to assess the influence of habitat characteristics on the abundance and diversity of bees visiting hemp plots. Using the 2018 National Agricultural Statistics Service Cropland Data Layer for New York State in ArcGIS, we estimated the proportion of land in agricultural uses (row crops, orchards, fruit and vegetable fields) at radii of 500 and 1,000 m. The cover of forests (wooded wetlands, deciduous, coniferous, and mixed forest stands), seminatural habitats (fallow fields, shrublands, hay fields, and wetlands), and urban lands were also quantified at each scale.

Bee Community of Hemp

Bees were netted from the flowers of male plants in 20-min sampling transects through hemp plots and around plot perimeters. Twenty-minute sampling periods were roughly split between transects through the field and walks around plot perimeters, depending on the farm and field layout. Any bee seen landing on or collecting pollen from a male hemp flower was collected. Sampling was focused on areas of the field that had the greatest prevalence of open flowers and accessible pollen. Each of the sites were visited four separate times over the course of the sampling period, amounting to a total of 80 min of sweep-netting per site throughout hemp's flowering period. All sampling were conducted between July 30 and September 15 of 2018.

Dry ice was used to freeze captured bees on site, and collected bees were cleaned and pinned for ease of identification. All pinned bees were identified to the species level using the DiscoverLife.org keys, published revisions (Gibbs 2011, Gibbs et al. 2013), and reference materials maintained in the Cornell University Insect Collection (http://cuic.entomology.cornell.edu/).

Statistical Methods

Total abundance and species richness of wild bees through time was calculated for each sampling site and date across the sampling period. The European honey bee, *Apis mellifera* L. (Hymenoptera: Apidae), is a nonnative, highly managed species and their abundance on hemp is likely to represent local hive density rather than landscape context. Consequently, we evaluated the effects of landscape composition, sampling date, and plant height on honey bees and wild bees separately. Although the common eastern bumble bee, *Bombus impatiens* Cresson (Hymenoptera: Apidae), can also be commercially managed, use of managed colonies in this region is uncommon and we did not observe managed bumble bee colonies at any of our field sites. The effects of variation in landscape composition at each spatial scale on the abundance, and diversity of hemp's bee community were analyzed using generalized linear models with Poisson error structures as implemented in the lme4 package (Bates et al. 2015). Separate models were fit for each land cover type and scale and ranked based on Akaike Information Criterion scores corrected for small sample size (AICc). The effects of plant height and sampling date were included in each model as separate fixed effects. We then used model averaging to calculate estimates and *P*-values across models with a cumulative weight ≥0.95. Post-hoc Tukey tests were used to evaluate whether significance of differences among plant height categories. Additionally, we evaluated the variation in the composition of the community using NMDS based on Gower distances and tested whether community dissimilarity was explained by gradients in land cover variables by permutational multivariate analysis of variance (Oksanen et al. 2018) with 1,000 permutations.

Results

The Bee Community of Hemp

Throughout the sampling period, hemp supported a total of 16 bee species (Table 1) and 355 individuals were captured from the 11 sites over the sampling period. The most abundant species were *A. mellifera*, constituting nearly 60% of all captured individuals, and *B. impatiens*, which constituted nearly 30% of hemp's bee community (Fig. 1).

Effect of Landscape, Plant Height, and Sampling Date

The proportion of agricultural land cover had the strongest effect on the bee community visiting hemp (conditional model-averaged estimate = −0.66, z = 2.779, P = 0.005). Specifically, increased agricultural cover at the 1,000-m scale reduced the average number of wild bees visiting hemp flowers by as much as 76% (Fig. 2a, Supp Table 1 [online only]). Urban cover at the 1,000-m scale was associated with an increase in bee visitation (estimate = 7.41, z = 2.285, P = 0.022); however, the model including urban cover was not different from a model without any land cover variables (ΔAICc = 1.27, Supp Table 1 [online only]). The height of hemp plants also had a strong influence on the abundance of wild bees visiting hemp flowers, with tall plants attracting nearly 17 times the number of visits compared to short plants (estimate = −3.49, z = 4.139, P < 0.005, Fig. 2a, Supp Table 1 [online only]). Additionally, the average number of wild bee visits increased across the sampling period (estimate = 0.46, z = 2.908, P = 0.003, Supp Table 1 [online only], Fig. 2b).

