Ceres Trust Graduate Student Grant: Final Report

Project title: Wild bee abundance and diversity on organic vegetable farms in response to local landscape factors

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ABSTRACT

Agricultural intensification has been linked to the decline of pollinators like bees. Organic farms often support a richer wildlife community than conventional farms, and help provide necessary pollinator habitat in intensively farmed, homogeneous areas. Central Wisconsin represents such an intensively farmed area, but the landscape is far from homogeneous. Conventional rotations of processing vegetables with varying degrees of pollinator dependence are grown in high concentrations in this region. The suitability of central Wisconsin as pollinator habitat, both within the bounds of organic farming operations and in the surrounding landscape, has not been well studied. This project's aims were to quantify the bee species living in central Wisconsin and determine whether organic farms located in this area influence local pollinator communities as compared to marginal lands in the same region. We surveyed the seasonal abundance, diversity, and species richness of a small-scale organic vegetable farm, a large-scale organic vegetable farm, and of semi-natural conventional vegetable field margins during the 2015 growing season. The large-scale and small-scale organic farms bore no significant differences in bee community metrics, though each harbored several unique bee species. The organic sites did not differ from semi-natural edges in abundance or diversity, but had significantly higher species richness. These results suggest that organic farms in agriculturally intensive but heterogeneous regions may harbor a higher number of bee species, but the overall diversity of the bee population and number of bees is no different than in surrounding unmanaged lands. Organic farmers in such a landscape who wish to conserve wild bee pollination on their property, regardless of their operation's scale, would do well to focus on improving local habitat features to increase overwintering abundance and diversity while recognizing that their farm's bee community is also affected by surrounding land uses.

INTRODUCTION

Wisconsin is a place where organic agriculture is growing. From 2000 to 2010 the number of organic farms in the state roughly doubled (Haines et al 2010), and Wisconsin now ranks fifth in the nation in terms of total organic sales (USDA NASS 2014). Although the majority of these sales are generated by dairy operations clustered in the southwestern region of the state (Haines et al 2010), about 10% of Wisconsin's total organic sales are vegetables (USDA NASS 2014).

The presence of organic farms in agricultural landscapes can be a boon for populations of wildlife and insects (Hole et al 2005). Wild and domesticated bee species have been experiencing a global decline during the last several decades (National Academic Press 2007, Potts et al 2010) that has been exacerbated by habitat loss from expanding agriculture (Klein et al 2007**,** Kennedy et al 2013, Kremen et al 2007, Ricketts et al 2008). Though cash crops like maize and soybeans would be largely unaffected by bee decline because they do not rely on insect pollination, many fruit and vegetable crops like cucurbits, tomatoes, berries, and tree fruit are heavily dependent on pollination by bees (USDA 2015a) and thus may be vulnerable to a decline in crop yield. Such pollinator-dependent crops are often grown on organic Wisconsin farms (Carusi et al 2015).

When compared to conventional farms, organic farms consistently harbor higher plant diversity, due in part to decreased agrochemical use (Hole et al 2005, Andersson et al 2014, Bengtsson et al 2005, Gabriel et al 2010). Both decreased pesticide use and increased floral diversity can benefit highly mobile species like birds, beetles, and butterflies (Bengtsson et al 2005, Hole et al 2005). The suitability of organic farms as refuge habitat for bees, however, is not always certain (Brittain et al 2010). Bees are central place foragers whose movement is limited to within the radius of a centrally located nest site. Thus, the bee community of organic farms is a function of both on-farm practices as well as the suitability of the surrounding landscape (Brittain et al 2010, Gabriel et al 2010, Andersson et al 2014, Tscharntke et al 2005). Organic farm practices may only beget increased pollination services when the farm is situated in a heterogeneous area (Andersson et al 2014).

Central Wisconsin is unique in that it is heavily cultivated but also heterogeneous when compared with other agriculturally intensive regions. The region's soil is sandy with poor water retention (WI DNR 2014), but extensive irrigation has made central Wisconsin well-suited for growing high-value specialty crops like cranberry, potatoes, sweet corn, and other vegetables (Haines et al 2010). Central Wisconsin is now a prominent region of conventional vegetable cultivation. A variety of fields growing pollinator-dependent and nondependent vegetables share space and rotation, resulting in a mosaic of diverse crops and management regimes across the landscape. The central Wisconsin region is also the least-studied bee community in the state (Wolf & Ascher 2008).

