CHICAGO BEES: GREEN ROOFS, PARKS, AND PRAIRIES

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Project Summary

The native tallgrass prairie that covered most of Illinois is one of the most threatened ecosystems worldwide; less than 1% of it remains. Much of this native bee habitat has been lost to agriculture and development, although portions of it have been transformed into other forms of green space, such as fields, lawns, and parks.

In human dominated environments, potential wild bee habitats need to be investigated to determine if native bees are able to utilize anthropogenically-altered green space. This has already been proven successful in agricultural zones of the northeast (Winfree, 2007), and in New York City gardens (Matteson et al., 2008). This study will expand upon investigations of urban landscape to include rooftop gardens, and green roofs in and around the Chicago region, and compare urban bee communities to those at restored prairies.

The objective of this study was to compare bee communities at urban sites and native habitat sites via pollinator observations, and two collection methods. All were implemented for one field season, between June and October, 2008. A total of 18 sites representing two types of urban green space, and a baseline native habitat setting as a control were surveyed.

Six green roofs, six city parks, and six restored prairies were surveyed for one season in 2008 to determine the bee communities at each site, and within each site type. Urban sites (green roofs and city parks) are compared to expected bee communities of restored prairies, and the historic survey of J.F.W. Pearson from 1933 in the Chicago area.

This study included pollinator observations at two bee-pollinated flowering plants, with different floral morphologies: a *Penstemon sp*. and a member of Asteraceae. This is an expansion of typical bee surveys, since observational data of pollinator services was provided for all sites. Active net sampling and passive collecting with pan traps were used to collect voucher specimens for pollinators, and to compare the actual to the entire potential pollinating communities within each site.

All bees were identified to species level. Voucher specimens are housed at the Chicago Botanic Garden, and duplicate specimens will be shared with Illinois Natural History Survey, and The American Museum of Natural History.

It was hypothesized that urban sites, green roofs and parks, would have more cavity dwelling species of bees compared to the baseline habitat prairie sites and compared to the historic survey. It was also expected that a greater proportion of bees in urban habitat types would be exotic compared to the modern native habitat and the historic survey.

Overall, 80% of the 68 bee species collected were native to the region. The greatest abundance and species richness levels were found at prairie sites, followed by city parks, and green roofs. There was a greater percentage of soil dwelling compared to cavity dwelling bee species in urban sites, however this proportion was lower than that of the baseline native habitat, or the historic study.

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Introduction

It is a frequently cited statistic that in Illinois, less than 1/10 of 1% of native tallgrass prairie remains (Chicago Region Biodiversity Council, 1999). This degree of habitat destruction and fragmentation has been detrimental to many native prairie flora and fauna. For example, in Illinois nearly one quarter of native insects are restricted to prairie remnants, including some native bees (Panzer et al., 1995). However many native bee species are also are able to persist, and even thrive, in portions of fragmented habitat (Panzer et al., 1995) and are potentially doing so within urban areas as well.

Increased habitat fragmentation often coincides with an increase in urbanization or development. Development includes any alteration of native habitat for anthropogenic use, such as farming, or creation of parks and trails. Often, in highly developed urban areas, the only green spaces left are parks and gardens. Urban green spaces are usually drastically different type of habitat than the native precursor to development (McFrederick & LeBuhn, 2006). In urban situations, ruderal areas of cities can contribute to urban ecosystem quality, serving as refugia for threatened species, dispersal centers, habitat corridors or stepping-stones, and even green islands (Saure, 1996).

For any bee species a minimal habitat includes rewarding patches of floral resources, which bloom at different periods, and suitable nesting sites within flight range of those resources (see appendix 1a.). Urban landscapes may provide fragments of suitable habitat, each utilized in potentially different ways. It is important to investigate potential native bee habitats in human dominated environments to determine the extent to which native bees are able to utilize anthropogenically-altered green space.

Studies to date are site specific, such as native bees of Tucson, Arizona (Cane et al., 2006), Vancouver, British Columbia (Tommasi et al., 2004), central Japan (Hisamatus and Yamane, 2006) and New York City community gardens (Matteson et al., 2008), with a San Francisco survey also focusing on one taxon, the genus *Bombus* (bumble bees) (McFrederick & LeBuhn, 2006), Chicago is a distinct, Midwestern, North American metropolis which does not have current literature regarding the status of its native bees. Although surrounded by agricultural fields, the greater Chicago area is home to many natural area preserves, and an extensive park system, thanks in large part to Chicago Wilderness, and the Burnham Plan (see appendix 1b).

Beyond the protected and restored fragments of natural landscape around the city, as well as the natural areas within Chicago city parks, Chicago is the leading city nationwide (see appendix 1c.) to provide the unique habitat of green roofs in urbanized areas. These two types of urban green space: green roofs and city parks, will be compared to each other, as well as the surrounding native baseline sites. This study is the first of its kind to incorporate a large-scale investigation of the bee fauna present on green roofs in North America. Previous site-specific studies have reported insect presence on rooftops, with bees identified only to the taxon level of family (Coffman and Davis, 2005).

It is only recently that green roofs have been studied as potential ecological systems, and considered to augment urban green space. There are two main types of green roofs, also called ecoroofs or rooftop gardens, which are currently being installed. In general, when the term rooftop garden is used, people are allowed access to the roof, and there may be paths or picnic tables also interspersed in the design. Green roofs typically describe rooftops that are not meant for people to access regularly, and may be on a slope. The term ecoroof may apply to either a green roof or a rooftop garden.

There are to main types of ecoroofs, termed intensive or extensive, which describe the type of flora installed, and the soil depth. Intensive roofs have deeper soil substrate layers, may have trees or larger plants installed, and require more maintenance. This style is more apt to represent rooftop gardens which allow people regular access to the site. Extensive roofs require less maintenance, and have a more shallow soil substrate layer. They are usually only accessed for maintenance purposes, and typically have a drought tolerant groundcover, such as *Sedum* spp. as the main, and sometimes only, plant type. There are also semi-intensive green roofs, which may or may not allow public access, with soil depths, and plant cover types representing an intermediate stage between intensive and extensive green roofs.

All reported studies on green roof systems to date, have determined both insects and wild birds are utilizing the green space provided by the rooftop. Insects and spiders were surveyed in England and Switzerland, but mainly on extensive roof systems, with both invertebrate groups present on the green roofs (Brenneisen, 2003; Jones, 2002; Kadas, 2002).

All of these studies have demonstrated the presence of rare insects, regardless of system structure. Spider and beetle studies show significant differences in diversity across ecoroofs, while a general invertebrate community study did not.

Williams et al. (2001) calls for such a native habitat setting control to account for natural variation in urban, or fragmented site bee studies, as opposed to the impact of interest. For example, an urban study may report low bee diversity, or greater exotic bees, yet the natural areas surrounding the urban center may also have a similar bee community. This would prevent the low diversity, or high proportion of exotic species to be attributed to the "urbanness" of the site.

In the same vein, historic studies were also used as baseline data, as bee communities at restored prairies may be drastically different from those of the past. Records from this study will be compared to faunal bee surveys from the late 1920's and early 1930's completed in and around Chicago by Jay Frederick Wesley Pearson, in his Ph.D. dissertation for the University of Chicago (Pearson, 1933). Pearson visited multiple sites in and around Chicago in an attempt to familiarize himself with bee species present, as well as understand their relationship with local plant communities.

Results from this project will be presented in the context of assessing native bee communities within urban centers, and more specifically the importance of green space within urban matrix as habitats for native bee species of Illinois. In addition this study will track adventive and exotic bee species movement with urban bee surveys.

Objectives

The objective of this study was to compare bee communities at urban sites and native habitat sites via pollinator observations, and two collection methods. All were implemented for one field season, between June and October, 2008. A total of 18 sites representing two types of urban green space, and a baseline native habitat setting as a control were surveyed. Bee species and abundance data at urban sites will be compared to historic \ and modern natural habitat bee communities to evaluate the similarities and differences between bee communities. It is hypothesized that urban habitats, green roofs and parks, will have more cavity dwelling species of bees compared to the baseline habitat prairie sites and compared to the historic survey. It is also expected that a greater proportion of bees in urban habitat types will be exotic compared to the modern native habitat and the historic survey.

Methods

Site descriptions

Bees were observed and collected at 18 sites in and around the Chicago Wilderness area in Illinois. The18 sites were divided into six replicates of three habitat types: green roofs, city parks, and restored prairies. (Figure 1, Table I).

All sites had at least one species of *Penstemon*, and or one member of the Asteraceae family was flowering during observation and collection periods. Some green roofs did not have one of the required plant species; in these cases the desired species were purchased or donated by Intrinsic Landscaping, then planted or placed at the site for the observation and collection days. At green roof sites without any *Penstemon* spp., there were other species of flowering plants available to bees.

Green roofs

All green roofs were established by 2007, and the oldest has been planted for over 5 years. Floor location of green roofs ranged from the second to 15th story. The Notebaert Nature Museum rooftop had both required plant species. The Tyner Interpretive Center at Air Station Prairie and the Kersten Physics Building at the University of Chicago had a member of the Asteraceae family, but no *Penstemon* spp. At the Optima Views

Condominium building in Evanston, and at all remaining sites, except the CTA and the Joffrey Building, potted plants were plugged in before the first observation, and remained for all observation days. At the two remaining rooftop sites planting was prohibited, and potted plants were used for observations.

These sites are all managed by Intrinsic Landscaping of Glenview, IL. Periodic maintenance throughout the growing season includes weeding, and removal of dry, dead plant material. The Kersten Physics building at the University of Chicago, and the Notebaert Nature Museum rooftops are both irrigated, and have plants representative of a native prairie (Figure 2).

Parks

All but two of the parks included in this study were established by 1920. The remaining parks were completed in the 1980's, and 90's, although The Lurie Garden was not planted within the existing Millennium Park until 2007.

The parks chosen for the study extend throughout the Chicago Metropolitan area and had both required plant types. Four of the Chicago City Parks included in this study had a portion of natural area maintained by the Chicago Park District; maintenance includes removal of invasive plants, and annual burning. The remaining two: Garfield Park Conservatory and The Lurie Garden at Millennium Park had native plantings but no natural areas.

Prairies

The restored prairies are maintained parcels of land that may or may not have been previously developed or farmed. If never developed, the date of management establishment is listed for the site. As all potential prairie sites had at least one species of Asteraceae, sites were chosen based on presence of *Penstemon digitalis*, and proximity to Chicago.

Paired Sites

The Notebaert Nature Museum has a green roof, and is located within Lincoln Park proper. Observations and collections were completed on the same six days at these two sites. The second story roof of the Tyner Interpretive Center and the surrounding Air Station Prairie were both used as sites as well, observations and collections were made on the same days.

Site characterization

Spatial analysis

Percent green space in a 500m radius around each site was determined using ArcMap (ArcGIS version 9.2, 2006 ESRI) Geographic Information Systems (GIS) software program. Images were acquired in Google Earth (Version 4.3, 2008), and transformed into the map. A 500m radius was drawn around the center of the observation site using ArcMap, and polygons were drawn around each landscape border. Landscape categories included: urban, suburban, green space, and water. Suburban was designated it's own category as it provides a significant suitable habitat for native bees, however lawns and yards differ from typical open green space due to the intense garden plantings, as well as frequent mowing and mulching (Fetridge et al., 2008).

Pollinator observations

Pollinator identification categories

For pollinator observations, bees visiting the forbs of interest were recorded using identification categories. Field ID included genus level identification of *Apis* (honeybees), *Xylocopa* (carpenter bees), and *Bombus* (bumble bees), as all three genera are easy to identify "on the wing" based on their size and color. Other bees were identified based on size and color categories (Table II, Figure 3).

Observation periods

Upon arriving at a site, the observer would designate an area containing the focal plant species to use for the first observation period. The observer counted the number of open flowers to be simultaneously observed. Often the designated group included flowers of neighboring plants of the same species. Flowers not at peak bloom were avoided. Observers did not include flowers that were not easy to see into or around as small bees that entered or landed would not be seen.

On each observation day, four 15-minute observation periods were completed at 0900, 1030, 1200 and 1330. There were six observation days at each site, three observing *Penstemon* spp., and three observing a member of the Asteraceae family. During each observation period, the observer remained motionless within 1m of the plant, or group of plants being watched. The observer recorded each bee that visited the designated flowers, and counted the number of flowers or heads visited until the bee left the observer's field of vision. If a bee landed on a flower not previously designated as one to be observed, the visit was not recorded. Four observers performed over 2,500 minutes of pollinator observations between June and October of 2008 for this study.

Weather data collection

At the end of each observation period, observers recorded weather data. Specifically, temperature in the shade and a 30 second mean wind speed with a digital anemometer. Sky condition was also recorded as one of three options: clear, partly cloudy, or overcast. Observations were not performed on rainy days. If a light drizzle began, and lasted more than 15 minutes, the rest of the observations were cancelled. Data from rain out days was not used in any analysis. All rain out days were rescheduled.

Observations were not performed if the temperature was below 20°C, or if the average wind speed exceeded 6.0 m/s. The majority of bee species are known to be most active during hot, sunny days. Many take cover under flowers or leaves, or return to their nests during rain, so rainy and/or cold days were not included in the study (T. Griswold, *pers*. *comm*.).

Floral density and diversity estimates

Each site was characterized by the bloom density of the focal plant species, as well as diversity and density of other flowering species within the vicinity of each designated observation area. Bloom density of the focal plant species, was measured as the number of open blooms within ¼ m^2, centered in the patch of observed flowers. Floral diversity and density were recorded as the number of blooming plants within a 5m radius around the focal plant/s measured using four equally spaced 5m-transects radiating out from the central focal plant. The observer recorded the total number of flowers or heads of all blooming plants that fell directly under the tape, as well as their species. Non-flowering plants and grasses were not recorded. Each of the recorded flowering species was categorized into a floral type based on bloom color and morphology. These floral morph types were used in lieu of species comparisons between sites due to the vast number of species across all sites, and the frequent occurrence of one blooming species occurring at only one site on one of the observation days.

Pollinator collection

Aerial net collection

At each site, active collection of pollinators was conducted twice in the season; the first collection was early in the season after a *Penstemon sp* observation and then again later in the season after an Asteraceae sp observation. Pollinators were collected using nets after the last observation period, the observer net collected all pollinators that landed on the focal plant for a total of 15 collection minutes; which does not exclude the time taken to transfer pollinators into the kill jar. Collection minutes were used to help minimize the effect of different collection abilities. The collector was not limited to the focal flowers from the observation period to collect from, but stayed within a 5m radius of the observation site. Collected bees were stored in a freezer until pinned.

Pan trap collection

Bee Bowls (pan traps) were set out twice at each site. As opposed to typical pan traps, used to sample insects, Bee Bowls are used to best sample the native bee community. Bee Bowls were constructed using the USDA Bee Lab protocol. Three oz. Solo cups were painted white or UV reflective blue or yellow (Krylon Products Group, Philadelphia, PA) inside and outside. Bowls were filled ½ to ¾ of the way with water and a drop of Dawn® blue dish soap, (Procter & Gamble) to act as a surfactant.

At all sites 15 of the painted bowls, 5 of each color, were placed approximately 5m apart in a grid formation, with colors randomly placed. If a site was too small to allow for this, the 15 bowls were spaced as evenly as possible. The Bee Bowls were left out for 24 – 28 hours after placement. If it rained during the 24-hour period the pan trap collection was repeated on a different day. For nearly all sites, this was completed once after a *Penstemon sp* observation round during the first half of the study, and once after an Asteraceae *sp* observation round during the second half. Due to time restrictions, at Burnham Park and Lyons Woods Forest Preserve, both pan trap collections were completed during the second half of the study.

At parks and prairies, vegetation was typically between 1/2m and 2m tall. In order to keep the bowls at approximate floral height, bowls were mounted on 1m tall wood dowels. Mounted bowls were also placed 5m apart. The Lurie Garden at Millennium Park is the only non-roof site at which mounted bowls were not used. Collected insects were stored in 70% ethanol until pinned.

Insect processing

Washing

Insects were processed using a modified version of the USDA Bee Lab Bee Washing Protocol. They were removed from the freezer or 70% ethanol, placed in a tea strainer, and repeatedly dunked into a beaker containing warm soapy water. Insects were then rinsed until the water ran clear, they were then dipped in 70% ethanol as a final wash. Finally, a standard blow drier on high speed was used to dry the insects before pinning.

Pinning

Bees and wasps were pinned by C. Askham, A. Debo, J. Disch, K. Ellis, B. Siddiqui, and R. Tonietto. All other insects were stored in 70% ethanol.

Bees were later identified to genus by R. Tonietto using "The Bees of North and Central America" (Michener, McGinley, and Danfourth, 1994), and www.discoverlife.org. The majority of species level identifications were completed by John S. Ascher at the American Museum of Natural History, with remaining *Lasioglossum* males determined by Sam Droege at the USDA Bee Lab in MD, and females by Jason Gibbs at York University, Toronto, ONT.

Measurements

After pinning, each bee was measured from tip of the head to the tip of the abdomen to the nearest half mm. Pinned bees were then visually assigned ID codes using the categories previously used in the field by three observers. This allowed us to categorize pinned bee genera to each bee identification category used in the field as well as provide an accurate size measurement.

Statistics

Data was analyzed in R version 2.8.1 (The R Foundation for Statistical Computing. 2008) unless otherwise noted.

Analysis of site characteristics

Site and date of establishment, as well as surrounding green space and local floral diversity and density measurements were analyzed using Wilcoxan rank sum test with continuity correction for all comparisons in this portion, as variances were not normal. Correlations between landscape scale environmental factors with site age and site type were completed with Spearman's rank correlation rho, as variance in the data was not normal.

Analysis of pollinator observations

Observation data was assigned a Poisson distribution, as many observation periods throughout the study experienced zero bee visitors. Then, an ANOVA comparison of generalized linear models (glm) was used to determine the significant associates with one of the two response variables; the number of bees per observation period, or the number of flowers visited by bees per observation period. The models were run using backward elimination, and the most saturated model included the following independent variables: a categorical habitat type (green roof, park, or prairie), the density of focal flowers in ¼ m^2, a measure of bloom density within a 5m radius of the observation site, as well as the number of blooming species within the same 5m radius.

Two potential predictors were dropped prior to running the glm's, as they were significantly correlated with other predictors. The percent green space within a 500m radius of each site was significantly correlated with site type, and the number of flowers observed was significantly correlated to the focal floral density within ¼ m^2.

Ordinations

Ordinations were used to detect differences in the blooming plant, and bee communities based on site and site type. Nonmetric Multidimensional Scaling (NMS) was used for this analysis as it does not require normalcy in the data, nor does it make assumptions between the morpho-species or species data and site environmental data. Species or morpho-types that did not occur in 5% of sites were removed as recommended by McCune and Grace (2002). Wisconsin relativization was employed as a transformation when deemed necessary by a high coefficient of relativization > 90% (McCune and Grace, 2008). NMS ordination analyses were conducted in R using 100 permutations, as denoted by the statistical program to sufficiently explain the ordination.

Cluster analysis

A cluster analysis was used to compare the species presence of bees and plants across all sites respectively. Agglomeration, or grouping of objects or groups, is a common type of cluster analysis in ecology since it's first use in 1967, specifically when derived from multivariate data (McCune and Grace, 2002). Clustering is based on a dissimilarity matrix, with most similar groups placed together, or closer together, on a distance measure, in this instance Euclidean metrics. The analysis is hierarchical, with few large groups containing multiple smaller groups, each becoming more similar, or less dissimilar with each branch. Cluster analysis was completed using R statistical software.

