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Wild Bee Community Assemblages Across Agricultural Landscapes¹

Erika M. Tucker² and Sandra M. Rehan^{2,3}

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ABSTRACT Wild bees are essential to the functioning of both agricultural and natural ecosystems, yet these pollinator communities are declining worldwide. Agricultural intensification by means of habitat and floral resource loss is thought to be one of the leading causes of wild bee population deterioration. This study examined multiple agricultural land use systems in New Hampshire to determine how wild bee biodiversity and community interactions are affected by different land use practices. A total of 2292 wild bees were collected during these surveys, representing 112 species. A high species overlap was found at all land use systems, although all sites had some species exclusivity. Land use significantly affected species abundance and richness. The moderately managed sites supported both the greatest pollinator abundance and species richness, while the low management sites had the smallest abundance and the same level of richness as the high management sites. The findings of this study support the importance of floral landscape diversity in bee conservation efforts and suggest that not all agricultural practices negatively affect the pollinator community.

KEY WORDS Apoidea, ecological associations, New England, New Hampshire, plant-pollinator interactions, agricultural land use

One of the primary factors contributing to the decline of wild bee population levels is the loss of habitat for nesting sites and foraging grounds in response to agricultural intensification (Matson et al. 1997, Tilman et al. 2001, Tschardt et al. 2005, Hernandez et al. 2009, Potts et al. 2010, Bartomeus et al. 2013, Vanbergen 2014, Senapathi et al. 2015). Agricultural intensification is an increase pesticide use, in agricultural land cover per unit space, or both. Intensification of the same kind of land cover often produces monocultures, which reduces both diversity and resource availability leading to lower pollinator richness and abundance (Matson et al. 1997, Potts et al. 2010, Bartomeus et al. 2013, Senapathi et al. 2015). The use of chemicals to control pest insects and undesirable plants in intensively managed systems is also high, negatively affecting pollinators by reducing potential forage as well as adversely altering prospective nesting sites (Hernandez et al. 2009, Potts et al. 2010).

The negative impact of agricultural intensification, its associated practices and the resulting landscape fragmentation, on biodiversity is supported by many

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studies (Robinson & Sutherland 2002, Tschardt et al. 2005, Hernandez et al. 2009, Weiner et al. 2014). For example, studies in North American watermelon fields and tropical rainforests indicate negative impacts on bee abundance and species richness with the introduction of agricultural practices using pesticides (Kremen et al. 2002, Cairns et al. 2005, Kennedy et al. 2013). Studies on farms across Europe showed decreases in wild bee biodiversity compared to nearby natural and semi-natural areas as agricultural practices in non-mass flowering crops and animal production increased (Goulson et al. 2008, Le Féon et al. 2010, 2013, Potts et al. 2010). While much research supports this outcome, other studies have found contradictory results and there is a growing body of literature with findings suggesting that lands used for agricultural purposes support enhanced pollinator biodiversity compared to non-managed areas (Pimentel et al. 1992, Jackson & Jackson 2002, Rosenzweig 2003, Tschardt et al. 2005, Winfree 2011).

Examples of agriculture increasing biodiversity in an ecosystem include, agroforestry areas and open cacao field systems (Hoehn et al. 2010). Organic farming techniques are often touted as supporting higher biodiversity than conventional practices (Holzschuh et al. 2007, Kovács-Hostyánszki et al. 2011). However, several studies have found no significant benefits of less managed agricultural farms, or organic farms, compared to conventional farming or naturalized lands (Weibull et al. 2000, Kleijn et al. 2001, Kehinde & Samways 2012). Research on pollinators and their services in vineyard settings also found organic management to have no positive effect on insect communities (Brittain et al. 2010, Bruggisser et al. 2010, Kehinde & Samways 2012).

There are, however, other factors to consider when evaluating the impact of habitat disturbance and agricultural land use practice. Belfrage et al. (2005) found farm size to be more influential than organic versus conventional practices in predicting species diversity and abundance. Many of these responses appear to be dependent on the system or region studied as well as the reference system to which practices are compared (Hernandez et al. 2009, Hoehn et al. 2010, Weiner et al. 2014). Floral diversity and abundance are also keys in determining bee community composition (Gathmann et al. 1994, Tschardt et al. 1998, Hostetler & McIntyre 2001, Steffan-Dewenter & Tschardt 2001, Carvell 2002, Potts et al. 2003, Gill et al. 2016). Bee diversity often correlates with floral and landscape diversity (Andersson et al. 2013, Rutgers-Kelly & Richards 2013, Ellis & Barbercheck 2015), which may be a more important factor in determining the bee community than specific agricultural practices.