As goals are set to conserve declining pollinator populations at both federal (USDA 2015b) and state (WI DATCP 2016) levels, the role of organic farms in pollinator conservation efforts needs to be further explored. Since on-farm management practices can be influential, the effect of an organic operation's scale merits further investigation. So too does the habitat suitability of the heterogeneous conventional landscape of central Wisconsin. Though untilled pollinator habitat exists in marginal lands, its suitability when located in close proximity to conventional agriculture is not yet known. Previous research from the United Kingdom has found that semi-natural plant communities on marginal lands tend to be better for pollinators when they are not immediately next to conventional fields (Hanley & Wilkins 2015).

Central Wisconsin is not an organic stronghold - there are only 11 fresh market vegetable farms in the most intensively farmed central three counties (Portage, Waushara, and Adams Counties), and only four of these farms are certified organic as of 2016 (Farm Fresh Atlas 2016). But organic farmers in this region and others like it deserve to know how wild bee populations respond to their farm management practices. Such data will inform pollinator conservation practices for organic growers who are not isolated, but are also not surrounded by conventional cash crop rotations.

OBJECTIVES

The objectives of this study were to compare the effect of location on the season-long abundance, diversity, and species richness of bee communities on organic farms within central Wisconsin. We compared a large-scale organic vegetable farm, a small-scale vegetable organic farm, and semi-natural marginal lands bordering conventional vegetable fields as three land use types which may equally or differentially offer safe harbor for pollinator communities within the area.

MATERIALS AND METHODS

Data Collection

Two certified organic farms were selected for this study from within the three most heavily farmed vegetable growing counties of central Wisconsin (Portage, Adams, and Waushara Counties). Flyte Family Farms of Coloma, WI (Waushara County) has hundreds of acres in organic vegetable production. A 255-acre portion was selected as a study site to represent large-scale organic cultivation. The second organic site was Whitefeather Organics LLC of Custer, WI (Portage County), a 23-acre diversified vegetable and livestock operation that represented this study's small-scale organic farm. Both farms were situated in areas of predominant conventional agriculture (**Fig. 1**).

The farm sites were visited weekly for ten weeks during the height of bee activity, from June 10 to August 11, 2015. At each site the bee community was sampled within a 100 m^2 grid of nine evenly spaced "bee bowls" -plastic bowls colored white, blue and yellow (three of each color) to specifically attract foraging bees, based on recommendations by Droege (2008). The bowls were filled with a mixture of water and dish soap that prevented any landing bees from escaping the bowls. Each grid was placed near the edge of a flowering crop within the bounds of the farm for 24-48 hours to capture the full temporal range of range of bee activity. At the end of the sampling period, any bees caught were collected from the traps, mounted, and identified to the species level with the assistance of Dr. Jason Gibbs, Michigan State University.

In addition to setting traps on the two organic farms, bee community data were obtained from thirteen semi-natural, conventional vegetable field margins (**Fig. 1**). Each semi-natural site was located in a patch of untilled land directly adjacent to a conventionally grown, flowering vegetable crop (peas, beans, or sweet corn as the season's phenology dictated). Sampling periods of semi-natural areas coincided with the organic farms' sampling periods, and were also undertaken using 100 m^2 grids of colored bee bowl traps set for 24-48 hours.

To obtain a measure of bee abundance, the total number of individual bees captured at each site was divided by the number of hours in that particular sampling period. To obtain a measure of species richness, the total number of different species captured during each sampling period was calculated. To obtain a measure of bee diversity, the Shannon-Wiener Diversity Index value (*H*) was calculated for each site using the following formula:

$$H = -\sum[p_i \cdot \ln(p_i)]$$

Where p_i = the proportion of each site's population comprised by bee species *i*.