Similarity Percentage (SIMPER)

A similarity percentage (SIMPER) analysis was completed in PRIMER (Primer 5.2.7, PRIMER-E Ltd) to compare the degree of similarity between species contributions of the three site types, and between specific paired sites of interest. Data were standardized, as a Wisconsin transformation was previously employed for Permanova analysis. Cut off for a low contribution was set at 90%.

Shannon Diversity Index

The Shannon Diversity Index was used to compare the bee species diversity, and evenness, between the three habitat types: green roofs, parks, and prairies. Bee species abundance was calculated within each habitat type as a whole. The products of the natural log of the proportion ($\ln P_i$) of individuals within each species, over the total number of bees collected within the site type (P_i) were added to determine the H value for each habitat type. High values of H represent a more diverse community with more even distribution.

$$H = \sum_{i=1}^{s} - (P_i * \ln P_i)$$

Results

Site Characteristics

Site age, size, and landscape

Site type was significantly correlated with site size (rho = 0.636, $p = < 0.01$), and date of establishment (rho = 0.928, $p = < 0.001$) (Table I, Table III).

Based on a Wilcoxan rank sum test, used to compare means between habitat types with non-normal variation, green roofs were smaller and younger than parks ($p < 0.01$, $p < 0.01$) and prairies ($p < 0.01$, $p < 0.01$). There was not a size difference between prairies and parks (p.0.42), but prairies were older than park sites ($p = 0.01$).

The percentage of green space within a 500m radius of each site was significantly greater around prairies than green roofs ($p = 0.016$). As the percentage of green space has been determined a significant predictor of bee abundance and diversity, this signifies that a more diverse, and larger community of bees would be expected in prairies than in green roofs. There was not a significantly different percentage of green space around green roofs and parks ($p = 0.14$), or around park and prairie sites ($p = 0.06$). However this was in part confounded from the use of paired sites in this study. Once one half of each pair was removed for surrounding green space analysis, each site type had a significantly different percentage of green space in the surrounding landscape (Figure 1, see appendix 2.01).

Floral characteristics

Wilcox tests were used to compare the focal floral density, as well as the surrounding floral density and diversity between habitat types. Compared to parks and prairies, green roofs had significantly lower focal floral density ($p < 0.001$, $p < 0.001$), surrounding bloom density ($p < 0.001$, $p < 0.001$), and surrounding bloom diversity ($p < 0.001$, $p < 0.001$) respectively (Table III).

Parks had significantly denser focal floral displays than prairies ($p = 0.001$), and greater density of blooms in a 5m radius of observation sites ($p < 0.001$). The diversity of blooming plants within the same 5m radius was not significantly different between parks and prairies ($p = 0.09$).

There were no significant correlations between site type and the number of flowers observed ($r^2 = 0.18$), focal floral density ($r^2 = 0.252$), surrounding bloom density ($r^2 = 0.07$), or surrounding bloom diversity ($r^2 = 0.35$). However, the focal floral density was had a significant positive correlation to the number of blooms observed ($r^2 = 0.57$, see appendix 2.02).

Plant floral display morphs by site and site type

The step-down results of nonmetric multidimensional scaling was used in order to compare the floral morph types at each site, as well as between habitat types (Figure 5). This test led to 7 runs, and a stress of 17. None of the potential landscape or local environmental factors were significant vectors in an ordination of plant morphs observed and site, yet total bees observed throughout the season was ($p = 0.02$) (see appendix 2.03).

In a permanova analysis of plant morph types the interaction of site and type was a significant predictor for the floral morphological community ($p < 0.01$, $p < 0.01$). This indicates that there is a different plant community at each site, and within each habitat type during the pollinator observation periods. The floral displays are not the same within habitat type, or between habitat types overall. Site type alone ($p < 0.01$), as well as site alone ($p < 0.01$), were significant predictors of the bloom community. The same significance trends were determined for a permanova analysis of plant species and the interaction of site and type ($p < 0.01$) as well as each factor alone: site ($p < 0.01$), type ($p < 0.01$).

Plant species

A cluster analysis was used in order to access plant species density at each site using Euclidean distance (see appendix 2.05) In this analysis parks and prairies frequently overlapped, and were similar in plant species composition, for example the two most similar sites were Montrose (park) and Midewin (prairie). Green roofs have a specific subset of plant species, and tended to cluster together, with the exception of Notebaert which was intentionally planted as a prairie.

Pollinator observations

Observed blooms on green roofs received fewer bee visitors than those at parks and prairies. Most likely because across all site types, the number of bees that visited blooms per observation period were drastically lower when corrected for the number of blooms observed (Figure 6). For example, although parks had the highest mean visitation rate per observation period, the density of observed floral displays in parks were also the highest. Since the observer was watching more flowers, the odds of seeing more bees increased. In order to correct for this, the number of bees observed was divided by the number of flowers observed, which brought the visitation rate of bees to flowers in parks closer to the rate on green roofs.

Observed bee morphs by site and site type

An ordination was used to determine the bee morph community observed at each site during pollinator observations. The step-down results of nonmetirc multidimensional scaling led to 10 runs, and a stress of 23. This stress level is slightly elevated, which is probably due to the relatively low sample size. The green roof Joffrey was removed from analysis as no bees were observed there.

None of the potential environmental factors (wind, temperature, sky condition) or plant density and diversity, or bee behavioral measures (total bees, total bee visits, bees per flower, or visits per bee) were significant in an ordination of bee morphs observed (Figure 7a).

In a Permanova analysis of bee morph type visitation, the interaction of site and type is a significant predictor for the floral morphological community ($p < 0.01$, $p < 0.01$). When tested alone, only site ($p < 0.01$) was a significant predictor of bee morphs observed. Within each habitat type, site identity is a significant predictor of bee morphs observed: prairies ($p < 0.01$), parks ($p < 0.01$), green roofs ($p < 0.01$). For example, in a comparison of the two sets of paired sites, there was little overlap between Lincoln Park and the Notebaert Nature Museum, nor between Air Station Prairie and the Tyner Interpretive Center (see appendix 2.08).

Pollinator Collection

Survey methods comparison

Overall, there were 48 incidents at sites where bee identification categories representatives were observed visiting focal flowers, and caught in pan traps (Table IV).

An identification category of bees was observed visiting a focal flower, yet not caught in pan traps at that site 39 times. There were 17 occasions when a bee identification group was sampled in the pan traps, yet never seen visiting the focal flowers at a site.

At all sites, if small dark bees were observed visiting focal flowers, they also were caught using pan traps. At three sites, one green roof, one park, and one prairie, small dark bees were the only identification category to be observed and caught in pan traps.

Small metallic green bees were either seen visiting flowers, or collected in pan traps, but at no site were they both observed and collected. Tiny dark bees were observed and collected at only one prairie site, as was *Xylocopa*.

Although observed at many sites, the species *Apis mellifera* was only collected in pan traps in the Lurie Garden. Collectors were instructed to avoid netting honeybees due to their recent population declines.

Species richness

The greatest number of species was collected at a prairie, and the second greatest at a park in Chicago (Table V). Of the 68 total species collected 32% are singletons, only collected once during the summer, regardless of collection method.

Prairies had greater species richness than all other site types, with the exception of one park with 20 species collected (Figure 8, Table V). Green roof sites had the two lowest levels of species richness, one site with zero species, and another with only one.

Based on the Shannon Diversity Index, the prairie habitat type had the greatest species diversity and evenness level (H) of 3.29. Green roofs had the middle H level of 2.54, and parks had the lowest H value of 2.44. When analyzed by site, as opposed to habitat type overall, prairies generally had the higher H levels, followed by parks and green roofs (Figure 9). There was a significant positive correlation ($y = 0.0085x + 1.8278$, $r^2 = 0.69$) between prairie sites diversity indices, and the percentage of green space surrounding each site. A significantly negative correlation was found between percent green space and the diversity indices rankings of park sites ($y = -0.0275 + 2.5514$, $r^2 = 0.72$), and for green roofs ($y = -0.0066x + 1.7246$, $r^2 = 0.69$) as well. Two green roofs were removed from the correlation analysis, CTA Headquarters and the Joffrey Building, as both had Shannon diversity index rankings of 0. CTA due to only one species collected, and at Joffrey no bees were collected.

Native and adventive bees

Over 80% of all bee species collected within each site type were native (Table V, Table VI). Prairies had the greatest percentage of native species collected with 87% (n = 89), green roofs had the second greatest percentage of native species with 80% (n = 25), and 45 native bee species were collected in Chicago city parks, making up 80% of total species collected there. There was a greater percentage of non-native bees at the urban sites compared to the restored prairie sites.

Even though 100% of bees were native at three of the green roof sites: Notebaert, Optima, and University of Chicago's Kersten Physics Building, the fact that none of the bees collected on the rooftop of CTA Headquarters dropped the habitat type average to one percent below that of parks. No park had 100% native bees, but Montrose was the closest with 95% natives, and Garfield Park had the fewest natives, with only 50%. The

Dixon Prairie had 100% native bees in the collection, although non-native honey bees were frequently observed during pollinator observations, and the lowest native percentage of bees was 75% at Lyons Woods.

Nesting types

Over 60% of all bee species collected within each site type were ground nesters (green roofs n = 20, parks n = 40, prairies n = 74, Table VI). There was one species of a clepto-parasitic bee within each site type, each represented by one individual. Within the ground nesters, a vast majority of individuals (over 50%) and species (over 60%) were soil dwelling, as opposed to the ground dwelling bees that nested in hives (mainly *Bombus* spp) (Table VII).

Wood, and pith nesting species were found in parks and prairies, but not on green roofs (Table VII). These represented 3% of species of each site type, and ½% of individuals collected within each habitat type. Soft, or rotting wood nesting species were only collected in prairie sites, making up a little over 3% of species collected, and 1% of individuals. The remaining bees were cavity dwelling species, which made up approximately 30% of species across all habitat types, and range from nearly 30% of individuals collected from green roofs, to only 8% of individuals collected at parks (Table VII).

Comparison to Historic Surveys

Jay Frederick Wesley Pearson (1933) collected 35 of the 68 species collected during this study (Table V, Table VI). However, of those he did not collect, 3 specimens have yet to be identified to species, and reside within genera he collected. Overall, more than 45% of species collected within each site type category were also collected in the historic study in the 1920's and 1930's in and around Chicago. Parks had the most in common with the historic survey with 59% species similarity (n = 34), while 56 species collected in the prairie during this study made up over 50% of the bee species collected in historic surveys of Illinois. Green roofs had the least similar species make-up when compared to historic studies with 47% similarity representing 15 species overall.

In his dissertation, Pearson briefly commented on his methodology (Pearson, 1933). Although Chicago was the primary area of interest, his collection sites also included multiple cities in Illinois: Somonauk, New Lenox, Palos, Lemont, Matteson, Willow Springs, Volo, Zion, and Waukegan, as well as Valparaiso, and Tremont, Indiana. Pearson also noted bees were collected in other scattered localities throughout the region of northeast Illinois, and northwest Indiana.

His collection method was only using an aerial net, and at times, selectively choosing certain bees. At points in the record, relative terms are used to describe the number of males or females of a species that were collected, so the percentages of individuals caught cannot be compared. Also, as the collection methods were not standardized, it may not be suitable to do so. Pearson only employed aerial net collection, and at times was selectively picking bees from floral species of interest. The fact that he did not collect a certain species does not mean it was not present, or that it was inherently rare. His collection results are considered a historical baseline, although not representative of only the city of Chicago, and not necessarily representative of all bees in their correct proportions within the community in the late 1920's and early 1930's.

Bee species collected by site and site type category

The step-down results of nonmetirc multidimenstional scaling led to 9 runs, and a stress of 22, potentially due to large sample size. The green roof Joffrey was removed from analysis as no bees were observed there. None of the potential environmental factors (wind, temperature, sky condition) or plant density and diversity factors were significant in vector determination. However total bees was a significant ($p = 0.02$) directionality in the ordination, leading toward park sites, as well as *Ceratina calcatata*, and *Bombus griseocollis* (Figure 4b).

In a Permanova analysis of bee species abundance the interaction of site and habitat type is a significant predictor for the floral morphological community ($p < 0.01$, $p < 0.01$). When tested alone, only the individual site ($p < 0.01$) was a significant predictor of bee morphs observed, and not the habitat type category of green roof, park, or prairie. The habitat type is also a proxy for site age, size as both were significantly correlated with the categorical habitat type.

In a cluster analysis based on bee species abundance, four of the six prairies group together, even though they are not next to each other (Figure 10). The exception within this cluster is the park Montrose, which has been restored and maintained to represent a "natural area" within the city.

Similarity percentages

Based on bee species collected, prairies had an overall similarity of 21.73%, while parks were lower at 17.99%, and green roofs were the least alike with a similarity of 10.93%.

Parks and green roofs were the most dissimilar (88.75%), followed by prairies and green roofs (85.69%) and prairies and parks (80.65%).

The two paired sites used in this study had dissimilarity ratings over 50% (see appendix 2.09). Although Midewin and Montrose had very similar plant and bee species communities, the dissimilarity percentage was over 77%, illustrating the importance of species abundance, as opposed to diversity when discussing the present community.

Discussion

This study provides first year baseline data for the current status of wild and adventive bees in the Chicago region. Further survey is warranted to allow for the temporal and seasonal fluctuation within bee communities, and species presence and activity.

Overall, older, larger, sites with greater surrounding green space, and with greater plant density and diversity had more abundant and diverse native bee communities. Urban sites did not have greater percentages of cavity dwelling, or non-native bees compared to natural sites as opposed to other urban bee studies (Matteson et al., 2008).

In this study multiple methods were used to survey bee communities. Had only pollinator observations been performed, the greatest level of bee diversity reported for any given site, or site type, would have been nine identification groups based on size and color morph identification categories.

No single sampling method is known to effectively capture the entire bee community at a given site. For example, pan traps cover sample small-bodied bees, especially sweat bees, and miss many taxa all together (T. L. Griswold, *personal* *communication*), while there were multiple instances that one identification category of a bee was collected, but never observed pollinating and vice versa (Table IV).

It's also important to distinguish between species incidence, and species presence, as a reported species absence may reflect a failure to collect a certain species, which may have been overlooked or rare at a site (Marlin and LeBerge, 2001 in Cane, 2001). In addition, many species are only active for distinct portions of the summer. Hence it is paramount for researchers to use multiple survey methods to sample the native bee community at a site, and when possible, to do so throughout the blooming season, over multiple years.

In this study we collected and identified over 68 species of bees within the Chicago region, this is compared to the 163 species a University of Chicago graduate student surveyed in 1933. Over half of the species that he identified, 52% were still present today, and 42% of total species in this study were not collected in the 1930's survey.

The lack of some species does not necessarily imply that they are lost but suggest they are less common. For example, within the genus Bombus alone Pearson collected 12 species of bumblebees: *Bombus affins*, *borealis*, *rufocinctus*, *pennsylvanicus*, *vegans*, *citrais*, and *variabillis* were all collected by Pearson, but not found in this study. Only 5 species of bumblebees were collected in this study, all 5 were found in prairies, 4 of which were also in parks, and only one species, *Bombus impatiens* was collected at least one site of all three habitat types (Table VI). Two of the missing species, *B. citrais* and variables are cuckoo bumblebees, and require a specific host species to also be present.

The absence of *B. affins* is not surprising, as this native species is now very rare in Illinois (Grixti et al., 2009).

Interestingly, compared to urban gardens in New York City (Matteson et al, 2008), Chicago's urban green spaces had higher numbers of native bees and importantly soil dwelling bees, suggesting there is ample nesting habitat. In Chicago, the urban bee community did not represent a distinct subset of bees when compared to surrounding natural areas, as was the case in New York, although the abundance of bees was lower in the urban areas.

Native and adventive bees were present at both types of urban sites, and in the natural areas surrounding the Chicago region. As was the case in other North American faunistic bee surveys, exotic bees, when present, did not dominate (Cane, 2005) The appearance of *Hylaeus hyalinatus* in the Chicago area is interesting, although not surprising. In 2007, *H. Hyalinatus* made up over half of specimens collected in community gardens of New York City. This European bee has also been collected in Pennsylvania, and in Toronto. This record is the first for the species in the Midwestern United States, let alone for Illinois (Tonietto and Ascher, in review). We collected 10 specimens of this species; five from one green roof site, three from Lincoln Park, and two from a prairie located in Lyons Woods.

Two species of *Anthidium* (Hymenoptera: Megachilidae) were also new records; *A. oblongotum* was collected from the same rooftop (19 specimens) and prairie (1 specimen) as *H. hyalinatus*, as well as at Burnham Park (1 specimen). Four specimens of *A. manicatum* were obtained from the grounds of the Garfield Park Conservatory (Tonietto and Ascher, in review).

Other genera of interest include bumble bees (*Bombus*), whose species declines over the past century have been documented in Illinois (Grixti et al., 2009). Hines and Hendrix (2005) determined that around prairie remnants, landscape characteristics within a 500 to 700m radius are useful predictors for bumble bee diversity and abundance, making them a good indicator of habitat quality. Of the sixteen species collected at 56 sites in IL by Grixti et al (2009) in 2007, five were also collected in 2008 in this study. Prairie sites had the greatest amount of green space within a 500m radius, and of the 60 *Bombus* specimens collected, 75% of them were collected from prairies, 23% from city parks, and only 1% from green roofs. Although not collected at all sites, *Bombus* were observed at all park and prairie sites, as well as 50% of the green roof sites.

Interestingly, Chicago Parks were found to be comparable to prairies for bee diversity. This may not be surprising given that like many natural areas and restored prairies within the Chicago region, many city parks included in this study are over a century old. In a large review paper considering over 48 native bee surveys, more bee species were discovered in larger areas with more sampling days, yet neither effect was significant on its own (Williams et al., 2001). Given that many of the prairie and park sites were comparable in area, it is not surprising that they had similar numbers of species. However, based on the Shannon Diversity Index, parks were much more comparable to green roofs, than to prairies. This indicates that although parks may have similar diversity levels to prairie sites, the abundance of each species (i.e. number of individuals) is not nearly as even as in prairie sites.

In more urbanized habitat types, in this study represented by green roofs and parks, the green space surrounding each site in this study was typically maintained lawn.

It is not surprising that at large parks such as Lincoln Park and Humboldt in Chicago, although there is a high percentage of green space surrounding the observation sites, the bee species diversity was low based on the Shannon diversity index. Habitually mowed and mulched lawns do not provide the multiple habitat types that a natural area (such as a prairie) would provide for bees to nest and forage. Of the parks included in this study, the three with the largest percentage of green space all have extensive lawn cover: Lincoln Park, Humboldt Park, and Burnham Park. These three also have the three lowest Shannon diversity index rankings of all parks in this study. The remaining parks: Montrose, The Lurie Garden, and Garfield Park Conservatory, have more diverse plantings in the surrounding 500m due to formal landscaping, or other patches of natural habitat nearby.

Surrounding many of the prairie observation sites is an expanse of prairie or subdivisions, which are able to provide more floral resources for foraging, and more nesting substrates for habitat than mown lawns.