The wild bee community is a complex system with the varied responses to agricultural influences requiring in-depth regionally relevant research before adequate bee conservation strategies can be successfully implemented (Potts et al. 2003, Hole et al. 2005, Kehinde & Samways 2012, Gill et al. 2016). Reconstructions of plant-pollinator networks can help in understanding complex communities (Grass et al. 2013, Weiner et al. 2014, Tucker & Rehan 2016). The interactions between plants co-occurring with pollinators form networks that determine the structure on the community, which when evaluated, provide information on pollinator floral preferences and habitat as well as identifying keystone species (Bartomeus et al. 2013, Burkle et al. 2013, Grass et al. 2013, Russo et al. 2013, Senapati et al. 2015, Wright et al. 2015). This information can be used to ascertain system vulnerabilities and requirements needed for community, species,

or interaction preservation (Montoya et al. 2006, Grass et al. 2013, Weiner et al. 2014, Tucker & Rehan 2016).

The northern New England area has a vast diversity of natural habitats intermixed with many farmlands of varying agricultural practices and management intensity. Previous research in northern New England has found that the pollinator community is likely to have high regional specificity requiring research into agricultural effects on bees in this area (Tucker & Rehan 2016). Modeling of historic wild bee population records and land use practices across the United States has also identified New England as a region with limited data, in need of further research on land management in relation to pollinator communities (Koh et al. 2016). With the wide diversity of bee community responses to agricultural practices in different locations, it is essential to research as many farming ecosystems and practices in different regions as possible to best understand how to conserve and promote wild bee populations. Additional regional specific research is also needed to evaluate how different agricultural land use affects bee biodiversity and community structure.

There are 113 bee species known to southern New Hampshire (Tucker & Rehan 2016). Our study aims to evaluate how agricultural practices affect wild bee communities by, 1) determining the variation in bee abundance and diversity across three land use types, 2) assessing bee community stability of plant-pollinator interactions among multiple landscapes to determine which are the most robust, and 3) identifying agricultural land practices most sustainable for wild bees in New Hampshire. This research will ultimately provide information essential to wild bee conservation efforts.

Materials and Methods

Experimental design. Three agricultural land use types were chosen in Strafford County, New Hampshire, and categorized as conventional, organic and meadow systems. Each site averaged 200 acres and distance between sites averaged 4.5 km apart. Three replicate sites for each land use type were established for sampling. Within each replicate site bees were actively sampled along three 100-m long transects (for a total of nine sampling transects per land use type).

Meadow sites were located on former farmland that were mowed once each fall and composed only of naturally-occurring plant species. We considered naturally occurring plant species to be plants not purposely planted by humans. These consisted largely of native and weedy like flowers such as *Rudbeckia*, *Solidago*, and *Trifolium* species. The organic farm sites were located on non-pesticide use farmland adjacent to forestland. Sites were actively mowed every 4–6 wk. These sites were adjacent crops of strawberries, raspberries and apples. The conventional farm sites were located on pesticide use, agricultural farmland surrounded by woodlands. Transects were adjacent to apple orchard, and squash and melon crops. All sites were surrounded by extensive forestland.

Biweekly sampling over a total of 11 weeks in 2014 began the last week of April and continued through the end of September. Both pan trapping and sweep netting methods were used. Twenty-seven sampling transects (3 land use types \times 3 replicates per land use type \times 3 transects per replicate site) were used for pan trapping. Transects comprised 10 pan traps (7 cm diameter) of 3 alternating colors

(yellow, blue and white), each set 10 m from the next. Pan traps were positioned before 0800 hours, filled with soapy water and retrieved after 1600 hours. As trap contents were obtained, they were emptied through a small sieve to be deposited in a vial of 70% ethanol labeled with collection information.

Standardized sweep net sampling was also conducted, with a collapsible aerial net (Tucker & Rehan 2016), to collect bees from blooms of flowering plants. Dense patches of flowers present at each site (i.e., we did not plant flowers to sample) and spanning at least 1 m were identified and targeted for sweep samples. On the same days as pan trapping, flower species from each site were sampled for 5 min in 30-s intervals with 1-min pauses between to allow for bees to return from disturbance. Flowering plant species were sweep sampled between 1000 and 1400 hours. Flowers were imaged and identified in the field using field guides (Niering et al. 2001). The specimens from sweep sampling were placed in vials of 70% ethanol labeled with collection information.