Data Analysis

All data were analyzed using R software, version 3.3.0 (R Core Team 2016). Comparisons of land use and bee community metrics were analyzed with a multiway analysis of variance (ANOVA) using a general linear model. Diversity and richness were analyzed as raw values, and abundance data were square root transformed to fit assumptions of normal distribution and equal variance. The effect of time was omitted as an interactive factor, and thus was not included in the models. *P*-values were adjusted using the Tukey-Kramer post-hoc test.

RESULTS

A total of 531 individual bees representing 58 species were collected during the course of this study, including 22 individuals of the domesticated honey bee *Apis mellifera* (**Table 1**). Fourteen bee species were unique to the large-scale farm, five were unique to the small-scale farm, and one was unique to organic farms. None of the bee species were uniquely found in semi-natural edge sites. One species, *Lassioglossum semicaeruleum*, was a new record east of the Mississippi river.

The bee communities of small-scale and large-scale organic farms did not significantly differ when we used time as our source of replication in the study (**Fig. 2**). There were no significant differences in the diversity (F = 0.080 on 1, 18 df, p = 0.780), the species richness (F = 0.233 on 1, 18 df, p = 0.635), nor the abundance (F = 0.106 on 1, 18 df, p = 0.748) of bees on the two organic farms. These data imply that, regardless of the size of representative organic growers in central Wisconsin, the number of unique bee species (species richness), and those species' relative abundances within the population (diversity) will likely be similar.

Given that the scale of organic farms did not influence measures of pollinator abundance or diversity, mean responses across both organically managed operations were compared to semi-natural conventional edge sites. Taken together, organic farms harbored significantly higher species richness (F = 5.84 on 1, 31 df, p = 0.022) (**Fig. 2**), though there was no significant difference in diversity (F = 1.780 on 1, 31 df, p = 0.192) or abundance (F = 1.77 on 1, 31 df, p = 0.193) among these land management types. A slight numeric increase in overall pollinator abundance and diversity was observed in the organic operations when compared to conventional field edges but was non-significant. Although the total number of different species (e.g. species richness) tended to be higher in organic sites versus conventional, this difference did not amount to a significant increase in overall bee activity, nor a more diverse bee community.

DISCUSSION

Organic farmers wishing to increase the prevalence of wild bees on their farms may consider prioritize retaining habitat for wild bee species to increase localized abundance and diversity. Since soil-nesting bees made up the majority (75%) of species captured in this study, setting aside patches of undisturbed nesting habitat within the bounds of the farm would be useful. Previous research in central Wisconsin vegetables has found a similar prevalence of soil-nesting bees (Lowenstein et al 2012). Such species benefit from minimized soil disturbances such as those caused by tillage, compaction from heavy equipment, and residual pesticides.

Since the wild bee diversity and abundance was similar across all study sites within the region, it remains inconclusive whether organic farms in central Wisconsin can be considered refuge for vulnerable bee species. Compounding this uncertainty is the fact that little information exists describing the conservation status of most North American bee species. In fact, of all the species found in this study only those in the *Bombus* genus have status listings with the International Union for the Conservation of Nature (IUCN), of which *B. fervidus* is considered "vulnerable" (IUCN 2016). Coincidentally, this species was collected from all three land use types.

The present study was limited in its replication and time frame. Greater replication of organic farms could have increased our statistical power to resolve the numeric responses we consistently observed in our investigations. The *p*-values comparing organic with field edges were much lower than the *p*-values of the two organic farms compared to each other, for example, so it's possible that a study encompassing more organic farms over a longer time period with greater sampling replication could result in a more pronounced difference in the bee community between sites. It is also possible that the heterogeneous agricultural landscape of Central Wisconsin is equally favorable for wild bees as are organic farms. If the community of organic vegetable growers in central Wisconsin follows the same increasing trend as the total number of organic growers in the state, further replication in the region may become possible.

CONCLUSIONS

Small-scale and large-scale organic farms in the heart of central Wisconsin's vegetable growing landscape harbor similar bee communities and have an overall greater number of species than the pollinator communities of semi-natural areas adjacent to conventional fields. Organic farmers in this region and others like it can adapt their farm management plans to focus on retaining these species on their farms to increase localized abundance and diversity.