Other factors, which may explain the greater diversity of bees in City parks, is the diversity and density of floral resources. The density of flowering plants was greatest in Chicago city parks compared to restored prairie sites and green roofs. Gardens are frequently planted in specific densities; at one park site, The Lurie Garden, plants are swapped out after flowering for constant bloom displays throughout the season. This would explain the drastic difference in bee visitation rate when accounted for the number of blooms observed, as opposed to simply number of visits. Dense floral displays, like in gardens, attract bees for longer foraging bouts, and may give a heightened value of bee abundance if activity is used as a proxy. Size and density of plant populations are known to affect bee behavior. During an urban bee study in and around Berkeley California, researchers found flowering species diversity, particularly that of native, bee attractive plants, increased bee diversity and abundance (Frankie et al., 2005). Bees stayed longer in more diverse gardens, and even visited plants not typically attractive to bees if they were in the presence of highly attractive, diverse displays.

Montrose Point was more similar to prairies than parks, and paired out with Midewin National Tallgrass Prairie for both plant and bee species abundance in data collected areas. This effect did not carry through to overall bee abundance levels based on observational data and collection counts, but it provides ample support for the management of natural areas within urban centers and their potential to house native bee communities similar to natural baseline levels. In Vancouver, British Columbia, lower bee diversity was found at traditionally managed urban landscapes (conventional flower beds and backyards) compared to natural areas, such as Naturescape parks, undisturbed lots, and community gardens (Tommasi et al., 2004). In the Chicago region, parks with larger natural areas, such as Montrose, may function more as areas of restored prairie within the urban landscape, as opposed to parks in regard to native bee habitat.

It is not surprising that green roofs had the lowest bee diversity as they are both the youngest and smallest sites. In Chicago, green roof installation has been gaining popularity over the past decade but not as established as parks or prairies Of all the green roofs, the only one to have no bees observed or collected was the youngest site: The Joffrey Building. This site had the lowest surrounding floral density, and diversity, and it is predicted that with time, this site will develop to become more like the other green roofs included in this study. There may be a threshold of green roof age, or plant bloom density in order to attract native bees to nest at, or visit the site.

The presence of *Sedum spp.* on green roofs, and not in the parks or prairies, made a large difference in the floral community of each site, and that of the site type overall. In the NMS ordination, the pink and white single flowers that pull the green roof ellipses away from other sites were mainly single *Sedum spp*. flowers. Half of the green roof sites were planted to represent a natural prairie planting, and had plants typically found in the natural areas of the parks.

Complete identification of bees to the species level gives a wealth of information not available if only morpho-species are used as descriptors. For instance, in this study, based on bee morpho-type NMS ordination, the visiting bee communities at green roofs, parks, and prairies saw large overlap, however, when compared to the species level ordination, green roofs have a distinct pollinating community compared to parks and prairies, which overlap.

Conclusions

This study provides first year baseline data for the current status of wild bees in and around the Chicago region. Further survey is warranted to allow for the temporal and seasonal fluctuation within bee communities, and species presence and activity.

Overall, older, larger sites with greater surrounding green space, and with greater plant density and diversity had more abundant and diverse native bee communities. Unlike other urban sites, Chicago parks and green roofs did not have greater percentages of cavity dwelling, or non-native bees compared to natural sites as opposed to other urban bee studies.

Surveys of larger remnant prairies are recommended as a baseline for the smaller restored prairies used as a control for this study. It is possible remnant prairie native bee communities more closely represent historic communities pre-development and urbanization.

In Chicago, in order to provide suitable habitat for wild bees, managers should attempt to provide natural areas within urban green space. The natural areas of some Chicago city parks are home to some bee communities that are as diverse as expected in large plots of restored prairie far from the urban center. Native plantings are recommended for green roofs as opposed to groundcover of *Sedum* spp. Although slightly more maintenance intensive, prairie-like habitat on green roofs is able to house a more diverse wild bee community than sites with a simple monoculture for groundcover. Specifically, CTA Headquarters and the Joffrey Building had the least number of bee species, plant species, and overall bee abundance. Both of which only had Sedum species, and the two focal plants had to be transplanted.

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Tables and Figures.

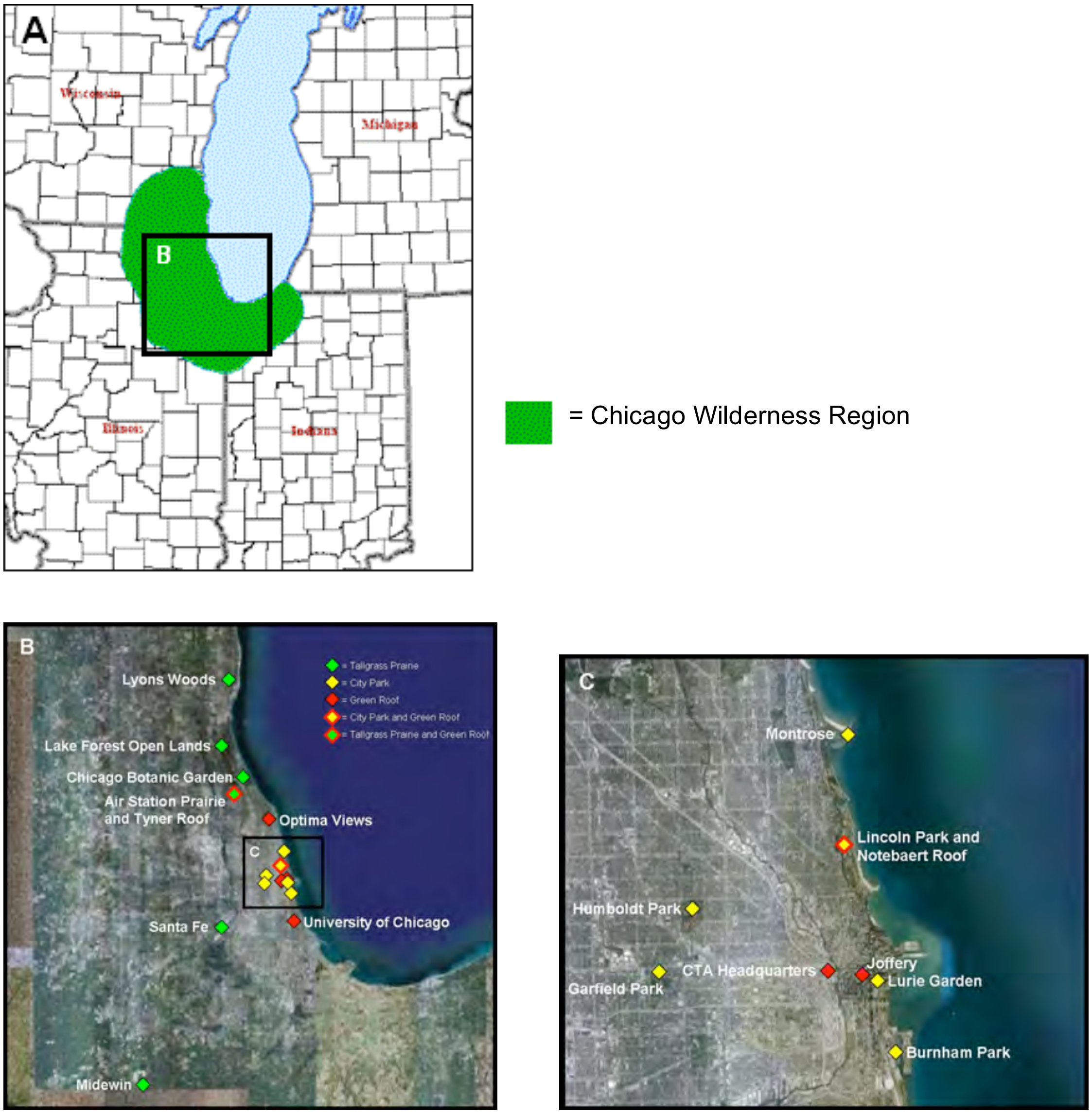


Figure 1 Site map. Three-part scaled maps of the study region. Image A (adapted from Welch, 2004) is an overview of the complete Chicago Wilderness Region, shaded in green, including surrounding state and county boundaries. Image B is a close-up map showing all 18 site locations. Image C is a close-up of the downtown Chicago area. Green diamonds indicate tallgrass prairies, yellow diamonds indicate city parks, and red diamonds indicate green roofs. Diamonds that have more than one color represent multiple study sites at a single location.

Table I. Site information: names, location, age, size and surrounding green space. Sites are grouped by habitat type with latitude and longitude location. The green roof floor is the story on top of which the green roof is located. Establishment dates indicate the day the site was completed, with the exception of prairie sites, in which case the date indicates the management start date. Site size is in acres, and green space percentage was determined within the surrounding 500m radius using Arc Map and Google Earth.

	Sites	Floor	City	County	Size (acres)	Established	Deg. N	Deg. W	% Green space in 500m radius
Green roofs	Tyner Interpretive Center	2	Glencoe	Lake	0.06	August, 2006	42 04'	87 48'	34
	Optima Views Condomimium	4	Evanston	Cook	0.57	June, 2004	42 02'	87 41'	1.1
	Notebaert Nature Museum	2	Chicago	Cook	0.37	October, 2003	41 55'	87 38'	38.2
	CTA Headquarters	15	Chicago	Cook	0.57	May, 2004	41 53'	87 38'	1
	Joffery Building	4	Chicago	Cook	0.11	October, 2007	41 53'	87 37'	4.3
	Kersten Physics Building at UChicago	2	Chicago	Cook	0.03	August, 2006	41 47'	87 36'	19.6
Parks	Montrose Point		Chicago	Cook	15	1980's	41 57'	87 38'	16.3
	Lincoln Park		Chicago	Cook	1,200	1860's	41.55	87.38	38.2
	Humboldt Park		Chicago	Cook	207	1850's	41 54'	87 42'	57.5
	Garfield Park Conservatory		Chicago	Cook	180	1907	41 52'	87 42'	24.6
	The Lurie Garden at Millennium Park		Chicago	Cook	2.5/24.5	2004	41 52'	87 37'	36.5
	Burnham Park		Chicago	Cook	598	1920 - 1930	41 51'	87 36'	31.1
Prairies	Lyons Woods Forest Preserve		Glenview	Lake	272	1976 - 1986*	42 24'	87 50'	80.6
	Lake Forest Openlands West Skokie Prairie		Lake Forest	Lake	30	late 1960's	42 13'	87 51'	68.4
	Chicago Botanic Garden Dixon Prairie		Glencoe	Lake	15	1972	42 08'	87 47'	57.9
	Air Station Prairie		Glencoe	Lake	32	2007	42 04'	87 48'	34
	Santa Fe Prairie		Hodgkins	Cook	11	1886 (1997*)	41 45'	87 51'	35.6
	Midewin National Tallgrass Prairie		Wilmington	Will	15,454	1996*	41 20'	88 08'	94.9

Figure 2. Images of green roof sites in order of establishment date.

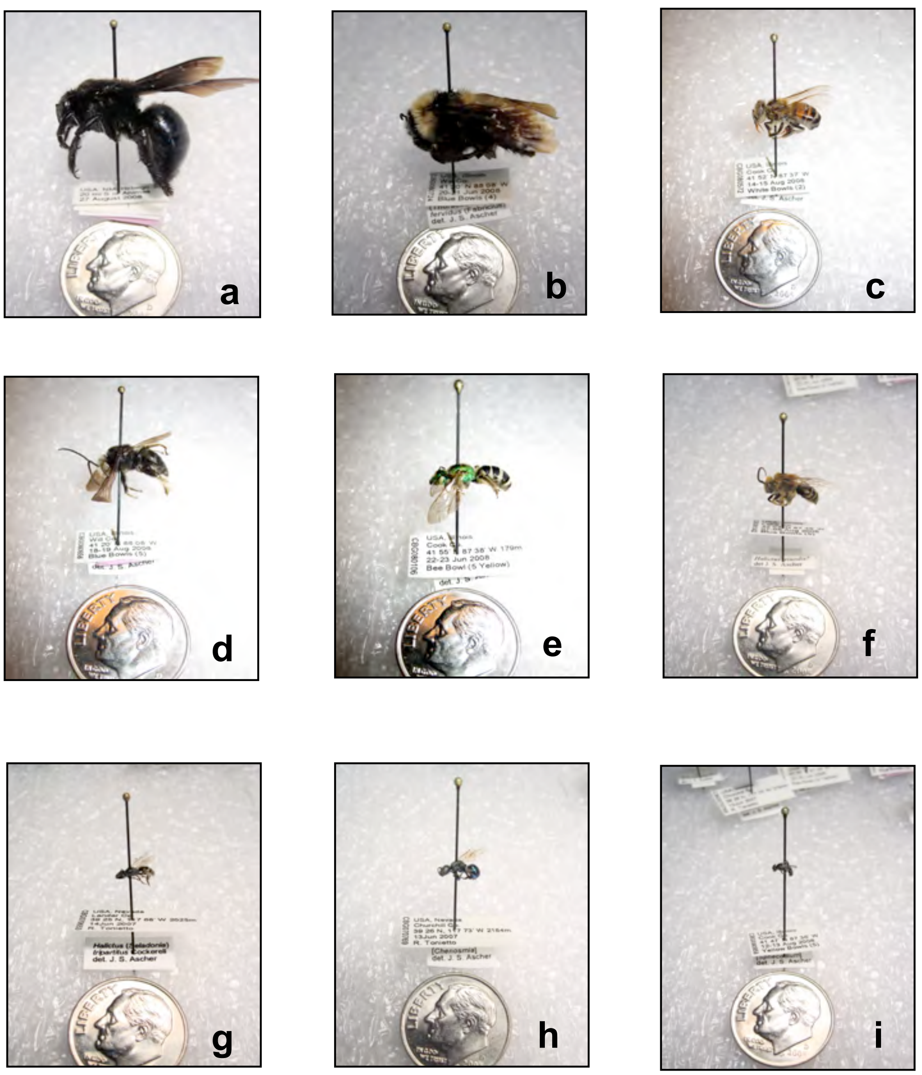
a) Notebaert Nature Museum
b) CTA Headquarters
c) Optima Views
d) Kersten Physics Building at University of Chicago
e) Joffrey Building
f) Tyner Interpretive Center at Air Station Prairie

Identification Category	Length (mm)
Tiny	< 6
Small	6 – 8
Medium	8 – 10
Large	> 10

Table II. Bee identification categories for field observation periods. During observations bees were grouped into categories based on size and color. In the field, size relative to the flowers being observed was used. Sizes in mm are based on voucher specimen measurements to give a quantifiable size range to the qualitative descriptions used in the field.

Figure 3. Images of bee identification code representatives.

a) *Xylocopa sp*
b) *Bombus sp*
c) *Apis mellifera*
d) Large dark
e) Large metallic green
f) Medium dark
g) Small dark
h) Small metallic green
i) Tiny dark



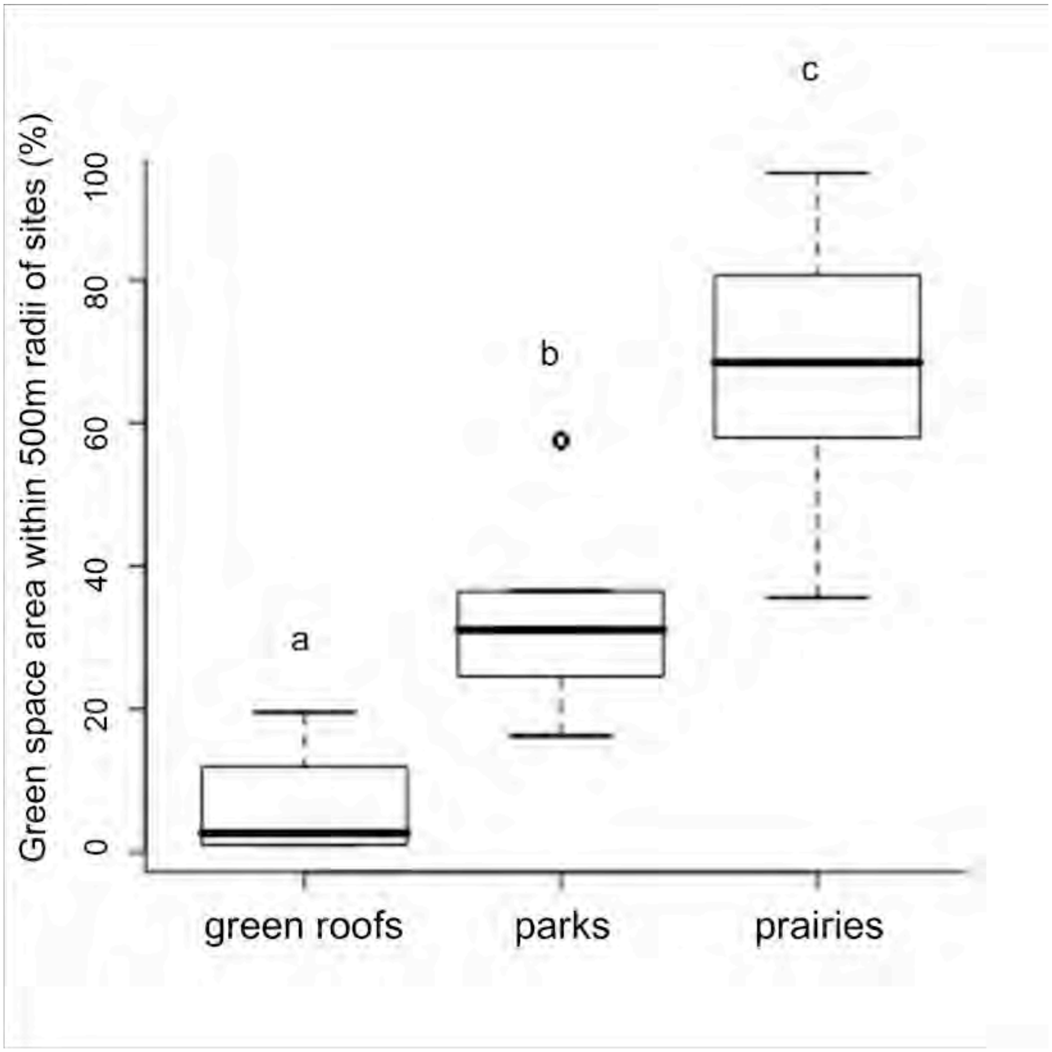


Figure 4. The area of green space within a 500m radius surrounding observation sites grouped by site type. Median, lower 25th, and upper 75th quartiles designated by boxes. Whiskers lead to min and max with points for outliers. Different lowercase letters indicate significance ($p < 0.05$). One half of each paired site (green roof in a park, green roof in a prairie, have been removed)

Table III. Floral and landscape characteristics of observation sites grouped by site type. Means ∓ standard deviation. Bold measurements indicate significance based on Wilcoxan rank sum test with continuity correction ($p < 0.05$).