Abundance of *A. mellifera* did not vary with landscape composition (Supp Table 2 [online only]) but, similar to wild bees, increased with plant height (conditional model-averaged estimate = −2.88, z = 2.80, P = 0.005, Supp Table 2 [online only]) and sampling date (estimate = 0.48, z = 2.84, P = 0.004, Supp Table 2 [online only]).

The species richness of hemp visitors was greatest on tall plants (conditional model-averaged estimate = −1.16, z = 2.25, P = 0.023, Fig. 3, Supp Table 3 [online only],) but was not influenced by sampling date (estimate = −0.01, z = 0.102, P = 0.918, Supp Table 3 [online only]). Landscape composition also did not have a significant effect on the bee species richness of hemp flower visitors (Supp Table 3 [online only]). However, both forest cover ($F_{(1,28)}$ = 2.76, P = 0.05) and seminatural habitat cover ($F_{(1,28)}$ = 4.38, P = 0.014) at the 1,000-m scale were associated with variation in community composition (Fig. 4).

Table 1. Species visiting male hemp flowers in New York and counts for each species observed

Species	Count
Apis mellifera	210
Bombus impatiens	105
Lasioglossum hitchensi	11
Augochlora pura	5
Xylocopa virginica	4
Lasioglossum ephialtum	4
Lasioglossum spp. (male)	3
Lasioglossum zonulum	2
Lasioglossum paradmirandum	2
Lasioglossum zephyrum	2
Halictus confusus	1
Lasioglossum imitatum	1
Lasioglossum laevissimum	1
Lasioglossum planatum	1
Lasioglossum versatum	1
Lasioglossum oblongum	1
Lasioglossum perpunctatum	1

Discussion

Crops serve as critical resources for pollinators in agricultural landscapes (Westphal et al. 2003, Le Feon et al. 2010). Hemp, a newly introduced and rapidly expanding crop in U.S. agricultural landscapes, offers an abundance of pollen resources to bees during a period of floral resource scarcity in agricultural landscapes (Dalio 2012). In this study, we sought to identify the bee community visiting hemp and to analyze the effects of landscape composition on bee visitation to hemp. Hemp supported a total of 16 different social species of bee pollinators. We found a negative impact of agricultural cover on the abundance of wild bees visiting hemp. The average number of bees visiting hemp flowers increased across the sampling period and both the abundance and diversity of the bee community visiting hemp increased with plant height.