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OUTREACH AND EXTENSION

The results of this study were presented at the 2015 MOSES conference in Lacrosse, Wisconsin, and the 2016 Entomological Society of America conference in Cleveland, Ohio. Additionally, a publication is in progress and planned for submission to the *Journal of Insect Conservation*.

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Figure 1. The location of small-scale (yellow) and large-scale (orange) organic farm sites along with 13 uncultivated conventional edge sites within the vegetable growing study region (vegetable fields indicated in green) located in Portage, Waushara, and Adams Counties of central Wisconsin.

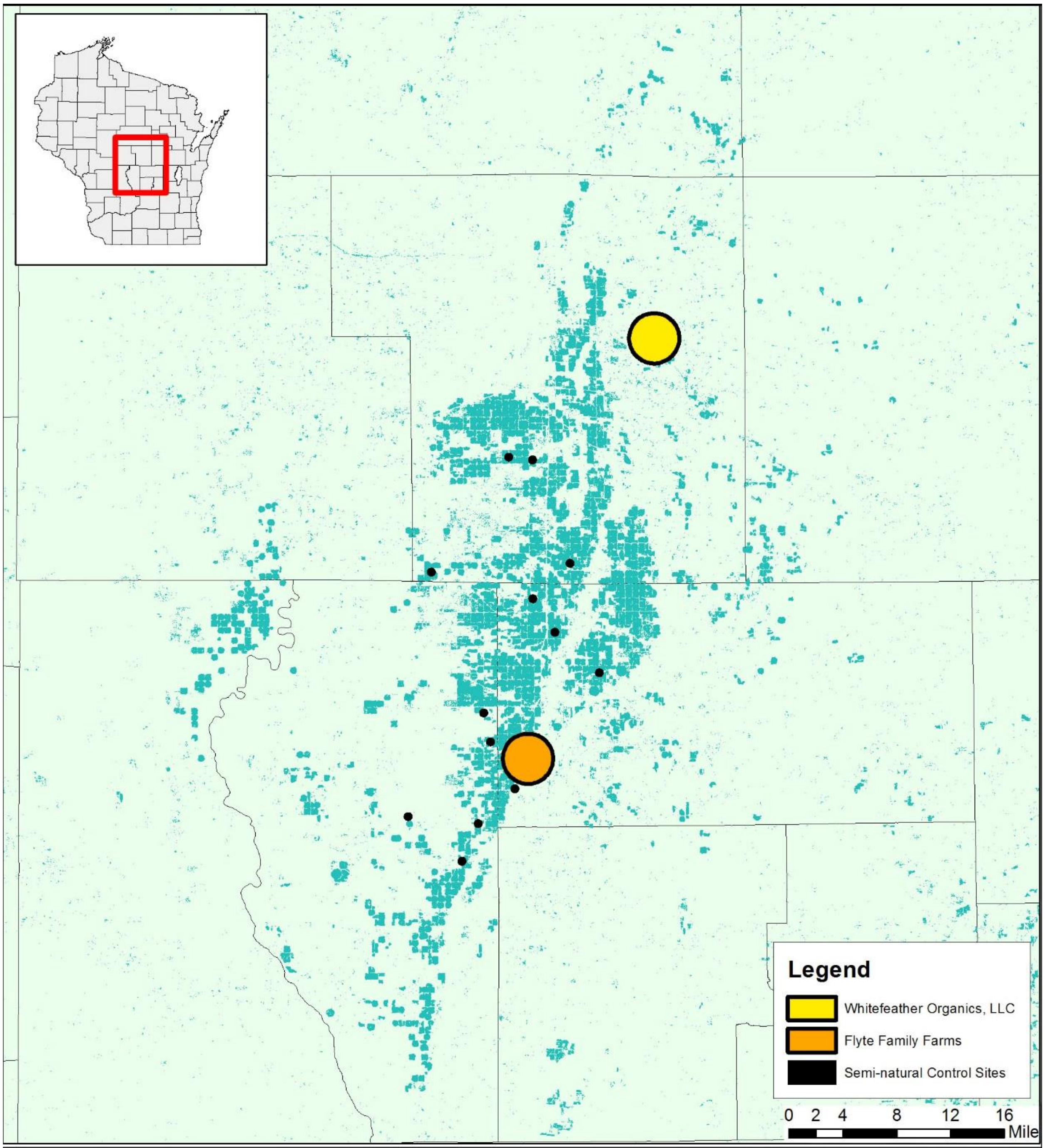

Figure 2. A comparison of the mean diversity, species richness, and abundance of bees in small-scale versus large-scale organic farms and bees in organic sites versus uncultivated conventional edge sites located in Portage, Waushara, and Adams Counties in central Wisconsin.