Characteristics	Green roofs	Parks	Prairies
Flowers observed	**16.76 ± 20.37**	**22.77 ± 12.11**	**26.13 ± 26.22**
Focal floral density	**20.64 ± 27.17**	**50.44 ± 41.42**	**49.49 ± 59.64**
Surrounding bloom density	**15.55 ± 22.23**	**26.71 ± 17.09**	**19.51 ± 24.19**
Surrounding bloom diversity	**4.19 ± 2.34**	7.23 ± 2.82	6.70 ± 2.63
% green space in surrounding 500m radius	**16.37 ± 15.39**	**34.03 ± 12.86**	**61.9 ± 23.31**

Focal flower density is the number of flowers of the observed species within ¼ m^2 of the observation site. Surrounding bloom density is an estimate of bloom cover based on four 5m transects stemming from the observation site. Surrounding bloom diversity is the number of species in bloom within a 5m radius of the observation site

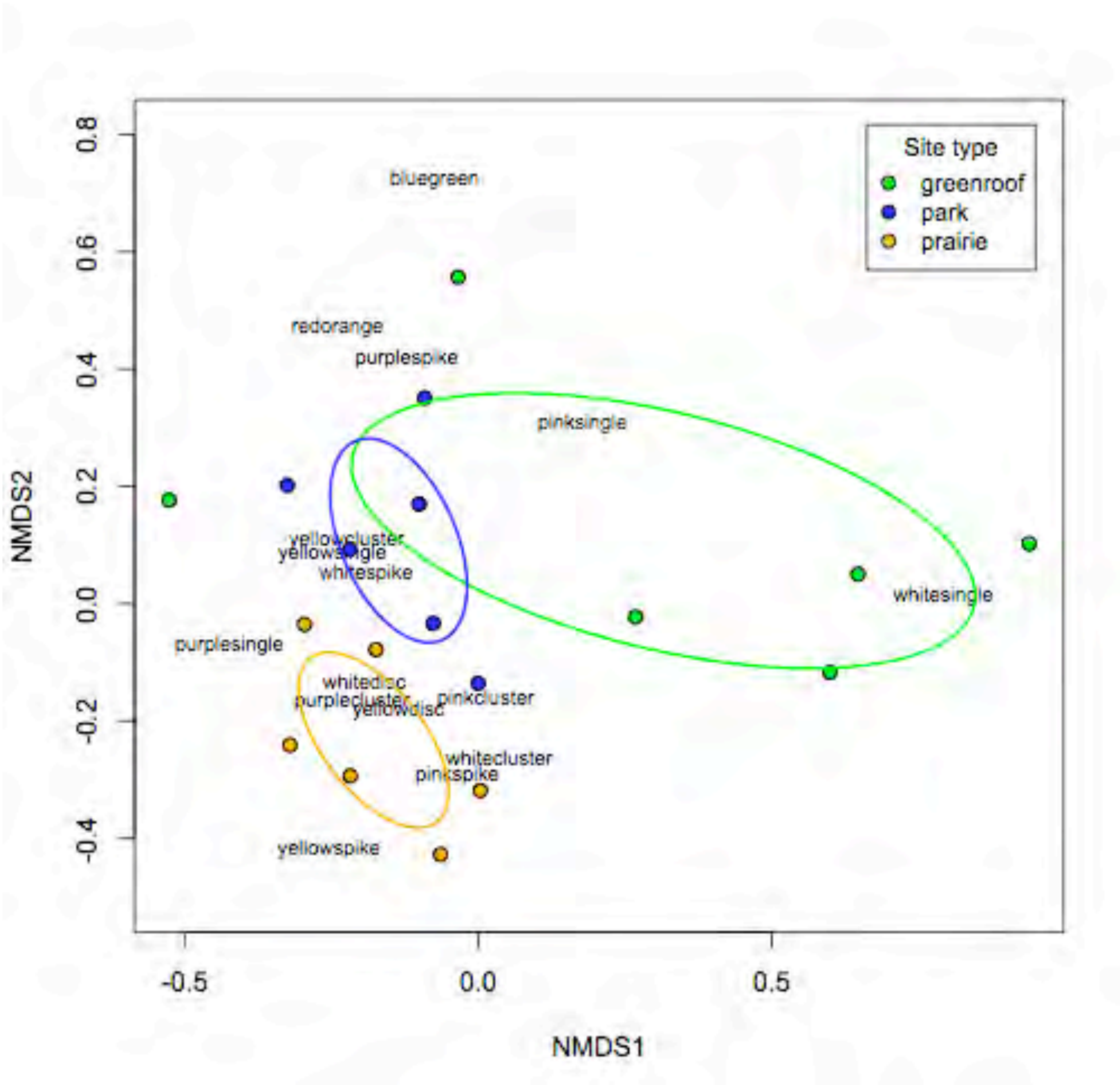


Figure 5. NMS ordination of plant bloom morpho-types by site type. Each point represents one site, green points for green roofs, blue points for parks, and yellow points for prairies. Ellipses represent the habitat type as a whole; color coding is the same as for sites. Floral types are labeled based on color, and morphology. See appendix 2.04 for plant species information.

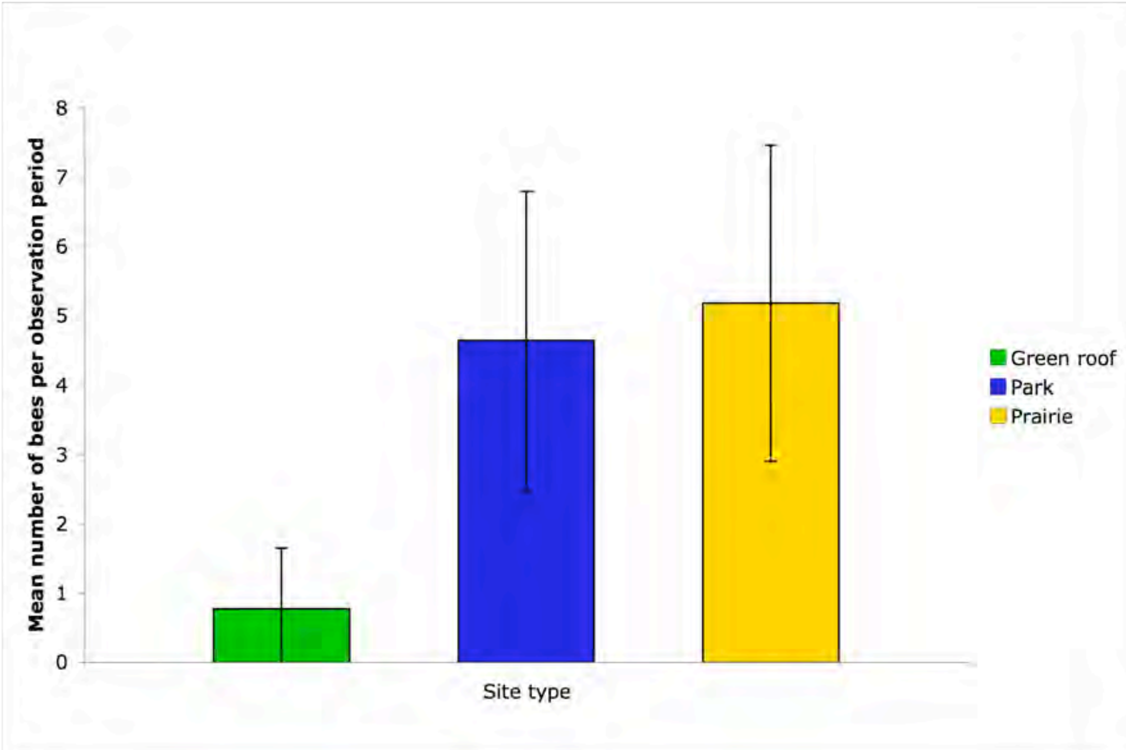
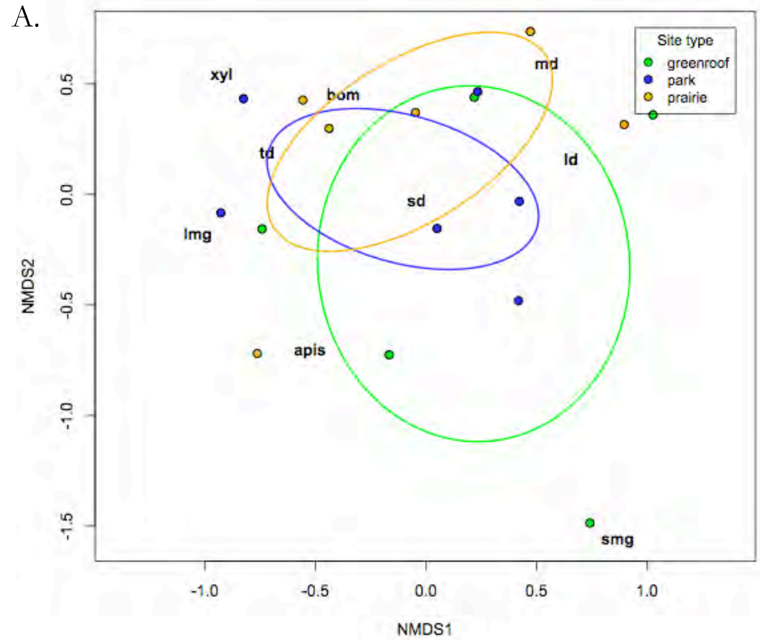


Figure 6. Mean number of bees observed visiting *Penstemon* spp. and Asteraceae flowers per 15 minute observation period. Bee visits were defined as a bee contacting the flowers reproductive parts. Means represent four 15-minute observation periods, over six days between June and October. There are six sites within each habitat type category of green roof, park and prairie.

A.



B.

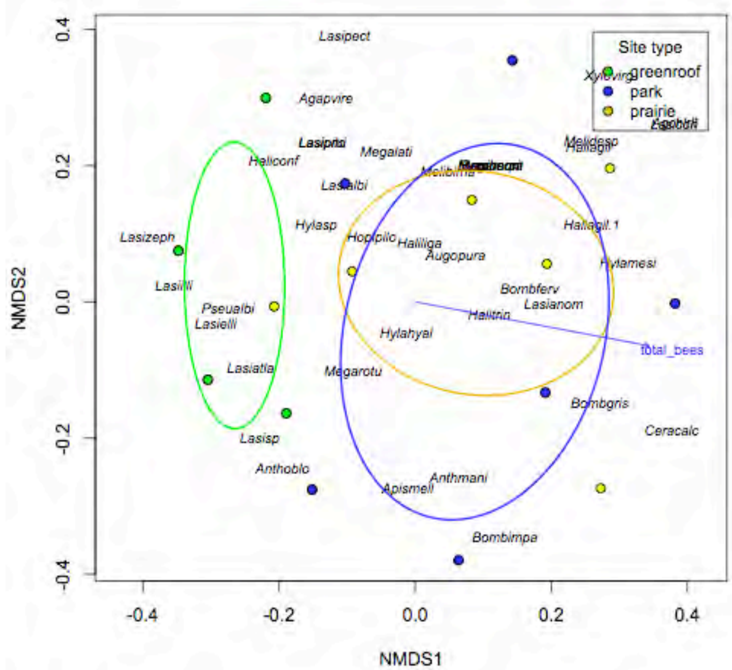


Figure 7. NMS ordination of a) bee morph types seen during observation periods across all sites and habitat types and b) bee species collected via pan traps or aerial net across all sites and habitat types. Bee identification codes are explained in Table V. Each point represents one site; green represents green roofs, blue for parks, and yellow for prairies. Ellipses represent the habitat type as a whole. The Bee ID code (a.) or bee species (b.) are layered on top of the ordination figure.

Site	*Apis mellifera*	*Xylocopa*	*Bombus*	Large Dark	Large Metallic Green	Medium Dark	Small Dark	Small Metallic Green	Tiny Dark
Tyner Interpretive Center				Patterned		Patterned	Black	Grey	
Optima Views Condomimium	Grey		Grey		Patterned	Grey	Black		
Notebaert Nature Museum				Grey	Black	Grey	Black	Patterned	Grey
CTA Headquarters			Grey	Grey		Black	Black		
Joffery Building									
Kersten Physics Building at UChicago	Grey		Grey	Grey	Grey	Grey	Black		
Montrose Point	Grey		Grey	Grey		Grey	Black		
Lincoln Park		Black	Black	Black	Black	Patterned	Black		Grey
Humboldt Park	Grey		Black	Black	Black	Patterned	Black		Grey
Garfield Park Conservatory	Black		Black	Grey			Black		
The Lurie Garden at Millennium Park	Black		Black	Black	Patterned	Grey	Black		Grey
Burnham Park			Black	Black		Grey	Black	Grey	Patterned
Lyons Woods Forest Preserve	Grey		Black	Black	Patterned	Grey	Black	Patterned	
Lake Forest Openlands West Skokie Prairie	Grey		Black	Black	Grey	Black	Black	Patterned	
Chicago Botanic Garden Dixon Prairie	Grey	Grey	Grey	Grey	Patterned	Grey	Black	Patterned	Grey
Air Station Prairie			Grey	Black	Patterned	Black	Black	Patterned	Black
Santa Fe Prairie			Black	Black		Black	Black	Patterned	
Midewin National Tallgrass Prairie	Grey	Grey	Black	Patterned	Black	Black	Black		

Table IV. Bee identification code presence in pan traps, and observed visiting focal flowers by site. Grey boxes indicate those ID codes only observed visiting focal forbs, patterned boxes represent bee ID codes caught in pan traps, but never seen visiting focal flowers. Black boxes indicate bee ID codes with representatives that visited focal flowers and were caught in pan traps. Blank boxes indicate the bee ID code was never observed or collected at the site.

Genus	(Subgenus)	species	Nest	Prairies						Parks						Green roofs						
				Air Station	CBG Dixon	LFOL W. Skokie	Lyons Woods	Midewin	Santa Fe	Burnham	Garfield	Humboldt	Lincoln	Lurie Garden	Montrose Point	CTA	MoMo	Notebaert	Optima	Tyner	UChicago	Sum
Apis		*mellifera**	H					(1)			(3)			2								2 (4)
Bombus	*(Bombias)*	*auricomus*	H					8														8
	(Cullumanobombus)	*griseocollis*	H		(2)		1	4 (2)					1									6 (4)
	(Pyrobombus)	*bimaculatus*	H					11														11
		impatiens	H		(5)	1	2	(3)	1	1 (1)	(3)				1						(1)	6 (13)
	(Thoracobombus)	*fervidus*	H			1		2			(1)				1							4 (1)
Xylocopa	*(Xylocopoides)*	*virginica*	W		(1)								1									1 (1)
Anthidium	*(A.)*	*manicatum**	C								(3)			1	(2)							1 (5)
	(Proanthidium)	*oblongotum**	C	3		1				1										16		21
	unknown	*unknown*	C	1																		1
Anthophora	*(Clisodon)*	*terminalis*	SW				(1)															(1)
Colletes		*latitarsis*	S			1																1
Eucera	*(Synhalonia)*	*hamata*	S					23														23
Melissodes	*(Eumelissodes)*	*denticulata*	S										1									1
	(Heliomelissodes)	*desponsa*	S					3	1													4
	(M.)	*bimaculata*	S			13		11				2		1	1			1 (1)				29 (1)
		UNKNOWN	S					1														1
Peponapis	*(P.)*	*pruinosa*	S			1																1
Pseugopanurgus		*albitarsis*	C	2																		2
Svastra	*(Epimelissodes)*	*obliqua*	S					1														1
	unknown	*unknown*	S					1														1
UNKNOWN		*UNKNOWN*																	2		1	3
Augochlora	*(A.)*	*pura*	SW*			1	1															2
Agapostemon	*(A.)*	*virescens*	S	1	1		3	49			1		9		3			21				88
Coelioxys		*banksi*	CP				1															1
Megachilie	*(Eutricharaea)*	*rotundata**	C										1			8				2		11
	(Litomegachile)	*mendica*	C												1							1
	(Megachile)	*centuncularis**	C																	1		1
	(Megachile)	*montivaga*	C					5														5
	(Xanthosarus)	*latimarus*	C					1							1							2
	unknown	*UNKNOWN*	C				1															1
Osmia	*(Melanosmia)*	*[Chenosmia]*	C		(1)																	(1)
		albiventris	C		(2)																	(2)
Ceratina	*(Zadontomerus)*	*calcarata or dupla*	P		(6)	1			1				1									3 (6)
	(Zadontomerus)	*dupla*	P		(6)			1														1 (6)
		UNKNOWN	C		(12)																	(12)
Halictus	*(Nealictus)*	*parallelus*	S					1														1
	(Odontalictus)	*ligatus*	S	13 (2)		2	2	21	3	(1)		11 (1)		3	8				2		1	66 (4)
	(Seladonia)	*confusus**	S	3			2	2		2					2			1				12
		agilis ?*	S			1		2 (1)	2		(1)	1										6 (2)
		agilis or trinodis**	S			3	1	1	3		(1)											8 (1)
		trinodis ?*	S	2	(1)			5	1						1							9 (1)
Hoplitis	*(Alcidaema)*	*pilosifrons*	C		(2)		(2)	1														1 (4)
		producta	C		(1)																	(1)
Hylaeus	*(H.)*	*mesillae*	C			1		2	1				2		1							7
		*leptocephalus**	C															1				1
	(Prosopis)	*affins*	C		(1)																	(1)
	(Spatulariella)	*hyalinatus**	C	1		2							3							4		10
		UNKNOWN	C			2	3	1							2 (1)				1			9 (1)
Lasioglossum	*(Dialictus)*	*albipenne*	S				1	1							3							5
		anomalum	S	1	(1)		1	2				1	45	4	19			1		5		79 (1)
		atlanticum	S	4		2	6	1		2	1			2	4				3	9	2	36
		illinoense	S	3			2		1										8	6		20
		michiganense	CP											1								
		pectorale	S									1			3			2				6
		perpunctatum	S					3														3
		pilosum	S												48							48
		pruinosum	S												2							2
		tegulare	S		(1)			4							3			1	4	2	3	17 (1)
		UNKNOWN	S		1									1	2 (3)					1		5 (3)
		zephyrum	S										1						13			14
	(Evylaeus)	*cinctipes*	S			1																1
	(Lasioglossum)	*coriaceum*	S						2													2
		*leucozonium**	S				1															1
Augochlorella		*UNKNOWN*	S		1																	1
		UNKNOWN	S						3													3
Sphecodes	*(Sphecodium)*		CP																		1	1
				34 (2)	3 (42)	34	28 (3)	168 (7)	19	6 (2)	2 (12)	16 (1)	65	14	106 (6)	8		28 (1)	33	46	8 (1)	618 (77)

Table V. Bee species collected on 6 green roofs, 6 city parks, and 6 restored prairies in and around Chicago, 2008. Species not native to Illinois are designated with an *, and nesting habit is denoted with the first letter of (s) soil nesting, (c) cavity nesting, (cp) clepto-parasitic or (h) hive nesters. Species names highlighted in grey were also recorded in Pearson (1933) for the Chicago region. Numbers inside parentheses indicate net caught individuals, and outside indicate those captured in pan traps. All species are organized into Bee ID Codes used in the field.

Figure 8. Bee species richness by habitat type. Green bar represents green roofs, the blue bar represents park sites, and the yellow bar represents all prairies. There were 68 total species collected. The total number of species collected at all six sites within each habitat type is labeled at the top of each bar.