Specimen curation and preservation. Voucher specimens of all species and associated data used for this study were deposited in the University of New Hampshire Insect Collection (Durham, NH). Bee specimens were pinned, given a unique barcode and identification number, and labeled with location, date, collection method and floral host where relevant. All specimens were subsequently identified to species using the interactive identification guides (Ascher et al. 2017) and recent taxonomic literature (Mitchell 1960, 1962, Gibbs 2011, Rehan & Sheffield 2011, Michener et al. 1994, Williams et al. 2014).

Bee abundance and species richness analyses. Datasets were compiled for both bee abundance and species richness to examine variation among management types, seasons, and replicate sites. Collection seasons were defined as early = April–May, mid = June–July, and late = August–September. Flower and bee species unique to each management system, unique to each site within a management system, common to all management systems and common to all sites in all management systems were determined. The flower dataset only contained sweep net sample data, and the bee datasets specific to sites within a land use type only contained pan trap sample data. Sweep net and pan trap samples were analyzed as separate datasets, as well as one combined dataset.

All statistical analyses were performed using the software program SPSS Statistics (IBM Corp. 2016). Ordinal logistic generalized linear models (GLM) tests were conducted on each dataset. Land use type and season were used as predictor variables and used to build main effects in the model. Post-hoc Tukey HSD analyses were subsequently performed to determine the source of significant differences. To estimate the ‘true’ species richness of the bee communities sampled and determine how well each landscape type was sampled a rarefaction test conducted with a Chao-1 estimate (Chao 1984, 1987, Colwell & Coddington 1994), an ACE and ACE-1 estimate (Chao & Lee 1992) and Jackknife estimate (Burnham & Overton 1978, 1979) using the R ‘SPECIES’ package (Wang 2011) for each landscape type.

Plant-pollinator analyses. There was no flower data associated with samples from the pan traps; therefore, plant-pollinator networks were based solely on data from the sweep net samples. Separate datasets were constructed for each of the three management types and for each management type by season (early, mid and late season). The R package ‘bipartite’ was used to construct interaction networks (Memmott 1999, Dormann et al. 2008, 2009). The function *plotweb* was

used to evaluate community interactions and produce a visual representation of the network (Tylianakis et al. 2007). To determine whether species were relatively independent of each other or dependent on keystone species, and to evaluate the stability and robustness of the plant-pollinator community, interaction network statistics were calculated using the function *networklevel* (Dormann et al. 2009). To identify the most influential participants in each community and evaluate individual bee and flower species contributions, statistics were calculated using the function *specieslevel* (Dormann et al. 2009).

Weighted nestedness and connectance were examined at the community level. Community patterns of species co-occurrence and biome structure were measured by considering interaction frequencies using weighted nestedness (Galeano et al. 2009), where chaotic interactions = 0 (no overlap between generalist and specialist species) and completely nested = 1 (generalist and specialist interactions completely overlap). Complexity and durability of a community to species loss was measured by connectance (Dunne et al. 2002) to evaluate the proportion of possible interactions actually achieved, where all possible interaction between species used = 1 (all bee species visit all flowers and system is relatively robust to species loss) and no interactions between species = 0 (only one bee species visits each flower and each flower is only pollinated by that one species so the system is greatly affected by individual species loss). We also examined the Pollination Service Index (PSI) normalized degree, and degree at the species level. Degree measures the unique interactions per individual species or species diet breadth (number of pollinator species per flower or number of floral hosts per bee). For unbiased comparisons between species a relative measure was used, normalized degree, which scales the species degree to the number of possible pairings between species. The relative importance of each pollinator (or pollen source) was measured with PSI (Dormann et al. 2008), where pollinator services essential to the functioning of the ecosystem = 1 and pollinator services unimportant for a functioning ecosystem = 0.

Results

Bee abundance. A total of 2292 bee specimens were recorded, with 541 from conventional farm (40 Andrenidae, 105 Apidae, 3 Colletidae, 383 Halictidae and 10 Megachilidae), 520 from meadow (28 Andrenidae, 198 Apidae, 5 Colletidae, 272 Halictidae and 17 Megachilidae), and 1231 from organic farm (67 Andrenidae, 332 Apidae, 6 Colletidae, 813 Halictidae and 13 Megachilidae) landscapes. Across all sites, 290 bee specimens were recorded from early season, 1052 from mid-season, and 950 from late season (Figure 1). Bee abundance was significantly different among land use types in the pan trap samples ($\chi^2 = 9.385$, $df = 2$, $P = 0.009$) and sweep net samples ($\chi^2 = 12.029$, $df = 2$, $P = 0.002$). Post-hoc comparisons indicate that the mean abundance in the organic farm sites was significantly greater than that in the meadow sites in the pan samples ($P = 0.027$), and was significantly greater than those in conventional farm ($P = 0.006$) and meadow ($P = 0.029$) in the sweep samples.