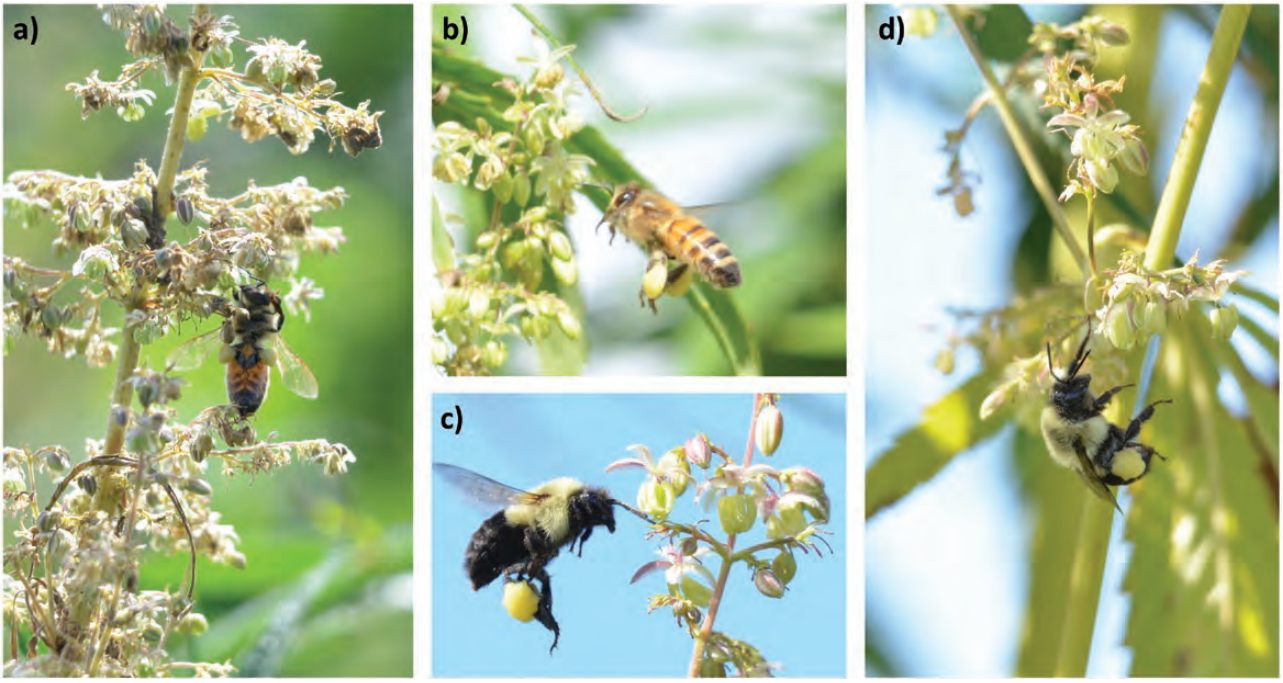

Fig. 1. Honey bees, *Apis mellifera* (a and b) and bumble bees, *Bombus impatiens* (c and d) collecting pollen from male hemp flowers.

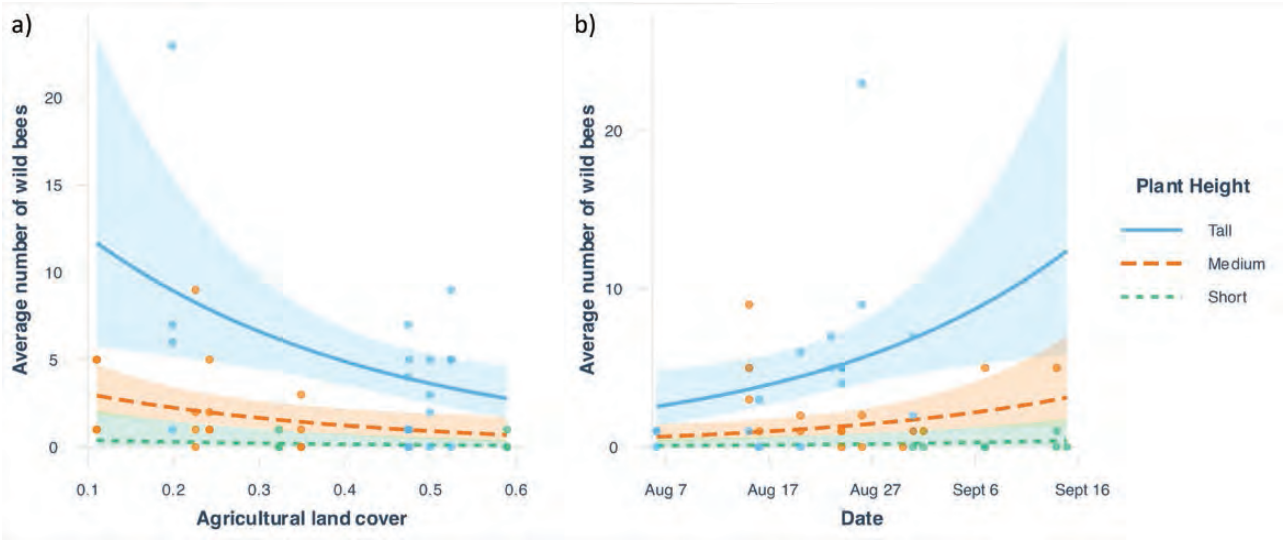

Fig. 2. The average number of wild bees visiting hemp flowers varies depending on a) plant height, the proportion of agricultural land cover at 1,000 m surrounding the field and b) the sampling date.