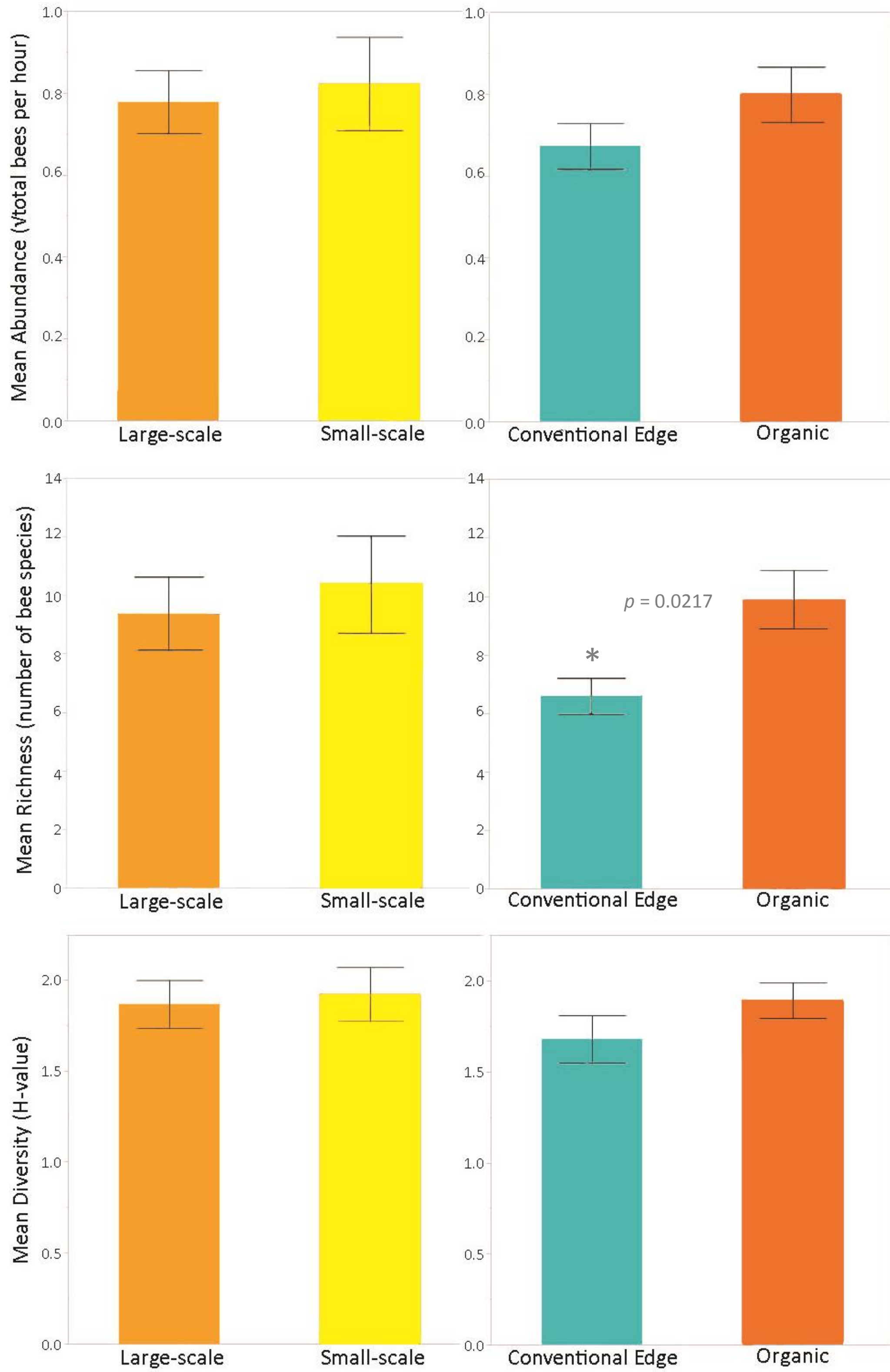

Table 1. Unique bee species collected and identified from small and large-scale organic farms and uncultivated conventional edge sites in Portage, Waushara, and Adams Counties in central Wisconsin