Bee abundance was significantly different among land use types ($\chi^2 = 17.32$, $df = 2$, $P = 0.0002$) and seasons ($\chi^2 = 11.59$, $df = 2$, $P = 0.003$) in the combined samples. Post-hoc comparisons of land use types indicate the mean abundance in

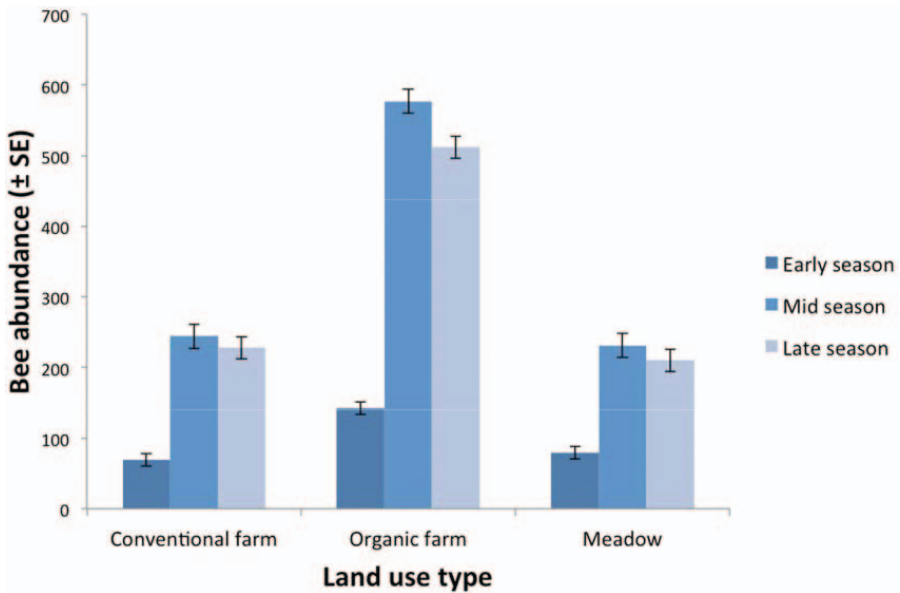


Fig. 1. Combined number of bee specimens from pan and sweep samples collected from each land use type by season. The organic farm land had significantly more bee abundance across all seasons. Across all land use types, there were significantly more bees collected mid-season.

the organic farm sites was significantly greater than those in meadow ($P = 0.001$) and conventional farm sites ($P = 0.001$). Post-hoc comparisons of seasons indicate the mean abundance in the mid-season was significantly greater than that in the early season ($P = 0.032$).

Species richness. A total of 112 bee species were recorded across all land use types, with 66 from the conventional farm sites (15 Andrenidae, 16 Apidae, 2 Colletidae, 26 Halictidae and 7 Megachilidae), 67 from the meadow sites (17 Andrenidae, 12 Apidae, 2 Colletidae, 29 Halictidae and 7 Megachilidae), and 78 from the organic farm sites (22 Andrenidae, 13 Apidae, 3 Colletidae, 32 Halictidae and 7 Megachilidae).

The rarefaction estimate of sampling completeness, using the ACE test lower bound, estimates true species richness to be 88 species for conventional farm (76% sampling effectiveness), 83 species for meadow (80%), and 87 species for organic farm (87%) sites. Other species richness tests provided similar species diversity estimates for the three landscape types (Chao = 86, 87, 85 species; ACE-1 = 96, 88, 89 species; Jackknife = 120, 92, 89 species). The overall estimate of sampling completeness for all farms was 83% of species sampled (ACE = 136 species; Chao = 140; ACE-1 = 144; Jackknife = 156).