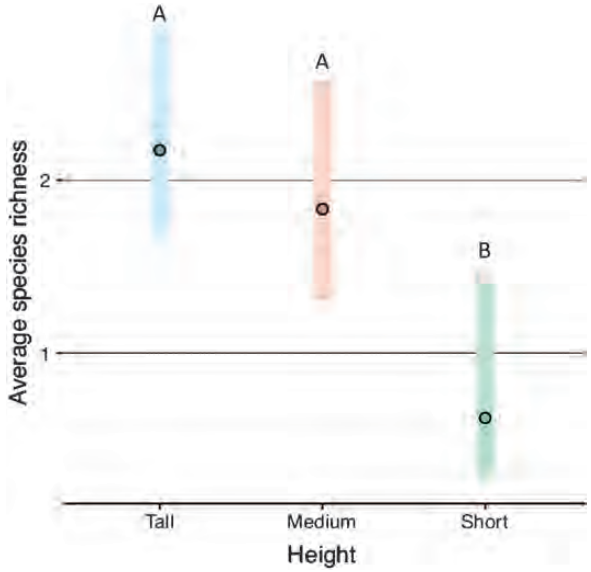

Fig. 3. The average species richness of bees sampled from hemp varied with plant height. Letter values indicate significant differences ($P < 0.05$) based on post hoc contrasts with a Tukey correction.

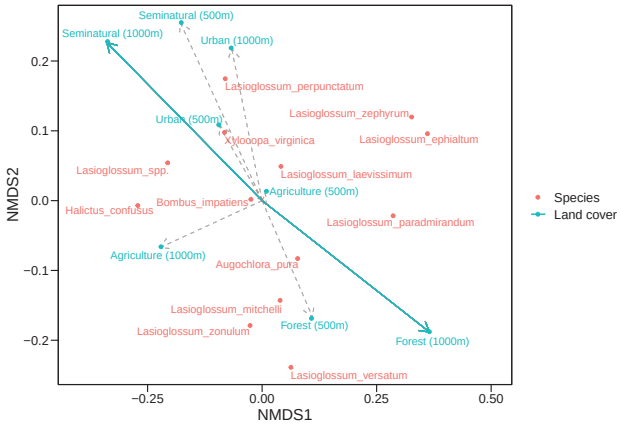

Fig. 4. Ordination plot showing the position of hemp visiting species (points) relative to the vectors of environmental variables (lines). Solid lines indicate that the environmental variable was significantly associated with variation in the community.

Hemp provided pollen resources to important pollinators in the NYS agricultural landscape. Overall, the community was not dissimilar to prior work describing hemp visitors in northern Mississippi (Lago and Stanford 1989), which reported primarily *A. mellifera*, *B. impatiens*, and *Lasioglossum (Dialictus)* spp. (Hymenoptera: Halictidae) but did contrast with recent work in Colorado (O'Brien and Arathi 2019) which found a large number of *Melissodes bimaculata* Lepeletier (Hymenoptera: Apidae) and the cucurbit specialist, *Eucera (Peponapis) pruinosa* Say (Hymenoptera: Apidae). In New York, nearly 60% of hemp's bee community was represented by *A. mellifera*, which may be considered the most important and widely relied-upon species for agricultural pollination services in the United States (Morse and Calderone 2000). Nearly, 30% of the visitors captured on hemp were *B. impatiens*, a generalist pollinator that, like *A. mellifera*, is intensively relied upon in wild and managed contexts for agricultural pollination services (Kleijn et al. 2015). Hemp also supported a diverse community of nonmanaged bee pollinators. Wild pollinators enhance the effectiveness of pollination services through functional complementarity with managed species (Chagnon et al. 1993, Hoehn et al. 2008, Frund et al. 2013) and have become increasingly important in buffering the impacts of widespread declines in managed *A. mellifera* populations on agricultural pollination services (Kremen et al. 2007, Garibaldi et al. 2011, Brittain et al. 2013). As a late-season crop that blooms during a critical period of floral resource scarcity in agricultural landscapes, hemp may facilitate pollination services for crops in the following year by filling periods of late-season resource scarcity (Waser and Real 1979, Moeller 2004, Riedinger et al. 2014, Grab et al. 2017) and reducing the spatial and temporal variation in floral resources in agricultural landscapes (Schellhorn et al. 2015).