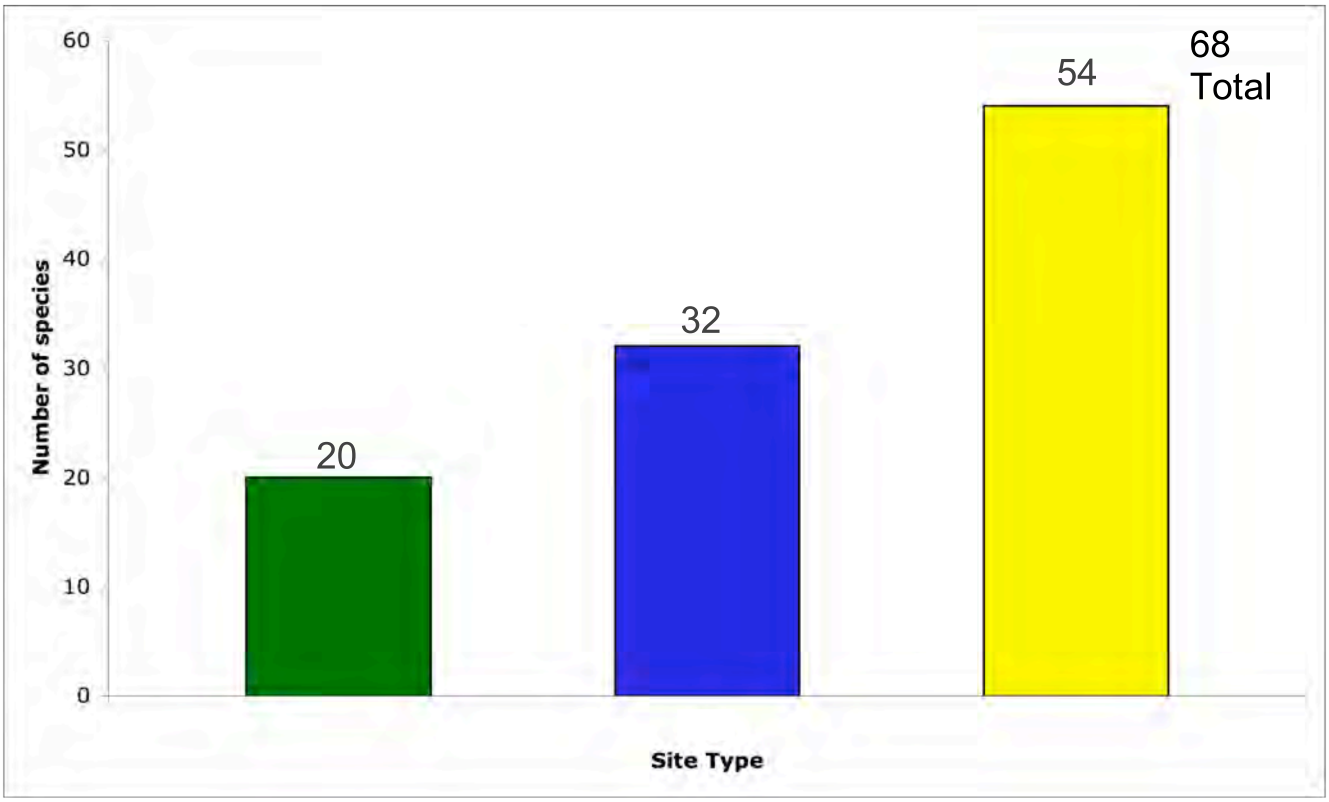


Figure 9. Percentage of green space in surrounding 500m radius of each site by the Shannon diversity index ranking. Points represent sites: green points for green roofs, blue for parks, and yellow for prairies. Site names are listed. Two rooftops, the Joffrey building and CTA Headquarters are excluded from analysis, as both have Shannon diversity index rankings of zero. This ranking is due to only having one species of bee (CTA) or having no bees collected (Joffrey). Trendline R^2 values are listed for each habitat type overall, and color coded to correspond with point color.

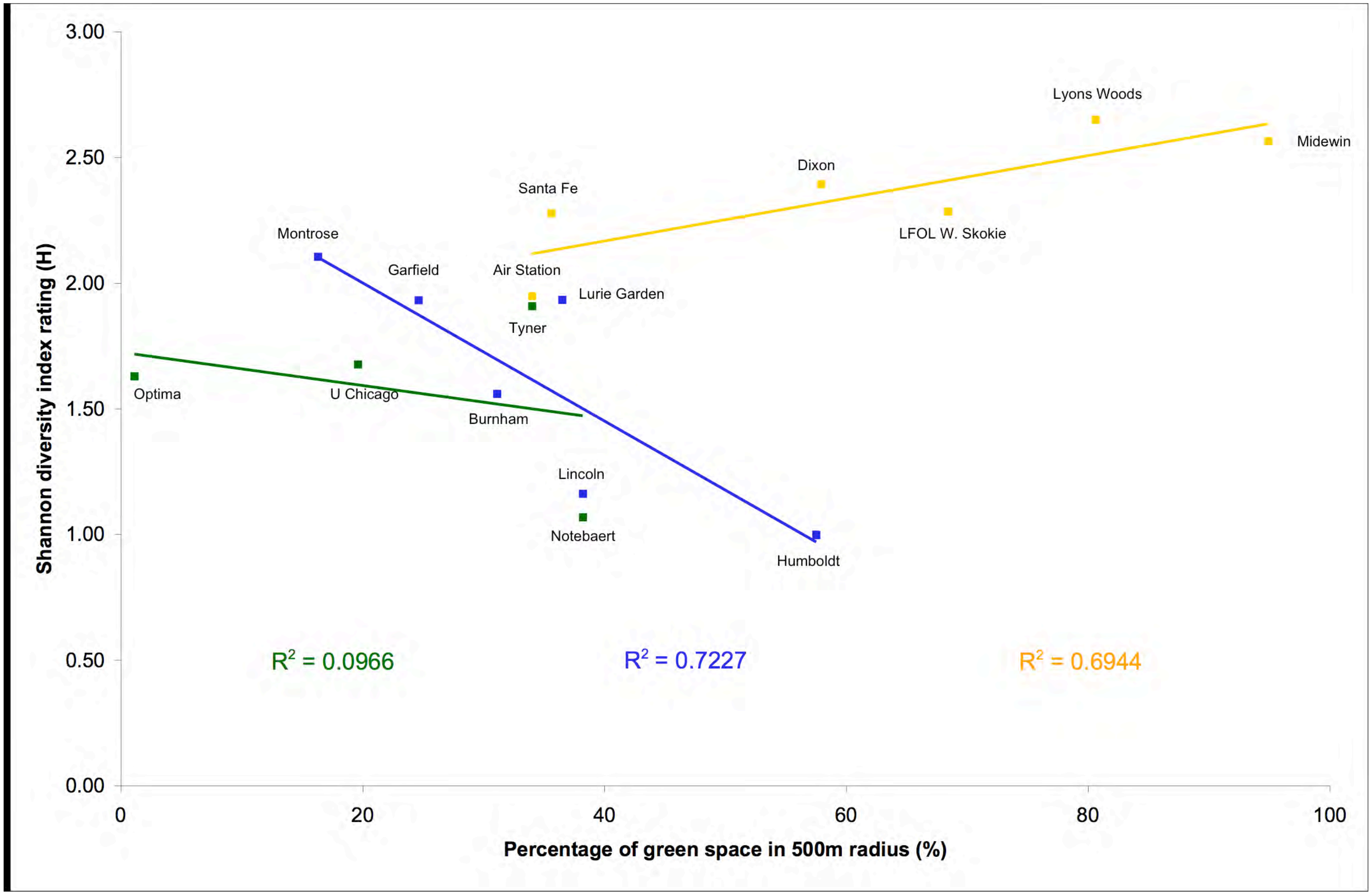


Table VI. Percent of species from each site by nesting habit, IL status, and presence in historic surveys. The green roof Joffrey was removed from analysis as no bees were collected at that site.

	Nesting habits %			IL status %		Comparison to past surveys %		Total
	Cavity	Clepto-parasite	Ground	Native	Non-native	in historic	Not in historic	species
Air Station	36	0	64	82	18	27	73	11
Dixon	41	0	59	100	0	53	47	17
LFOL	38	0	63	75	25	50	50	16
Lyons Woods	12	6	82	88	12	53	47	17
Midewin	20	0	80	90	10	70	30	30
Santa Fe	18	0	82	82	18	55	45	11
Prairie mean	**27**	**1**	**72**	**86**	**14**	**51**	**49**	**17**
Burnham	20	0	80	80	20	40	60	5
Garfield	25	0	75	50	50	50	50	8
Humboldt	0	0	100	80	20	80	20	5
Lincoln	50	0	50	80	20	70	30	10
Lurie	25	13	63	75	25	50	50	8
Montrose	25	0	75	95	5	65	35	20
Park mean	**24**	**2**	**74**	**77**	**23**	**59**	**41**	**9**
CTA	100	0	0	0	100	0	100	1
Joffrey								0
Notebaert	14	0	86	100	0	71	29	7
Optima	17	0	83	100	0	50	50	6
Tyner	44	0	56	56	44	33	67	9
U of Chicago	0	20	80	100	0	80	20	5
Green roof mean	**35**	**4**	**61**	**78**	**29**	**47**	**53**	**5**

percentages of total species per site

Table VII. Percentage of bee species (a), and individuals (b) collected based on habitat type, and nesting substrate. Missing values indicate there were no bee species, or no bees of the specified nesting type collected from any of the six sites within the habitat type.

A.	**Green roofs**	**Parks**	**Prairies**
Hive	5%	13%	11%
Soil	63%	56%	50%
Cavity	32%	25%	30%
Wood		3%	2%
Soft-wood			3.5%
Pith		3%	3.5%
n =	20	32	54

B.	**Green roofs**	**Parks**	**Prairies**
Hive	1%	6%	13%
Soil	72%	85%	66%
Cavity	27%	8%	15%
Wood		0.50%	0.20%
Soft-wood			1%
Pith		0.50%	4%
n =	122	231	334

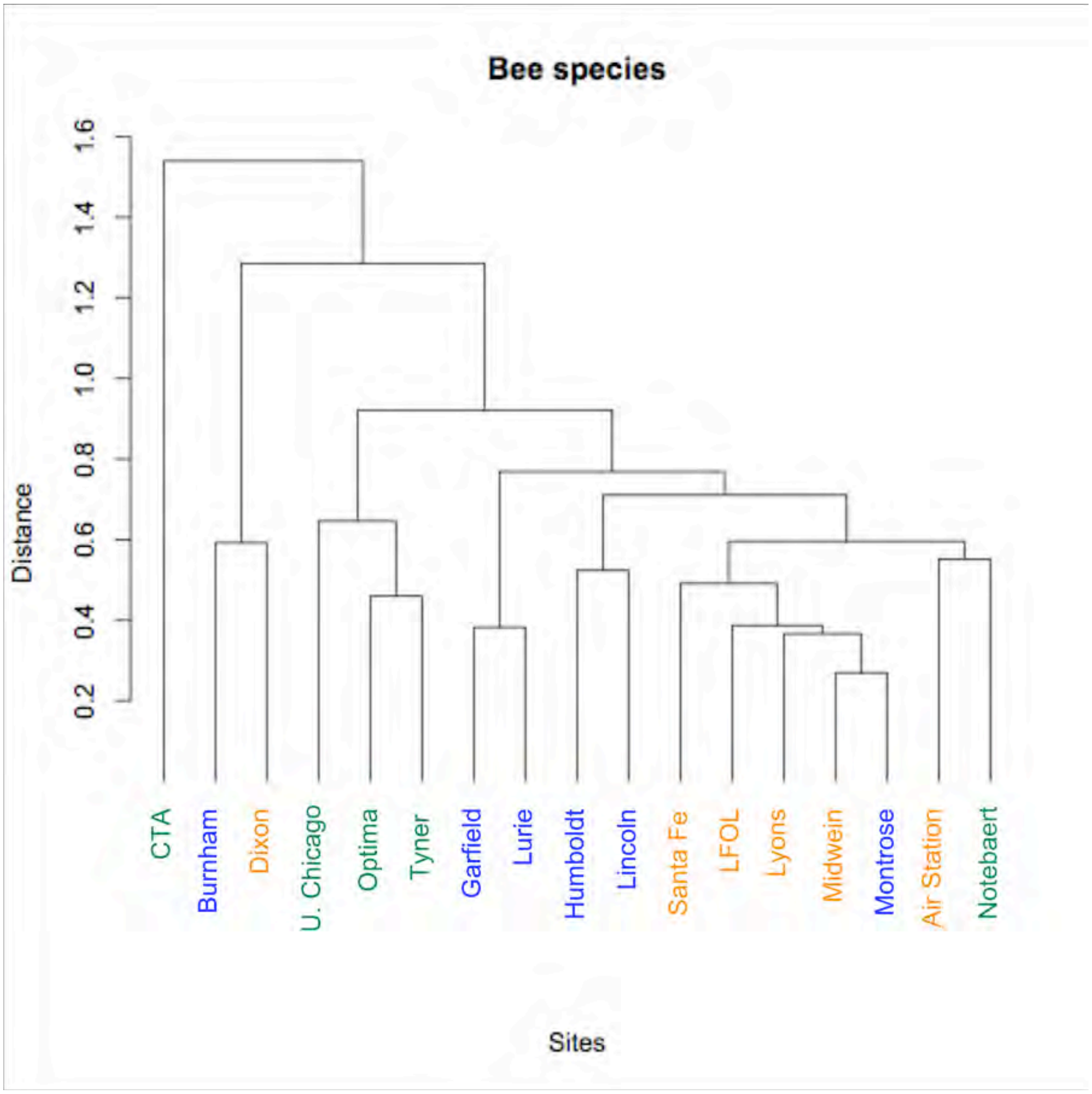


Figure 10. Cluster analysis based on bee species. The bee species presence, as well as abundance at each site was used to determine the relatedness of each site based on the bee community. Green text represents green roofs, blue text for parks, and yellow text for prairie sites. The later stages of branching represent more closely related sites; the two most closely related are Midewin and Montrose. The green roof Joffrey is not present as there were no bees collected at that site.

Appendix 1

1a. Urban bee studies

In a meta-analysis of published bee surveys, over 58% of individuals, and 68% of total bee species were collected from Asteraceae; however no bee species collected from Asteraceae were also collected on flowers of Scrophulariaceae, Boraginaceae, or Plantaginaceae (Williams et al., 2001). For this study, we chose to use Asteraceae, plus one genus within Plantaginaceae, which was classified in Scrophulariaceae in Williams et al.'s study.

Some cavity-nesting specialists are found in greater abundance in urban areas compared to the surrounding native areas (Cane, 2001).

The individual portions of a bee's home range can range from 1-2 km apart for medium sized bees (Cane, 2001). A review of 10 bee species found an average home range of 2.8km, with a median of 1.5km (J. H. Cane, *unpublished data*)

In other urban areas, wild bees are found in disturbed and ruderal areas such as disused railways, empty or abandoned lots, road sides or footpath borders (Saure, 1996). These areas function as nectar and pollen sources, nesting sites.

1b. Chicago green space history

The city of Chicago has a long history of conservation. Starting with some of the original city planners and extending all the way to the creation of the Chicago Wilderness Region in 1996, there have been people who have understood the importance of preserving portions of the natural land for future generations. The Chicago Wilderness coalition is a group of 34 organizations whose goal is to conserve the natural communities that still survive within the confines of the urban environment. "Urban living often results in an almost complete detachment of people from the land. An important goal of Chicago Wilderness is to reconnect a landless urban population with the pulse of nature" (Moskovits *et al.,* 2002).

The 552 parks in Chicago consist of over 7,300 acres of parkland. Parks chosen for this study all had a portion of natural area, a planted and maintained parcel of native prairie plants.

Gardening with native plants has been on the rise over the past 30 years, (McMahan, 2006) and is evident by the natural areas landscaping in Chicago's city parks (www.cityofchicago.org). Large urban parks are known to have locally specific landscaping (Loeb, 200X)

1c. Green roof background

Green roofs have been popular across Europe and the Mid-East for centuries, the Hanging Gardens Babylon circa 500 BC, or those of the Semiramis, in what is now Syria, is the most famous example, and considered one of the seven wonders of the ancient world. During the Middle Ages and renaissance, rooftop gardens were mainly for the rich, while during the frontier times in the United States, many plains settlers lived in sod homes built into hills. Modern green roofs were originally installed to mitigate the effects of sun wear and damage on roofs in early 20th century Germany (Oberndorfer et al., 2007). Although green roofs cost nearly twice that of conventional roofs to install, they double the roofs lifetime from 20 to 40 years (Getter and Rowe, 2006).

Chicago leads the United States in green roof installation, and as of 2007, 3 million square feet of green roofing, representing approximately 300 buildings, had been installed in the city (Taylor, 2007). These buildings are not only private residences, but also include commercial and civic buildings around the city.

Chicago has become the leader thanks, primarily to Mayor Daley's interest in green roofs he saw on a trip to Europe in the late 1990's. He returned to have one installed on City Hall in 1999. The city of Chicago not only gives a density bonus to developers who have included a green roof in new construction; thereby allowing an increased number of units on a piece of property, but also waives developer's fees for processing building permit applications. Green roofs are mandated for any developer receiving city assistance in the city of Chicago as well (Taylor, 2007).

Green roofs have been studied primarily for energy savings, and engineering or horticultural challenges in the past. For the building itself, green roofs provide fire protection (Kohler, 2003), and increase the longevity of the roof membrane (Porsche and Kohler, 2003). Within the building, sound insulation is increased (Dunnett and Kindsbury, 2004), and heating and cooling costs reduced (Del Barrio, 1998) via energy reduction. Environmentally, green roofs reduce the urban heat island effect, and mitigate storm water runoff, and remove pollutants from the city air. In Chicago, 1675kg of air pollutants were removed between August 2006 and July 2007 thanks to the 19.8ha of green roofs in the city.

Systems with a variety of substrate depths and vegetation types tend to have greater levels of diversity for spiders, beetles, and birds. Hummock contours correlate with higher diversity levels, and design criteria have emerged to develop roof tops, which allow for greatest ecosystem diversity. Both extensive, and intensive green roofs create wildlife habitat, regardless of original intent (Coffman, 2007).

There is one study which compared the insect, spider, and bird community diversity, based on one season of data collection, comparing extensive and intensive green roofs (Coffman, 2007). Four collections and observations were made on each site between 8-11AM from July – August of 2004, only one bee was collected, and identified only to the level of family.

Appendix 2
Additional results
2.0 The site observation day schedule and weather data. Sites are grouped by habitat type. The first three dates listed constitute Penstemon observation days, and the last three are Asteraceae family member observation days. The sky condition, temperature in the shade, and a 30 second mean wind speed were all recorded immediately after each 15 minute observation period. Blanks represent missing data, and were not included in analysis.