Among land use types, 54 bee species were collected from early season, 75 from mid-season, and 60 from late season (Figure 2). Bee species richness was not significantly different in either the pan trap (land use: $\chi^2 = 2.732$, $df = 2$, $P = 0.255$; season: $\chi^2 = 0.592$, $df = 2$, $P = 0.744$) or sweep samples (land use: $\chi^2 = 2.732$, $df =$

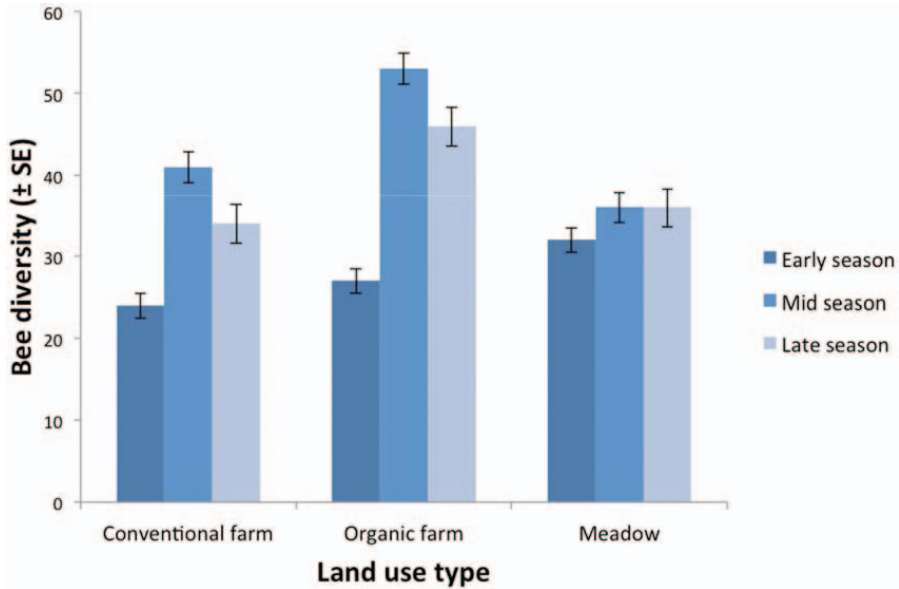


Fig. 2. Combined number of bee species from pan and sweep samples collected from each land use type by season. Bee species richness was significantly greater on the organic farm land, while season had no significant impact on bee species richness.

2, $P = 0.255$; season: $\chi^2 = 0.592$, $df = 2$, $P = 0.744$). It was, however, significantly different in the combined dataset among land use types ($\chi^2 = 8.774$, $df = 2$, $P = 0.012$), but not significantly different among seasons ($\chi^2 = 4.118$, $df = 2$, $P = 0.128$). Post-hoc comparisons of land use types indicate the mean species richness in the organic farm sites was significantly greater than those in other land use types (conventional farm sites: $P = 0.023$; meadow sites: $P = 0.047$).

Common and rare species. Species recurrence and unique associations were determined for each of the different land use types as well as for each of the sites within a land use type. There were 34 bee species found in all land use types, 13 species in all conventional farm sites, 8 species in all meadow sites, and 16 species in all organic farm sites (Table 1). The most common bee species were *Agapostemon virescens* (F.) (Hymenoptera: Halictidae), *Augochlorella aurata* (Smith) (Hymenoptera: Halictidae), *Bombus impatiens* Cresson (Hymenoptera: Apidae), *Lasioglossum coriaceum* (Smith) (Hymenoptera: Halictidae), and *Lasioglossum versatum* (Robertson) (Hymenoptera: Halictidae), which were found at all sites on all land use types. Conversely, 15 bee species were exclusively found at conventional farm sites, 16 only at meadow sites, and 21 unique to organic farm sites (Table 2). In the pan trap samples from all land use types, 40 species were found to be unique to one land use type, with 32 of those species only represented by single occurrence specimens.

Flower species were more land use specific. Only three flower species were found at all land use types: *Taraxacum* sp. (dandelion), *Trifolium repens* (white

Table 1. List of the most commonly found species and site specificity.