Bee Family	Bee Species	Number	Sociality	Nesting
APIDAE	*Apis mellifera*	22	Eusocial	Hive
	Bombus bimaculatus[1]	2	Eusocial	Hive
	Bombus borealis	2	Eusocial	Hive
	Bombus fervidus	10	Eusocial	Hive
	Bombus impatiens	7	Eusocial	Hive
	Bombus perplexus	2	Eusocial	Hive
	Bombus rufocinctus[2]	3	Eusocial	Hive
	Bombus ternarius	1	Eusocial	Hive
	Bombus vagans	1	Eusocial	Hive
	Melissodes agilis	1	Solitary	Soil
	Melissodes bimaculata	2	Solitary	Soil
	Melissodes druriella	4	Solitary	Soil
ANDRENIDAE	*Andrena alleghaniensis*[1]	1		
	Andrena crataegi[1]	1	Solitary	Soil
	Hylaeus affinis	4		
	Hylaeus mesillae[1]	1	Solitary	Cavity
	Perdita halictoides[1]	1		
HALICTIDAE	*Agapostemon sericeus*[1]	1	Solitary	Soil
	Agapostemon texanus	8	Solitary	Soil
	Agapostemon virescens	24	Solitary	Soil
	Augochlorella aurata	26	Eusocial	Soil
	Halictus confuses	26	Eusocial	Soil
	Halictus ligatus	2	Eusocial	Soil
	Lasioglossum acuminatum	1	Solitary	Soil
	Lasioglossum admirandum	22	Eusocial	Soil
	Lasioglossum albipenne	7	Eusocial	Soil
	Lasioglossum cinctipes	2	Eusocial	
	Lasioglossum coriaceum	6	Solitary	Soil
	Lasioglossum cressonii	3	Eusocial	Wood
	Lasioglossum floridanum[1]	1		
	Lasioglossum hitchensi	1		
	Lasioglossum leucocomum	49		
	Lasioglossum leucozonium	25	Solitary	Soil
	Lasioglossum lineatulum	9	Eusocial	Soil
	Lasioglossum lustrans	1	Solitary	Soil
	Lasioglossum oceanicum	13	Eusocial	
	Lasioglossum paradmirandum[3]	2	Eusocial	Soil

	Lasioglossm paraforbesii	4	Solitary	Soil
	Lasioglossum pectoral	28	Solitary	Soil
	Lasioglossum perpunctatum	8	Eusocial	Soil
	Lasioglossum pictum	12	Eusocial	Soil
	Lasioglossum pilosum	67	Eusocial	Soil
	Lasioglossum planatum[1]	1	Eusocial	Soil
	Lasioglossum pruinosum	1	Eusocial	Soil
	Lasioglossum semicaeruleum[1]	1		
	Lasioglossum smilacinae[2]	1		
	Lasioglossum subviridatum[1]	2	Eusocial	Soil
	Lasioglossum tegulare[2]	1	Eusocial	Soil
	Lasioglossum versatum	68	Semi-social	Soil
	Lasioglossum vierecki	6	Eusocial	Soil
	Sphecodes davisii	3	Parasitic	Soil
	Sphecodes dichrous[2]	1	Parasitic	Soil
	Sphecodes mandibularis	1	Parasitic	Soil
MEGACHILIDAE	*Megachile addenda*[1]	1	Solitary	Soil
	Megachile campanulae[1]	1	Solitary	Cavity
	Megachile latimanus[1]	5	Solitary	Cavity
	Megachile pugnata[1]	2	Solitary	Cavity
	Osmia distincta[2]	1	Solitary	Cavity
	Total Bees	531		

[1] Unique to large-scale organic site

[2] Unique to small-scale organic site

[3] Unique to organic sites