Weather data

Observation period	Julian date	one Sky	one Temp (deg C)	one Wind (mps)	two Sky	two Temp (deg C)	two Wind (mps)	three Sky	three Temp (deg C)	three Wind (mps)	four Sky	four Temp (deg C)	four Wind (mps)
Prairies													
	171	clear	-	-	clear	-	-	clear	-	-	clear	-	-
	182	clear	20	-	clear	21.1		clear	22.2		clear	25	
AirStation	189	overcast	25.8	1.3	overcast	27.2	1.4	overcast	28.8	2.7	overcast	33.4	1.4
	213	clear	29.5	0	clear	28	0.4	cloudy	28.5	0.4	overcast	28.5	0.3
	218	overcast	25.5	1.4	cloudy	30.1	1.2	cloudy	32.6	0.4	cloudy	33.8	1.1
	220	clear	24.5	0.8	clear	30.4	1.4	clear	28.8	1.8	cloudy	31.9	2.5
	168	clear	23.2	0.2	cloudy	24.1	1.4	cloudy	30.2	0.4	cloudy	27.4	1.3
	169	clear	20.4	0.1	clear	22.2	3.4	cloudy	31.8	0.6	clear	27.8	0.2
CBG Dixon	183	clear	24	0.7	clear	24.5	2.2	clear	25	0.9	clear	28.4	2.3
	198	clear	32.5	0				cloudy	29.9	0.2	cloudy	31.5	0
	200	cloudy	29.4	0	cloudy	30.4	0.8	overcast	30.3	0.5	cloudy	28.8	0.5
	233	clear	23.3	0	clear	25.8	0	clear	27.2	0	clear	26.5	0.2
	169	clear	72	0.9	clear	77	0.7	clear	20.6	2.2	clear	22.2	1.3
	190	overcast	26.6	0	overcast	25.5	0	overcast	28.8	0	overcast		
LFOL W. Skokie	192	clear	27.1	0	cloudy	28.5	0	overcast	27.2	0.1	overcast	23.8	0.3
	226	overcast			clear			overcast			cloudy		
	262	clear	20.5	0.1	clear	20	0.1	clear	20.5	0	clear	21.1	0.2
	280	clear	21.9	0	clear	25	0.1	cloudy	24.3	0	overcast	22.5	0
	184	clear	29.3	0.2	clear	28.7	2	overcast	28.7		overcast	29.8	1
	192	overcast	27.8		overcast	29.4		overcast	25.5		overcast	26.6	
Lyons Woods	196	cloudy	23.7	0	cloudy	25.4	0	cloudy	34.1	0	cloudy	29.1	1
	197	clear			clear			clear			cloudy		
	242	clear			clear			clear			clear		
	280	overcast	17.5	2.7	cloudy	23.7	0.2	overcast	29.5	0.3	overcast	32.5	0.2
	170	clear	23.8	0.1	clear	27.4	0.2	clear	31.2	0.2	cloudy	32.2	0.1
	172	clear	31.1	0.1	clear	32.9	0.1	clear	34.2	0	cloudy	35.8	0
Midewin	175	clear	23.4	0.3	cloudy	26.5	0.2	cloudy	29.2	0.2	cloudy	30.5	0.8
	205	clear	24.1	0.4	clear			clear	32.2	0	clear	31.2	0.8
	231	cloudy			cloudy			cloudy			cloudy		
	250	clear	21.1	0	clear	21.1	0	cloudy	22.5	0.1	cloudy	24.8	0.1
	177	overcast	24.4		overcast	23.3		overcast	22.2		overcast	23.3	
	183	clear	24.4		clear	25.5		clear	25.5		clear	27.7	
Santa Fe	185	clear	20	0.4	clear	21.1	0.5	clear	22.2		clear	23.3	
	232	clear	29.8	0	clear	27.2	0	cloudy		0	overcast	29.8	0
	246	clear			clear			clear			clear		
	266	clear	23.1	0	clear	24.6	0	clear	29.4	0	clear	30.9	0
Parks													
	166	clear	27.7	0.8	clear	28.8	4	clear	32.2	0.5	clear	33.8	2
	177	overcast	24.7	1.9	overcast	23.4	1.2	overcast	26.6	2.8	overcast	22.5	5.2
Burnham	182	cloudy	24.4	0.1	clear	25.1	0.2	clear	28.2	0.2	clear	30.2	0.2
	192	cloudy	27.8	0.1	cloudy			cloudy	33.1	0.2	cloudy	32.1	0.1
	232	clear	27.4	1.7	cloudy	31.4	1.2	clear	30.3	1.5	clear	30.1	1.9
	234	cloudy	26.2	0.8	overcast	26.9	0.9	overcast	27.8	0.7	overcast	28.4	0
	164	cloudy	28.5	0.3	cloudy	32	0.4	clear	32.7	2.2	clear	35.9	0.3
	170	clear	21.5	0	clear	23.8	0.3	cloudy	32.1	0.8	cloudy	28.8	0.3
Garfield	178	clear	22.7	0.2	clear			clear	28.5	0.2	clear	32.1	0
	190	overcast	24.3	0	clear	32.5	0.2	cloudy	34.1	0.2	clear	33.5	0.3
	199	clear	32.1	1	clear	33.5	0.9	cloudy	34.5	0.9	cloudy	34.8	1.9
	226	overcast	24.2	0	cloudy	25.2	0.5	cloudy	28.1	0.1	cloudy	24.5	0.4
	159	cloudy	24.8	1.9	cloudy	27.5	2.7	cloudy	27.2	3.2	cloudy	25.2	2.9
	171	clear	23.7	1.3	clear	24.1	0.8	clear	31.8	0.2	cloudy	31.7	1.2
Humboldt	175	clear			clear	31.7	0.1	clear	30.9	0	clear	32.8	0
	197	clear	24.5	0.4	clear	30.2	0.6	clear	33.4	0.6	clear	32.2	0.4
	216	cloudy	25.8	0.5	clear	32.4	0.6	clear	34.5	0.7	clear	35	0.7
	222	overcast			overcast			overcast			overcast		
	163	clear	28.1	1.1	clear	31.4	1.1	clear	33.2	2.1	clear	32.4	0.8
	174	overcast	22.6	0	cloudy	26.9	0	cloudy	25.4	0.2	cloudy	27.4	0.3
Lincoln	179	overcast	25.6	0.8	overcast	30.5	0.4	overcast	34.4	0.3	overcast	30.2	1.3
	199	clear						clear	32.1	0.7	clear	34.1	0.4
	207	cloudy	24.1	0.9	cloudy	27.6	0.1	cloudy	29.8	0.6	cloudy	31.8	1.1
	224	cloudy			cloudy			cloudy			cloudy		
	165	overcast	25.3	0.3	overcast	28.6	0.4	overcast	30.5	0.1	overcast	29.4	0.86
	170	clear	20.5	0.2	clear		0.3	clear	23.3	0.3	clear		1
Lurie Garden	176	clear	23.4	0.3	clear	28.2	0.6	cloudy	27.4	0	cloudy	27.9	0.2
	198	cloudy	33.4	0.7	cloudy	36.9	0	cloudy	36.1	0.3	cloudy	39.7	0.8
	204		24	0.2	cloudy	29.4	0.2	clear	30.2	0.4			
	227	cloudy	24.8	0.1	cloudy	26.3	0.2	clear	28.9	1.2	clear	32.5	1.6
	173	overcast	23.3	0.4	cloudy	23.3	0	clear	23.8	0.2	cloudy	24.4	0
	174	cloudy	28	0	cloudy	27.9	0.1	cloudy			cloudy	30.8	0.1
Montrose	181	cloudy	20.35	0	cloudy	21.1	0.1	cloudy	21.1	0.2	overcast	20	0.3
	200	cloudy	32.2	0	clear	30.5	0.1	cloudy	31.7	0.2	cloudy	30.7	0.1
	204	overcast			cloudy			clear			clear		
	228	clear	26.7	0	clear	28.8	0.3	clear	32.2	1.2	clear	33.8	0.5

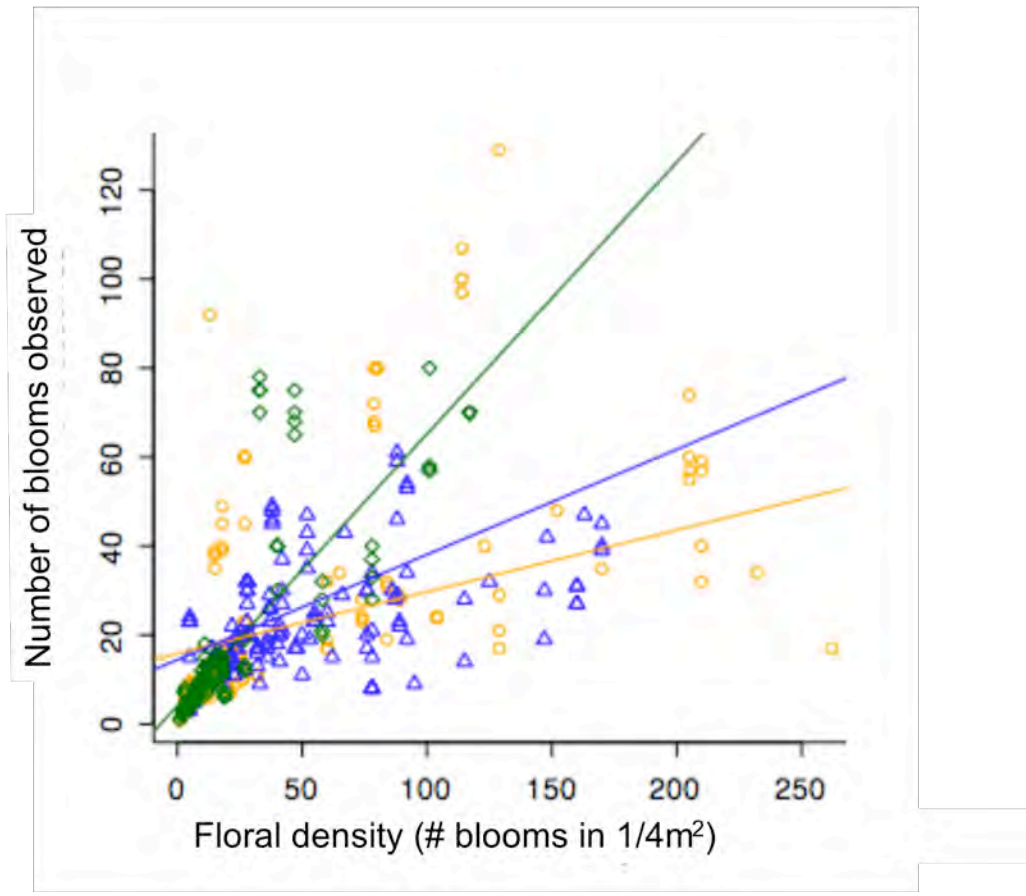
2.0 continued.

Observation period	Julian date	one Sky	one Temp (deg C)	one Wind (mps)	two Sky	two Temp (deg C)	two Wind (mps)	three Sky	three Temp (deg C)	three Wind (mps)	four Sky	four Temp (deg C)	four Wind (mps)
		Weather data											
Green roofs													
CTA Headquarters	178	overcast	26.6		overcast	26.6	0.6	overcast	32.2	0.6	overcast	33	0.6
	183	clear	33.1	1	clear	35.1	0.1	clear	44.1	0	clear	41.7	0
	190	overcast	31.6	2.9	cloudy	33.6	2.5	cloudy	42.1	1.3	cloudy	28.2	0.2
	219	clear	28.2	0.2	clear	30	1.6	cloudy	33.8	2.1	overcast	32.2	2
	225	cloudy	25	0.5	cloudy	27.7	0.3	overcast	29.1	0.8	overcast	27.6	0.8
	231	clear	24.9	0.3	clear	28.8	0.6	cloudy	31.1	1.9	cloudy	35.1	1.1
Joffrey	184	overcast	28.8	0.2	clear	20.4	3	cloudy	20.6	2	cloudy	19.9	2
	185	clear	20.4	3	cloudy	20.6	2	cloudy	19.9	2	clear	20.7	
	191	clear	20.7	2.7	clear	23	0	clear	22.9	0	clear	35.1	0
	205	clear	21.8	1.3	clear	20.5	0.4	clear	22.2	1.4	clear	38.1	0.5
	206	clear			clear			clear			clear		
	212	clear	26.8	0.9	clear	26.6	0.7	cloudy	30.2	0.6	cloudy	30.5	0.6
Notebaert	174	cloudy	22.5	0	cloudy	23.9	0.3	cloudy	24.2	0	cloudy	24.3	0.2
	177	overcast	24.5	0	overcast	25.1		overcast			overcast	26.1	0.3
	179	cloudy	25.6	0.8	overcast	30.5	0.4	overcast	30.2	1.3	cloudy	34.4	0.3
	207	cloudy	22.7	0.9	cloudy	28.4	1	clear	29.7	1.1	clear	32.5	0.4
	224	cloudy	24.5	0	cloudy	24.2	0	clear	29.4	0.4	clear	33.2	0.1
	233	overcast	26.7	0	cloudy	29.6	0	overcast	29.8	0.1	overcast	26.5	0
Optima	171	clear	22.4	0	clear	30.4	0	clear	24.9	0.2	clear	23.5	0
	176	clear	24.6	0	clear			clear			clear		
	178	overcast	29.2	0.9	cloudy	32.9	0.2	clear	31.7	0.3	clear	31.1	0.6
	213	clear	30	0.3	clear	35.1	0.7	clear	33.5	1	cloudy	36.6	0.3
	219	clear			clear			overcast			overcast		
	221	clear			clear			clear			clear		
Tyner	191	clear	24.7	1.9	clear	25.7	1	clear	31.1	2.6	clear	31.7	0.8
	193	cloudy	27.1	0.1	clear	33	0.2	clear	26.4	0.2	clear	30.6	0.3
	196	clear	29.5	0.6	clear	31.8	0.8	cloudy	31.4	0.5	clear	33.5	0.1
	213	clear	29.5	0	clear	28	0.4	cloudy	28.5	0.4	cloudy	28.5	0.3
	218	overcast	25.5	1.4	overcast	30.1	1.2	overcast	32.6	0.4	overcast	33.8	1.1
	220	clear	24.5	0.8	clear	30.4	1.4	clear	28.8	1.8	cloudy	31.9	2.5
University of Chicago	176	cloudy	21.1		cloudy	22.2		cloudy	22.2		cloudy	23.3	
	179	clear			cloudy	27.7	0.2	clear			clear		
	184	clear	26.1	0.2	clear	33.8	0.5	cloudy	35.2	1.1	overcast	36.8	1.6
	204	cloudy	25.6	0.3	cloudy	27	0.8	cloudy	25.6	1.2	cloudy	25.8	0.8
	225	overcast			overcast			overcast			overcast		
	234	overcast	25.7	0	overcast	24.5	0	overcast	28.8	0	overcast	27.2	0

2.01 Surrounding green space
There was significantly less green space surrounding green roof sites than parks ($p = 0.03$) and prairies ($p = 0.01$). Prairies had the greatest amount of green space in the surrounding 500m compared to green roofs or parks ($p = 0.03$). The same significance trends resulted when half of the suburban area was added to green space. Half of the suburban area was added to account for landscaping and lawns typically surrounding homes in the suburbs.

2.02 Floral density and number of blooms observed. The significant correlation between the number of blooms observed and the focal floral density within each habitat type is shown: green points illustrate observations at green roofs, blue at parks, and yellow at prairies. Each line represents the trendline, with colors as previously described.

2.02 Floral density and number of blooms observed.

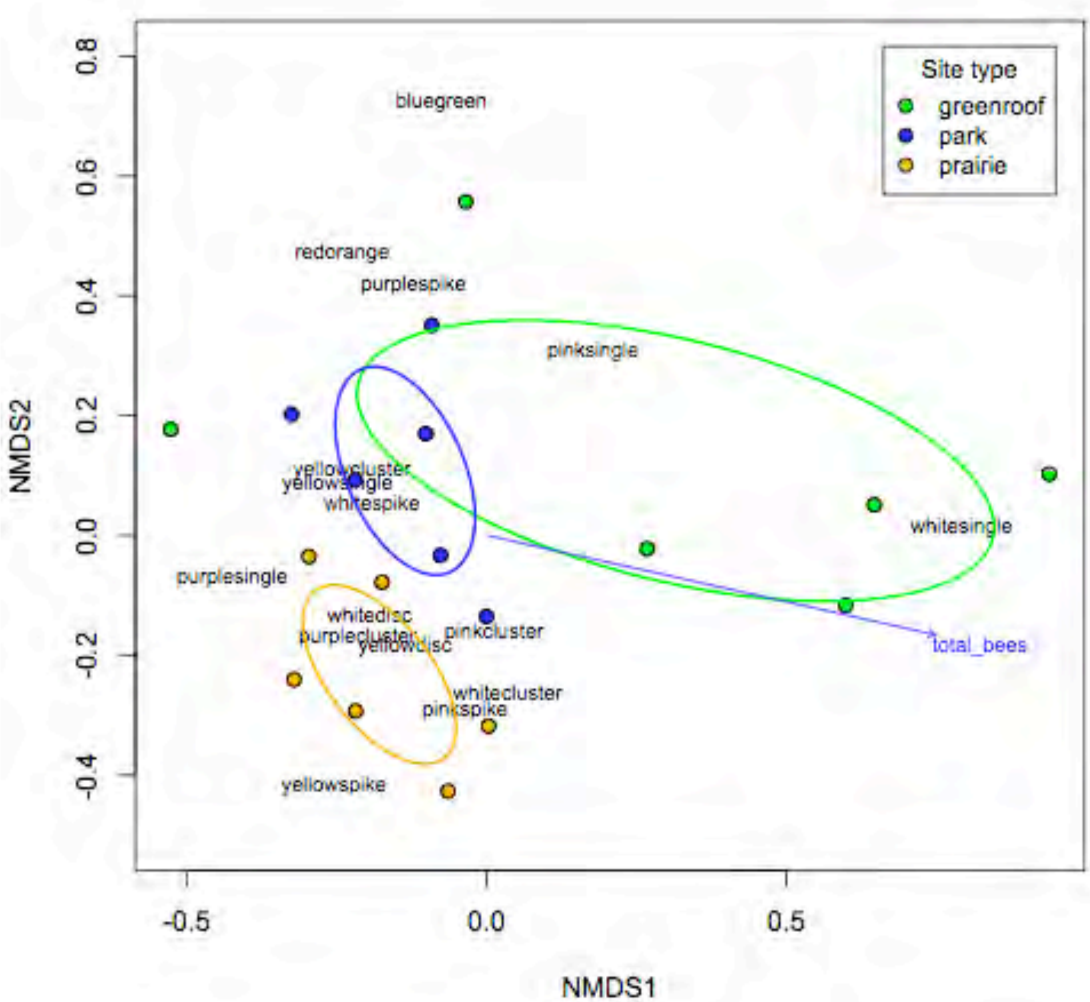


Appendix figure 2.02 Floral density and number of blooms observed. The significant correlation between the number of blooms observed and the focal floral density within each habitat type is shown: green points illustrate observations at green roofs, blue at parks, and yellow at prairies. Each line represents the trendline, with colors as previously described.

The number of blooms watched during observation periods based on floral density. Density determined by the number of heads or flowers in ¼ m^2. Each point represents one observation period. Prairies represented by yellow circles and yellow trendline, parks by blue triangles and blue trendline, green roofs by green diamonds and green trendline.

Across all sites, flowers observed and focal floral density, were correlated (Figure 2, r = 0.57). However, when sites were separated by type, there was only a significant correlation at green roof sites (r = 0.81, p < 0.001). This correlation was nearly significant at prairies (r = 0.53, p < 0.001), and not significant at parks (r = 0.48, p < 0.0010).

2.03 NMS ordination of plant bloom morph types with significant vector for total bees per site.



Appendix figure 2.03 NMS ordination of plant bloom morph types with significant vector for total bees per site. Colors and codes explained in Figure 5.