The height of hemp plants provided a strong indicator for both the diversity and abundance of hemp's bee community. In addition to potentially providing a greater overall amount of pollen, tall plants are more apparent than shorter varieties, which may explain why they attracted a more abundant and species rich community of pollinators (Russo and Shea 2017). The abundance of bees visiting

hemp plants also increased throughout the sampling period, which may reflect the increasing importance of hemp as a pollen-forage resource as the flowers of other late-season crops senesce at the end of the summer. Hemp varieties that are taller and later flowering varieties may therefore better support the pollinator communities of other crops in the agroecosystem.

At the landscape level, hemp plantings located at sites with moderate agricultural cover are also likely to support a more abundant population of crop pollinators, as we found that the number of wild bees visiting hemp declined as the proportion of agricultural cover in the landscape increased. Landscape simplification has been shown to restrict the availability of foraging and nesting resources for pollinators in agricultural landscapes through reduced diversity of floral resources and seasonal periods of resource scarcity (Di Pasquale et al. 2016), which imposes nutritional stress on bee populations (Naug 2009). Our findings confirm the negative impacts of agricultural land use change on the abundance of wild bees visiting crop flowers. Because high agricultural land cover negatively impacts the abundance of hemp's bee community, hemp may provide a more effective resource for bees in more complex landscapes, where it is utilized by a greater number of bees. However, the average number of species utilizing hemp did not vary with landscape context suggesting that hemp will support a broad array of crop pollinators across a range of landscape contexts. We observed shifts in community composition that were driven mainly by differences in forest and seminatural habitat cover. These patterns are likely due to the availability of suitable nesting habitat as species like *Augochlora pura* Say (Hymenoptera: Halictidae), which nest in rotting logs (Stockhammer 1966), were associated with forest cover and species like *Xylocopa virginica* L. (Hymenoptera: Apidae), which often nest in man-made wooden structures (Gerling and Hermann 1978), were associated with urban cover. These findings suggest that hemp will support a different suite of species in landscapes with more open natural habitats, such as meadows and shrublands, compared with landscapes with greater forested cover, reflecting variation in habitat requirements, and life cycle characteristics of different bee species.

An important consideration that should be addressed in future research is the relative value of hemp pollen in supporting bee reproduction. Mass flowering crops can support pollinator populations (Westphal et al. 2003, Jauker et al. 2012), but the incorporation of novel pollens into the diets of generalist bees has been shown to have detrimental effects on larval development (Williams 2003). The presence of cannabinoids, particularly tetrahydrocannabinol (THC), in hemp pollen (York et al. 1975) is not likely to have an impact on bee development due to the loss of cannabinoid receptors in insects (McPartland et al. 2001).

Conclusion

Hemp is a high pollen producing crop flowering during a period of floral resource scarcity and supports a diverse array of bees in the northeastern U.S. landscape. The rapid expansion of hemp production in the United States (Schluttenhofer and Yuan 2017) may have significant implications for agroecosystem-wide pollination dynamics. The potential for hemp to serve as a floral resource for bees is influenced by landscape composition, the height of hemp plants, and temporal factors. Growers, extension agents and policy makers should consider risks to bees as pest management practices are developed for this crop (Cranshaw et al. 2019). As a late-season crop flowering during a period of seasonal floral dearth, hemp may have a particularly strong potential to enhance pollinator populations and subsequent pollination services for crops in the following year by filling gaps in late-season resource scarcity.

Supplementary Data

Supplementary data are available at *Environmental Entomology* online.

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