On all land use types	All conventional farm sites	All meadow sites	All organic farm sites
<i>Agapostemon texanus</i>	<i>Agapostemon virescens</i>	<i>Agapostemon virescens</i>	<i>Agapostemon texanus</i>
<i>Agapostemon virescens</i>	<i>Andrena asteris</i>	<i>Augochlorella aurata</i>	<i>Agapostemon virescens</i>
<i>Andrena carlini</i>	<i>Augochlorella aurata</i>	<i>Bombus impatiens</i>	<i>Augochlorella aurata</i>
<i>Andrena cressonii</i>	<i>Bombus impatiens</i>	<i>Lasioglossum admirandum</i>	<i>Bombus impatiens</i>
<i>Andrena dunningi</i>	<i>Halictus confusus</i>	<i>Lasioglossum coriaceum</i>	<i>Calliopsis andreniformis</i>
<i>Andrena nivalis</i>	<i>Halictus ligatus</i>	<i>Lasioglossum cressonii</i>	<i>Halictus confusus</i>
<i>Andrena wilkella</i>	<i>Lasioglossum admirandum</i>	<i>Lasioglossum laevissimum</i>	<i>Halictus ligatus</i>
<i>Anthidium oblongatum</i>	<i>Lasioglossum coriaceum</i>	<i>Lasioglossum versatum</i>	<i>Lasioglossum coriaceum</i>
<i>Augochlorella aurata</i>	<i>Lasioglossum fuscipenne</i>		<i>Lasioglossum cressonii</i>
<i>Augochloropsis metallica</i>	<i>Lasioglossum leucozonium</i>		<i>Lasioglossum fuscipenne</i>
<i>Bombus bimaculatus</i>	<i>Lasioglossum nymphaearum</i>		<i>Lasioglossum laevissimum</i>
<i>Bombus impatiens</i>	<i>Lasioglossum pectorale</i>		<i>Lasioglossum leucozonium</i>
<i>Bombus vagans</i>	<i>Lasioglossum versatum</i>		<i>Lasioglossum pilosum</i>
<i>Calliopsis andreniformis</i>			<i>Lasioglossum tegulare</i>
<i>Ceratina calcarata</i>			<i>Lasioglossum versatum</i>
<i>Ceratina dupla</i>			<i>Peponapis pruinosa</i>
<i>Ceratina mikmaqi</i>			
<i>Halictus confusus</i>			
<i>Halictus ligatus</i>			
<i>Hylaeus affinis</i>			
<i>Lasioglossum admirandum</i>			
<i>Lasioglossum albipenne</i>			
<i>Lasioglossum coriaceum</i>			
<i>Lasioglossum cressonii</i>			
<i>Lasioglossum fuscipenne</i>			
<i>Lasioglossum laevissimum</i>			
<i>Lasioglossum leucozonium</i>			
<i>Lasioglossum lineatulum</i>			
<i>Lasioglossum nymphaearum</i>			
<i>Lasioglossum pilosum</i>			
<i>Lasioglossum tegulare</i>			
<i>Lasioglossum versatum</i>			
<i>Osmia inermis</i>			
<i>Osmia inspergens</i>			

Table 2. List of the most uncommon bee species and site specificity.

Conventional farm only	Organic farm only	Meadow only	Only in 1 site (pan trap samples)	Single occurrence species (pan trap samples)
<i>Andrena carolina</i>	<i>Andrena alleghaniensis</i>	<i>Andrena erythronii</i>	<i>Andrena alleghaniensis</i>	<i>Andrena alleghaniensis</i>
<i>Andrena confederata</i>	<i>Andrena bisalicis</i>	<i>Andrena krigiana</i>	<i>Andrena bisalicis</i>	<i>Andrena bisalicis</i>
<i>Andrena fragilis</i>	<i>Andrena crataegi</i>	<i>Andrena robertsonii</i>	<i>Andrena braccata</i>	<i>Andrena carolina</i>
<i>Andrena hilaris</i>	<i>Andrena frigida</i>	<i>Andrena simplex</i>	<i>Andrena carolina</i>	<i>Andrena erythronii</i>
<i>Andrena regularis</i>	<i>Andrena geranii</i>	<i>Bombus fervidus</i>	<i>Andrena cressonii</i>	<i>Andrena fragilis</i>
<i>Anthidium manicatum</i>	<i>Andrena imitatrix</i>	<i>Bombus perplexus</i>	<i>Andrena dunningi</i>	<i>Andrena frigida</i>
<i>Hylaeus annulatus</i>	<i>Andrena nasonii</i>	<i>Calliopsis nebraskensis</i>	<i>Andrena erythronii</i>	<i>Andrena geranii</i>
<i>Lasioglossum abanci</i>	<i>Andrena vicina</i>	<i>Colletes inaequalis</i>	<i>Andrena fragilis</i>	<i>Andrena nasonii</i>
<i>Lasioglossum coeruleus</i>	<i>Anthophora terminalis</i>	<i>Lastoglossum atwoodi</i>	<i>Andrena frigida</i>	<i>Andrena robertsonii</i>
<i>Megachile relativa</i>	<i>Hylaeus mesillae</i>	<i>Lasioglossum imitatum</i>	<i>Andrena geranii</i>	<i>Anthidium manicatum</i>
<i>Melissodes desponsus</i>	<i>Hylaeus modestus</i>	<i>Lastoglossum oblongum</i>	<i>Andrena nasonii</i>	<i>Bombus fervidus</i>
<i>Melissodes trinodis</i>	<i>Lasioglossum bruneri</i>	<i>Lastoglossum oblongum</i>	<i>Andrena robertsonii</i>	<i>Colletes inaequalis</i>
<i>Nomada bella</i>	<i>Lasioglossum cinctipes</i>	<i>Nomada florilega</i>	<i>Andrena wilkella</i>	<i>Hylaeus annulatus</i>
<i>Nomada tiffonensis</i>	<i>Lasioglossum heterognathum</i>	<i>Osmia cornifrons</i>	<i>Anthidium manicatum</i>	<i>Lasioglossum atwoodi</i>
<i>Sphex minor</i>	<i>Lasioglossum hitchensi</i>	<i>Osmia georgica</i>	<i>Bombus fervidus</i>	<i>Lasioglossum coeruleus</i>
	<i>Lasioglossum leucocomum</i>	<i>Osmia taurus</i>	<i>Bombus griseocollis</i>	<i>Lasioglossum heterognathum</i>
	<i>Lasioglossum truncatum</i>	<i>Sphexodes levis</i>	<i>Colletes inaequalis</i>	<i>Lasioglossum oblongum</i>
	<i>Lasioglossum zonulum</i>		<i>Heriades carinata</i>	<i>Lasioglossum truncatum</i>
	<i>Peponapis pruinosa</i>		<i>Hylaeus annulatus</i>	<i>Lasioglossum zonulum</i>
	<i>Sphexodes autumnalis</i>		<i>Lastoglossum atwoodi</i>	<i>Megachile relativa</i>