2.04 Plant species list.

Appendix table 2.04. Plant species list. Blooming species and their density estimate, based on cm of bloom cover measured from four, 5m transects stemming from the focal floral display for observation periods.

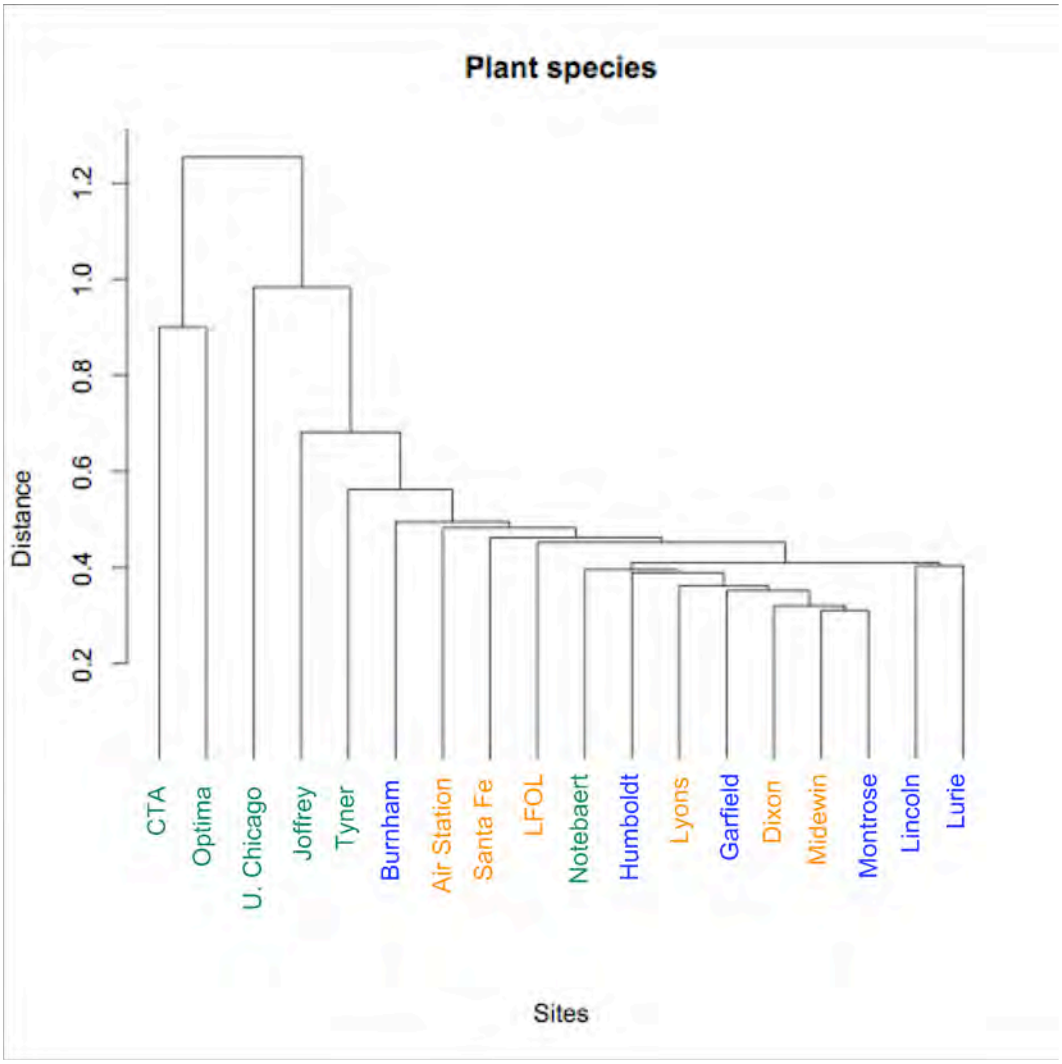
	Air Station	Dixon	LFOL	Lyons	Midewin	Santa Fe	Burnham	Garfield	Humboldt	Lincoln	Lurie	Montrose	CTA	Joffrey	Notebaert	Optima	Tyner	U of Chicago
Total cm bloom coverage	**Green roofs**						**Parks**						**Prairies**					
Achillea millefolium	0	20	20	0	0	0	9	0	43	0	0	0	0	0	0	0	0	0
Agastache scrophulariaefolia	0	0	0	0	0	0	0	144	0	0	0	0	0	0	0	0	0	0
Aletris unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Alisma subcordatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Allium canadense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	0
cernuum	72	0	0	200	0	0	0	0	0	0	0	0	32	20	0	0	68	0
tanguticum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amorpha canescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anthemis arvensis	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apocynum cannabinum	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arenaria stricta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aruncus dioicus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asclepias syriaca	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
tuberosa	0	0	0	0	0	0	0	0	0	160	0	12	0	0	0	0	0	0
verticillata	0	0	0	0	0	0	0	0	24	0	0	0	0	0	21	0	0	0
Aster ericoides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
lateriflorus	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
novaeangliae	0	0	0	170	0	0	0	0	0	0	0	0	0	0	0	0	0	0
puniceus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
simplex	0	0	90	0	0	0	0	60	0	0	0	0	0	0	0	0	0	0
undulatus	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
vmineus	0	0	64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Baptisia alba	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
lactea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
leucantha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bidens cernua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
connata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
laevis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Brassica nigra	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0
Calamintha nepta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calibrachoa unknown	0	0	0	0	0	0	0	53	0	0	0	0	0	0	0	0	0	0
Campanula rotundiflolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	0	0	0
Canna tropicana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Centaurea.Cyanus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cichorium intybus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chrysanthemum leucanthemum	400	0	10	0	0	0	4	0	42	0	0	0	0	0	0	0	0	0
Cirscium unknown	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
alitissimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
arvense	0	0	0	12	0	0	8	0	0	12	0	0	0	0	0	0	0	0
canadense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
discolor	0	0	0	140	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Claytonia virginica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Convolvulus arvensis	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0	0
sepium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coreopsis major	0	0	0	0	0	0	0	0	0	24	0	0	0	0	0	0	0	0
rosea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
verticillata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0
Dalea purpurea	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0
Daucus carota	0	0	0	210	152	108	0	0	102	0	0	108	0	0	0	0	0	0
Desmodium canadense	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
paniculatum	0	36	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0

Total cm bloom coverage	Air Station	Dixon	LFOL	Lyons	Midewin	Santa Fe	Burnham	Garfield	Humboldt	Lincoln	Lurie	Montrose	CTA	Joffrey	Notebaert	Optima	Tyner	U of Chicago
	Green roofs						**Parks**						**Prairies**					
Echinacea unknown	0	20	0	0	0	0	0	0	0	0	0	0	0	36	0	0	0	0
purpurea	0	4	0	0	0	0	0	0	0	0	2080	40	0	0	0	0	0	0
tennesseensis	0	0	0	0	0	0	0	0	0	0	56	0	0	0	0	0	0	0
Epilobium leptophyllum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Erechtites hieracifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Erigeron unknown	0	0	0	0	0	60	0	0	0	0	0	0	0	0	0	0	0	0
annus	248	213	0	356	5	0	111	0	0	6	0	1627	0	0	48	0	50	0
canadensis	0	0	0	240	0	0	0	0	0	0	0	0	0	0	0	0	0	0
philadelphicus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Erysimum oberianthoides	0	0	0	0	0	0	0	13	0	0	0	0	0	0	0	0	0	0
Erygium yuccifolium	24	12	0	0	0	0	0	0	0	0	336	0	0	0	0	0	0	38
Erysimum cheiranthoides	0	0	0	0	26	0	0	16	0	0	0	0	0	0	0	0	0	0
Eupatorium altissimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
maculatum	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0
rugosum	0	0	0	0	0	82	0	0	0	0	0	0	0	0	0	0	0	0
Euphorbia corollata	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0	0
Fragaria virginiana	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Galeopsis tetrahit	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Galium unknown	0	132	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
boreale	0	127	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Geranium unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	96	0	0	0
maculatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34	0	0	0
soboliferum	0	0	0	0	0	0	0	0	0	0	150	0	0	0	0	0	0	0
Geum canadense	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
laciniatum	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
triflorum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helenium autumnale	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
tenuifolium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0
Helianthus unknown	0	0	0	140	40	0	0	0	0	0	0	0	0	0	0	0	0	0
annuus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
divaricatus	0	472	24	0	52	0	20	0	95	158	0	456	0	0	0	0	0	0
giganteus	0	0	0	0	0	72	0	0	0	0	0	0	0	0	0	0	0	0
mollis	0	0	0	0	0	0	0	272	0	0	0	0	0	0	0	0	0	0
strumosis	0	0	0	0	0	260	0	0	0	0	0	0	0	0	0	0	0	0
Heliopsis helianthoides	0	28	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0
Heuchera americana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hieracium pilosella	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hypericum ellipticum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
perforatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inula magnifica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ipomoea purpurea	0	0	0	0	10	0	0	0	0	8	0	6	0	0	0	0	0	0
Iris pseudacorus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jasminum officinale	0	0	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0	0
Knautia macedonia	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0
Lactuca canadensis	0	0	0	68	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lespedeza capitata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Liatris pycnostachya	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lobelia siphilitica	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
Lychnis alba	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lysimachia ciliata	0	0	0	0	0	0	0	188	0	0	0	0	0	0	0	0	0	0
nemmularia	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
Lythrum alatum	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0
salicaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Medicago lipalipa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	84	0	0	0
Melilotus alba	0	0	0	0	20	0	40	0	16	0	0	0	0	0	0	0	0	0
officionalis	0	0	0	0	120	0	9	0	165.75	0	0	0	0	0	0	0	0	0
Mentha fistulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
piperita	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mollugo verticillata	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0

Total cm bloom coverage	Air Station	Dixon	LFOL	Lyons	Midewin	Santa Fe	Burnham	Garfield	Humboldt	Lincoln	Lurie	Montrose	CTA	Joffrey	Notebaert	Optima	Tyner	U of Chicago
	Green roofs						**Parks**						**Prairies**					
Monarda unknown	0	0	0	0	0	0	0	0	0	0	0	48	0	0	0	0	0	0
didyma	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
fistulosa	0	20	0	0	64	0	0	0	0	0	0	12	0	0	0	0	0	0
Nepeta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	0	0	0
Oenothera biennis	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0
fruticosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxalis europaea	0	0	0	152	0	0	0	0	0	4	0	0	0	0	0	4	0	0
grandis	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
stricta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paeonia lactiflora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pastinaca sativa	0	0	0	0	176	0	0	0	0	0	0	0	0	0	0	0	0	0
Penstemon digitalis	132	133	122	40	477	8	108	448	166.5	256	610	284	0	8	10	0	0	20
Petunia unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perovskia atriplicifolia	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0
Phlomis tuberosa	0	0	0	0	0	0	0	0	0	0	74	0	0	0	0	0	0	0
Phlox	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0
Phlox paniculata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Physostegia virginiana	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plantago unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
lanceolata	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0
Polygonum unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
persicaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potentilla unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
arguta	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
norvegica	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
recta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Prunella vulgaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pycnanthemum incanum	0	184	0	0	0	0	0	0	40	16	0	0	0	0	0	0	0	0
tenuifolium	0	192	0	0	0	0	312	0	0	0	0	0	0	0	0	0	0	0
Ranunculus acris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
repens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ratibida pinnata	12	0	0	0	0	0	0	0	610	1456	0	36	0	0	0	0	0	0
Rosa carolina	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rudbeckia unknown	0	0	0	236	0	0	0	0	0	0	0	0	0	0	0	0	0	0
hirta	284	0	0	0	0	0	0	0	0	0	0	148	0	0	0	0	0	0
serotina	132	0	0	154	36	0	20	244	3	0	0	60	0	0	0	0	0	550
speciosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
triloba	0	0	0	0	0	0	360	0	248	20	0	0	0	0	0	0	0	0
Ruellia humilis	0	0	0	0	0	0	0	0	0	0	80	0	0	0	0	0	0	0
Salvia sylvestris	0	0	0	0	0	0	0	0	0	0	52	0	0	0	0	0	0	0
Sanguisorba officinalis	0	0	0	0	0	0	0	0	0	20	8	0	0	0	0	0	0	0
Saponaria officinalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sedum acre	0	0	0	0	0	0	0	0	0	0	0	0	484	146	0	532	2230	0
aizoon	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0
spurium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
rosea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	448	0
unknown yellow	0	0	0	0	0	0	0	0	0	0	0	0	336	68	0	1452	920	0
unknown white	0	0	0	0	0	0	0	0	0	0	13	0	418	0	0	0	278	0
unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	40	28	0	0	0
Senecio vulgaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Silphium laciniatum	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
perfoliatum	0	52	0	0	156	0	0	0	0	0	0	24	0	0	0	0	0	0
Solanum nigrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solidago unknown	0	0	0	600	0	0	0	0	0	0	0	0	0	0	0	0	0	0
altissima	0	0	0	790	60	240	0	0	0	0	0	0	0	0	0	0	0	0
canadensis	0	0	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
gigantea	0	0	0	0	0	52	0	0	0	0	0	0	0	0	0	0	0	0
grandiflora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ohioensis	0	0	300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
odora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
rigida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Total cm bloom coverage	Air Station	Dixon	LFOL	Lyons	Midewin	Santa Fe	Burnham	Garfield	Humboldt	Lincoln	Lurie	Montrose	CTA	Joffrey	Notebaert	Optima	Tyner	U of Chicago
	Green roofs						Parks						Prairies					
Sonchus oleraceus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	52	0	0	0
Stachys officinalis	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
Taraxicum officinale	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Teucrium canadense	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0
Thalspi arvense	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thyme	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thymus serpyllum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56
Tradescantia unknown	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
ohiensis	0	104	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
virginiana	0	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trifolium campestre	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0
dubium	20	18	1	0	64	0	41.8	45	11	4	0	199	4	0	0	0	0	0
hybridium	0	4	0	0	0	0	1772	0	67.5	0	0	14	0	0	0	0	0	0
repens	112	0	10	0	38	0	0	0	23.5	12	0	12	0	0	0	0	0	0
pratense	0	0	0	0	293	0	0	24	177	0	0	349	0	0	0	0	0	0
procumbens	20	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0
unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Verbascum thapsus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Verbena hastata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	0	0
stricta	0	0	0	0	0	0	0	0	0	0	0	92	0	0	0	0	0	0
urticifolia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Veronicastrum virginicum	0	0	0	0	0	0	148	0	0	0	0	0	0	0	0	0	0	0
Viola sagittata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zinnia angustifolia	0	0	0	0	0	0	0	166	0	0	0	0	0	0	0	0	0	0
elegans	0	0	0	0	0	0	0	340	0	0	0	0	0	0	0	0	0	0
unknown	0	0	0	0	0	0	0	154	0	0	0	0	0	0	0	0	0	0
Zizia aurea	0	4	0	0	71	0	0	0	0	56	0	0	0	0	0	0	0	0

2.05 Cluster analysis of plant species by site. The plant species presence, as well as density, estimated via bloom cover, at each site was used to determine the relatedness of each site based on the blooming floral community. The later stages of branching represent more closely related sites; the two most closely related are Midewin and Montrose.



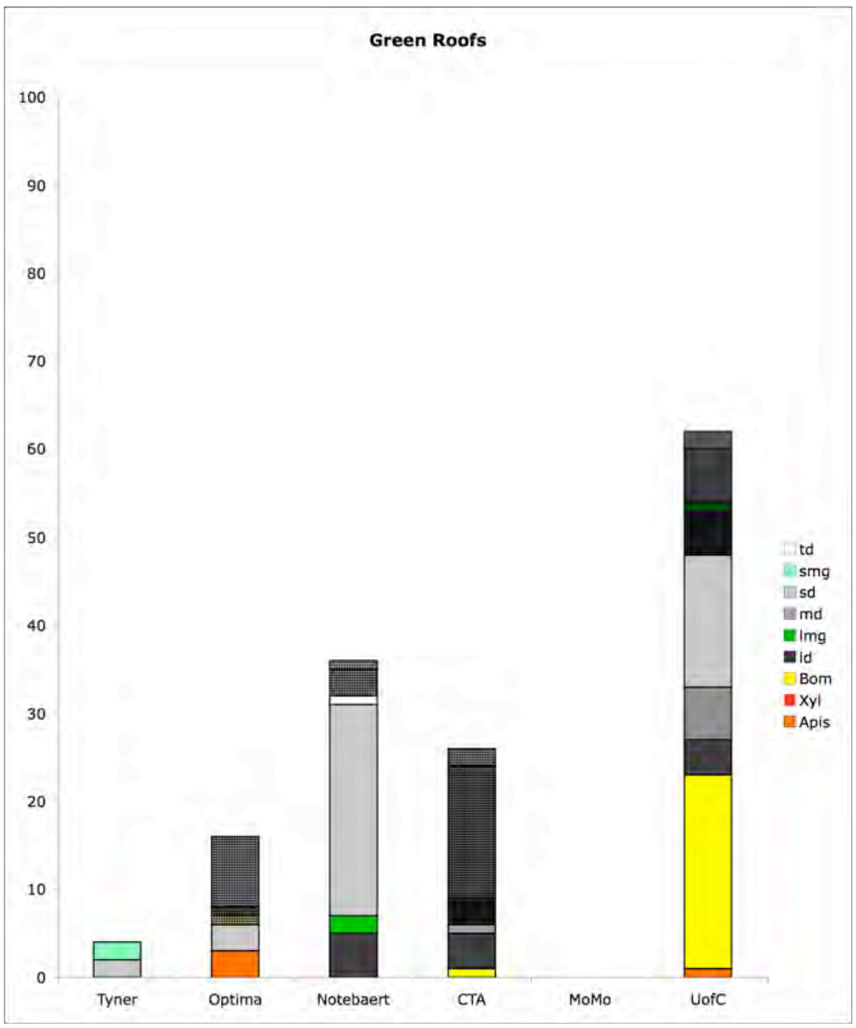
Appendix figure 2.05 Cluster analysis of plant species at each site. Sites are color coded: green roofs with green text, parks blue, and prairies yellow (See Table 1 for site information). All plant species and their bloom cover were included in this analysis.

2.06 Bee morpho-types visitation by site type

Green roofs

There were no bees seen during observations on the green roof of the Joffrey building, the only site to have no observed pollinating bees (see appendix). There were no *Xylocopa* spp. seen on green roofs during observation periods. Bumblebees, and *Apis mellifera*, the European honeybee, were each observed on only two of the six green roofs. The most commonly seen bees on rooftops were in the small dark identification category – consisting mainly of native sweat bees in the genera *Halictus* and *Lasioglossum*.