Table 2. Continued.

Conventional farm only	Organic farm only	Meadow only	Only in 1 site (pan trap samples)	Single occurrence species (pan trap samples)
	<i>Sphécodes clematidis</i>		<i>Lasioglossum cinctipes</i>	<i>Melissodes desponsus</i>
			<i>Lasioglossum coeruleus</i>	<i>Melissodes trinodis</i>
			<i>Lasioglossum heterognathum</i>	<i>Nomada bella</i>
			<i>Lasioglossum oblongum</i>	<i>Nomada florilega</i>
			<i>Lasioglossum truncatum</i>	<i>Nomada tiftonensis</i>
			<i>Lasioglossum zonulum</i>	<i>Osmia cornifrons</i>
			<i>Megachile centuncularis</i>	<i>Osmia georgica</i>
			<i>Megachile relativa</i>	<i>Osmia taurus</i>
			<i>Melissodes desponsus</i>	<i>Sphécodes autumnalis</i>
			<i>Melissodes trinodis</i>	<i>Sphécodes levis</i>
			<i>Nomada bella</i>	<i>Sphécodes minor</i>
			<i>Nomada florilega</i>	
			<i>Nomada tiftonensis</i>	
			<i>Osmia cornifrons</i>	
			<i>Osmia georgica</i>	
			<i>Osmia taurus</i>	
			<i>Sphécodes autumnalis</i>	
			<i>Sphécodes levis</i>	
			<i>Sphécodes minor</i>	
			<i>Xylocopa virginica</i>	

Table 3. List of the most uncommon and common flower species and site specificity.

At conventional farm sites only	At meadow sites only	At organic farm sites only	At all sites on all land use types
<i>Chelidonium majus</i>	<i>Lonicera sp.</i>	<i>Rudbeckia sp.</i>	<i>Taraxacum sp.</i>
<i>Ranunculus sp.</i>	<i>Daucus carota</i>	<i>Asclepias tuberosa</i>	<i>Trifolium repens</i>
	<i>Asclepias sp.</i>	<i>Rudbeckia hirta</i>	<i>Trifolium pratense</i>
	<i>Centaurea jacea</i>	<i>Coreopsis lanceolata</i>	
	<i>Solidago canadensis</i>	<i>Echinacea purpurea</i>	
	<i>Silene latifolia</i>	<i>Hieracium sp.</i>	
	<i>Vicia sp.</i>	<i>Heliopsis sp.</i>	
	<i>Lotus corniculatus</i>	<i>Lupinus sp.</i>	
	<i>Potentilla recta</i>	<i>Rubus sp.</i>	
		<i>Trifolium incarnatum</i>	
		<i>Vernonia fasciculata</i>	
		<i>Agastache foeniculum</i>	
		<i>Monarda fistulosa</i>	
		<i>Erigeron philadelphicus</i>	
		<i>Heliopsis helianthoides</i>	
		<i>Salvia patens</i>	
		<i>Hieracium sp. 2</i>	
		<i>Fagopyrum esculentum</i>	
		<i>Syringa sp.</i>	