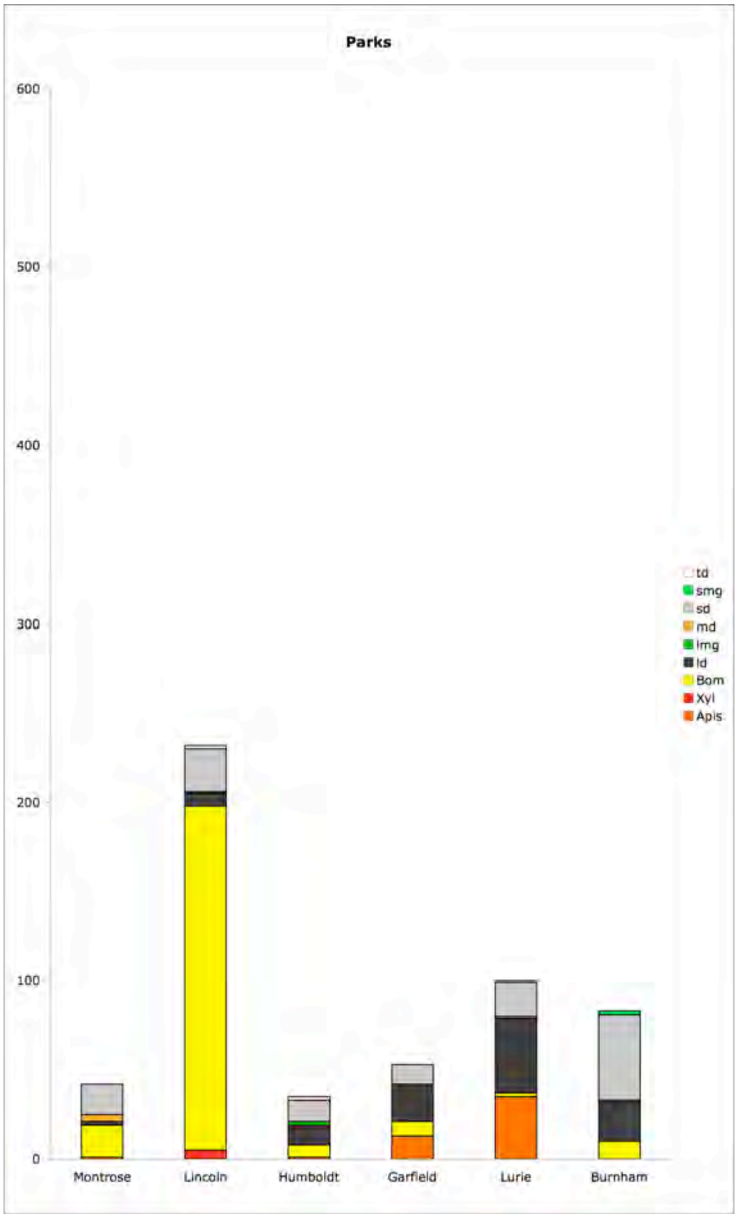
At many green roof sites, the addition of *Sedum* spp. observation periods drastically increases the number of total bees observed. All observations at *Sedum* spp. are included (Figure 2.08), and they were additionally observed whenever present, and blooming, on a green roof.



Appendix 2.06a. Total bees observed at green roof habitat sites. Sites are along the x axis, and total bees observed along the y axis. Color bands within bars correlate to the bee ID codes (see Table 2, and Figure 3).

Parks

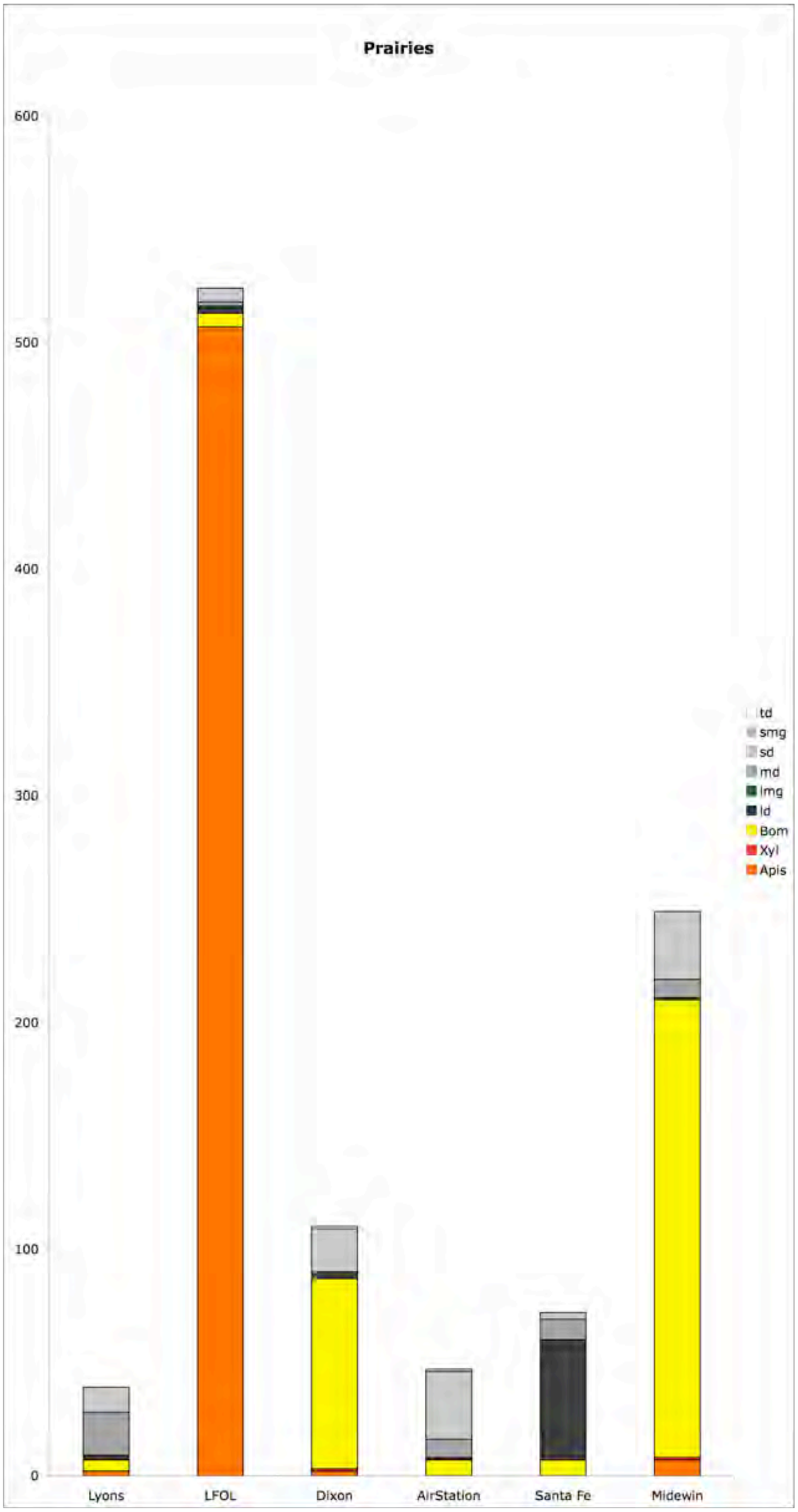
Bumblebees as well as small and large dark bees were seen pollinating observed flowers at all park sites. Honeybees were observed visiting focal flowers at four of the six park sites. Lincoln park had the greatest number of visitors, nearly twice as many as the second greatest visitor count at The Lurie Garden in Millennium Park.



Appendix 2.06b. Total bees observed at park habitat sites. Sites are along the x axis, and total bees observed along the y axis. Color bands within bars correlate to the bee ID codes (see Table 2, and Figure 3).

Prairies

The greatest number of bees observed pollinating focal flowers throughout the study was at the Lake Forest Openlands West Skokie River Prairie. The majority of these bees were honeybees. The greatest number of *Bombus* spp (bumblebees) were seen at Midewin National Tallgrass Prairie, yet none of the metallic green halictids were seen there (*Augochlora* spp, *Augochlorella* spp, *Agapostemon* spp). The large carpenter bees in the genus *Xylocopa* were observed only at the Midewin National Tallgrass Prairie and the Chicago Botanic Garden's Dixon Prairie.



Appendix figure 2.06c. Total bees observed at prairie habitat sites. Sites are along the x axis, and total bees observed along the y axis. Color bands within bars correlate to the bee ID codes (see Table 2, and Figure 3).

2.07 ANOVA results predicting total bee visits per observation period and visitation rate

For each generalized linear model, the predictors used were site type, focal floral density, number of blooming species within a 5m radius, and an estimate of bloom density within a 5m radius. Using a stepwise backward elimination method, an analysis of variance (ANOVA) was conducted to compare models (see appendix).

The four-way interactive model with site type, focal floral density, surrounding bloom density and surrounding bloom diversity was determined the most simplified model to predict the total bees seen on focal flowers per observation period ($p < 0.001$).

Appendix Table II.0.VI. Potential predictors of total bees per observation period total, and corrected for the number of flowers observed.

	Site type	Focal flower density	Surrounding bloom density	Surrounding bloom diversity
Total bees	***	***	***	***
Bees per flower observed	***	***	***`	***

n = 1525

Asterisks indicate significance * $0.01 < p < 0.05$, ** $0.001 < p < 0.01$, *** $p < 0.001$.

2.08 Paired site comparison of bee visitation

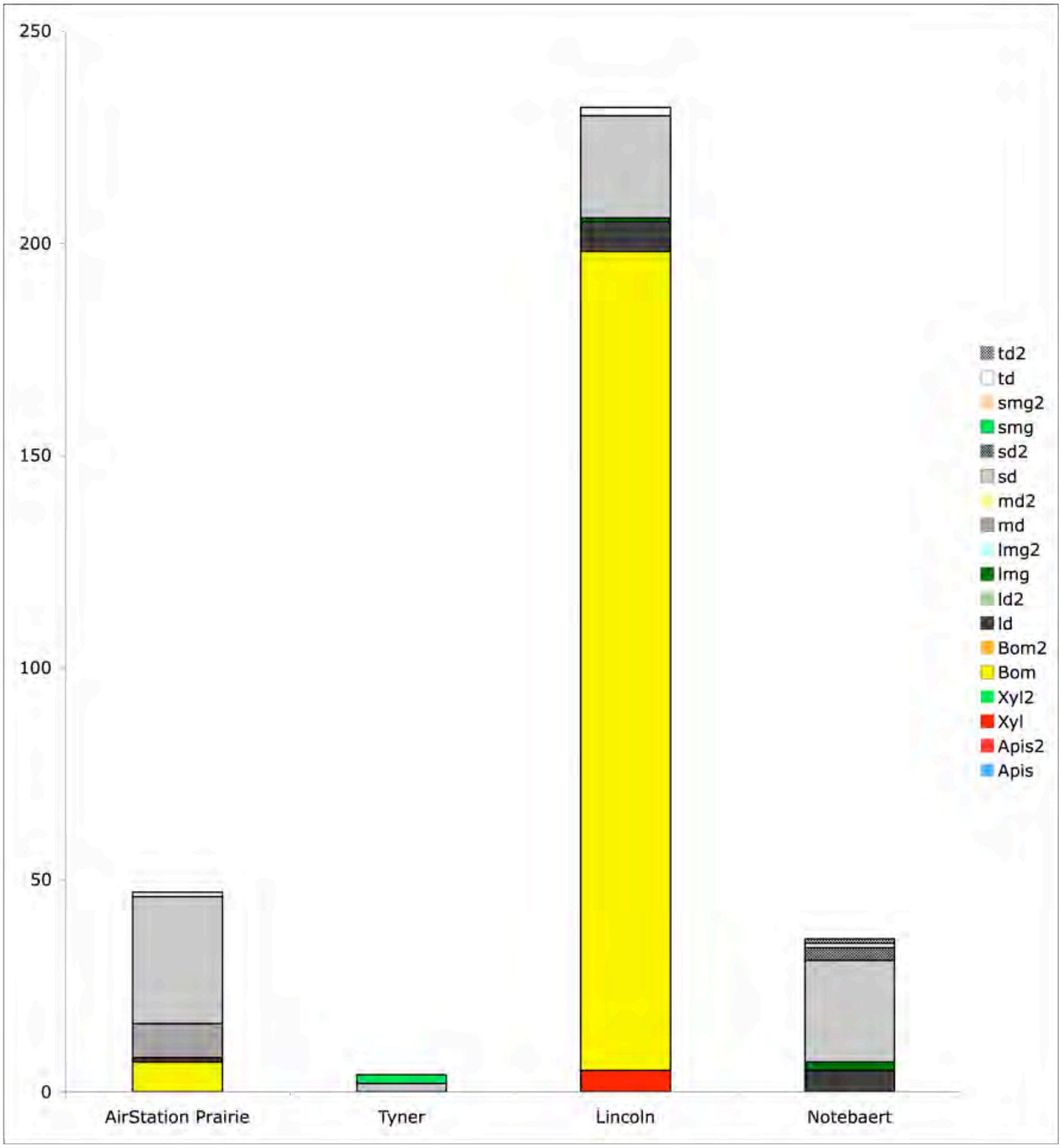
Both the green roof within a prairie and the one in a park had fewer bees per observation period than the ground counterparts (APPENDIX).

Air Station Prairie and the Tyner Interpretive Center

Observed flowers in the prairie received visits from five identification categories of bees, while those on the roof of the Tyner Interpretive Center were visited by only two identification categories. Only small dark bees were seen in both locations. Metallic green halictid bees were never seen visiting flowers in the prairie, but were spotted on the rooftop. There were nearly 10 times as many bees visiting flowers during observation periods in the prairie compared to the green roof.

Lincoln Park and the Peggy Notebaert Nature Museum

Nearly 200 more bees were observed in the park surrounding the green roof of the Notebaert Nature Museum compared to its green roof (Figure 10). Large carpenter bees (*Xylocopa*), and bumblebees (*Bombus*) were observed visiting flowers in the park, but not those on the rooftop. There were no identification categories of bees present on the green roof that were not also seen visiting observed flowers at the park below.



Appendix Figure 2.08. Observed bee identification categories at paired sites, by total number of visits per site per bee type at paired sites. The Tyner Interpretive Center green roof resides within Air Station Prairie, and the Notebaert Nature Museum green roof is surrounded by Lincoln Park. Sites are along the x axis, and total bees observed along the y axis. Color bands within bars correlate to the bee ID codes (see Table 2, and Figure 3).

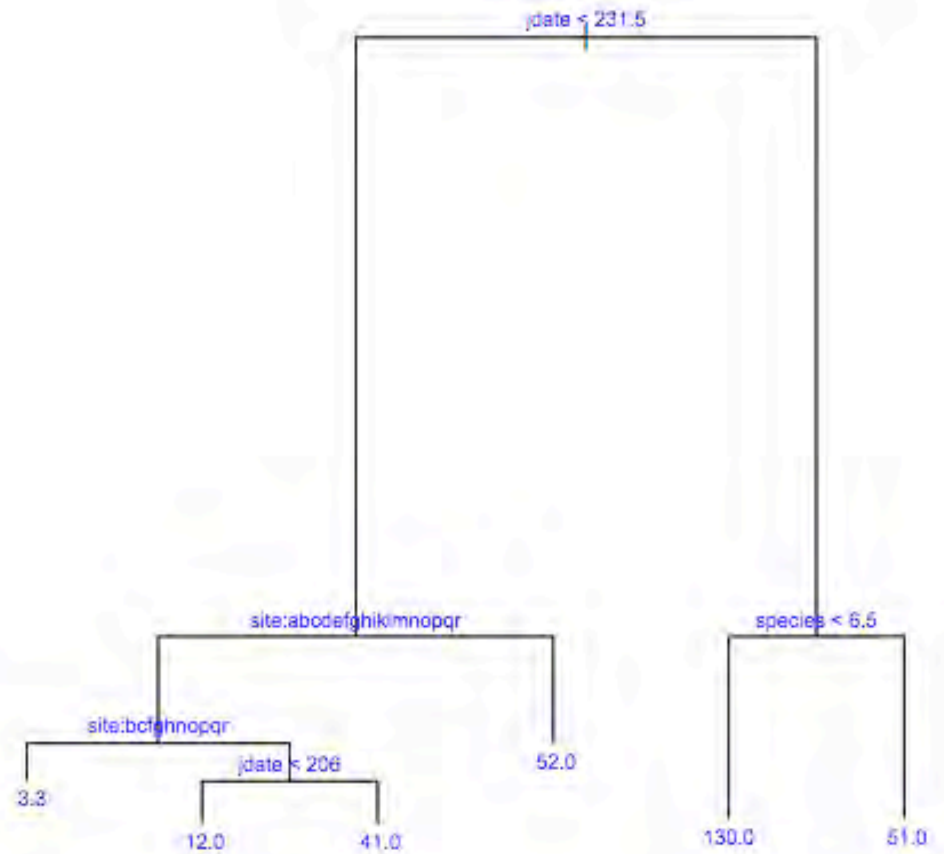
2.09 Similarity percentages of bee species abundance at paired sites of interest.
The Notebaert Nature Museum is surrounded by Lincoln Park and based on bee species abundance the two sites have an average dissimilarity rating of 82.09%. The majority of this contributed difference is due to the species *Lasioglossum anomalum*, accounting for approximately 40% of the dissimilarity. Likewise, the Air Station prairie in Glenview surrounds the Tyner Interpretive Center. Based on bee species abundance, these two sites are 52.63% dissimilar, with the bee species *Halictus ligatus* contributing to 30% of that differentiation.

A cluster analysis of sites based on bee species using Euclidean distance (Figure 8) designated Montrose Point and Midewin National Tallgrass Prairie, to be the two most alike sites based on bee species abundance, and plant species abundance.

Based on species contributions for a similarity percentage, the two sites are deemed 77.61% dissimilar.

2.10 Correlation of plant species and bee species
A Mantel test was used to compare the plant floral morphotypes at each site to the bee ID categories used for observation periods at each site. Wisconsin relativization was used, and found a Mantel statistic of 0.055, and a non-significant correlation of $p = 0.33$. When the same test was completed for all plant species recorded, and all bee species collected, there was a near correlation between bee species and plant species across sites in this study (Mantel statistic $r = 0.12$, $p = 0.08$).

2.11 Regression tree
The Julian date made the largest difference when determining the number of bee visits per observation period (Figure 9). For earlier days site was the next division, then site, and date again showing a nonlinear relationship. For later date observation periods the floral diversity within a 5m radius of the observation site made the largest difference in regard to the total number of bee visits, sites with less than 5.5 species in the 5m radius had more visits to the focal flowers of interest compared to sites with greater than 5.5 species in a 5m radius.



Appendix figure 2.11 Regression tree of total bee visits per site with all environmental, weather, and floral data as potential branches. Includes date of observation, floral morphology observed, habitat type, site, all floral data collected, as well as temperature, wind speed and sky condition. At the bottom of each branch is the number of observation days that fell under each hierarchical branching.

Appendix 3.0
Discussion expansion

3.1 Native plant species richness and insect species richness

Panzer and Schwartz (1998) determined that native plant species richness coupled with area explained 80 – 85% of variance in conservative insect species richness on average at 50 prairie reserves in the Chicago region. In this study, butterflies and leafhoppers were identified, yet bees were lumped into an "all insect" category. This indicates that plant species richness may be an indicator of insect richness in tallgrass prairie, a finding similar to this study.

3.2 Prescribed burns

The effects of fire have a major role in determining the short-term insect community (Panzer, 2001). Sites with spring burns include portions of the Dixon prairie at the Chicago Botanic Garden, the natural area of Lincoln Park, portions of Montrose Point and Humboldt Park and Burnham. Nearly ¾ of prairie inhabiting insect species in the Midwest also habitate in the surrounding landscape, and are unlikely to be affected by fire. Panzer et al. determined native bees not to be remnant dependant insects in Illinois prairies, and are assumed to be a part of the ¾ of species not greatly affected by fire. Highly sensitive species, requiring three or more years to recover from a burn, are considered both rare, and scarce, with nearly 75% of all insect species either unaffected, or recovered within one year.