clover) and *Trifolium pratense* (red clover). Most of the flowers (73%) sampled were distinct among land use types (Table 3), with 2 species unique to conventional farm sites, 9 species found only at meadow sites, and 19 species exclusive to organic farm sites.

Plant-pollinator interactions. Plant-pollinator networks were constructed for each land use type (meadow, organic and conventional farms; Figure 3) as well as for the three seasons (early, mid, late) within each land use type. Although weighted nestedness was similar in all three land use types, the rest of the community composition changed among land use types varying in size (number of species), interactions and connectance (Table 4). The community composition was largest at organic farm sites with 38 bee species and 23 plant species. Weighted nestedness (species co-occurrence) was greatest in both conventional and organic farm sites (0.42), while connectance (resilience to species loss) was greatest in conventional farm sites (0.32). This indicates the plant-pollinator community is at its most complex at the conventional and organic farm sites and when community size is at its lowest in conventional farm sites it is also most robust and resilient to species loss.

Within each land use type, community composition varied by season, but seasonal variations in community composition within each land use type were similar to the seasonal variations observed in each of the other land use types (with the exception of conventional farm sites, where the community size was too small early and late season to accurately calculate all community statistics as indicated by N/A; Table 5). All land use types had the largest community size mid-season,

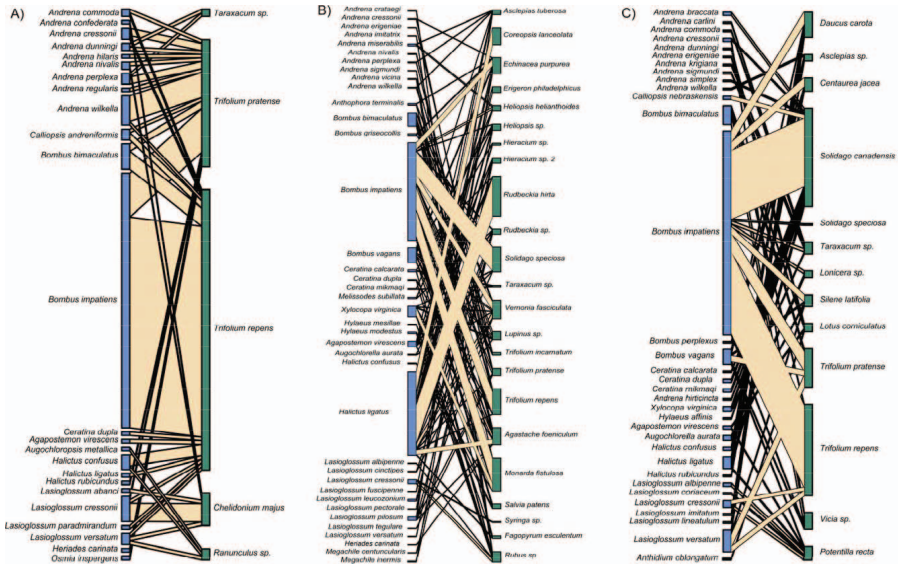


Fig. 3. Plant pollinator networks at different land use types. Bees are in blue on the left and flowers are in green on the right with number of interactions indicated by the breadth of the tan connections: A) conventional farm sites with 129 bees collected and total community size of 24 bee and 5 plant species, B) organic farm sites with 524 bees collected and a total community size of 39 bee and 23 plant species, C) meadow sites with 206 bees collected and a total community size of 33 bee and 13 plant species.

but organic farm and meadow had highest weighted nestedness in late season (0.90 and 0.59, respectively) and highest connectance early season (0.57 and 0.50, respectively).

Keystone pollinators and host plants. We used three species level network measures to assess the importance of individual bees (Table 6) at each land use type: degree (number of species associated with), normalized degree, and PSI. For conventional farm sites we found three bee species to be the most important pollinators, possibly keystone species in this habitat. *Lasioglossum cressonii* (Robertson) (Hymenoptera: Halictidae) and *L. versatum* had the broadest floral host breadth with the highest number of unique flower species interactions (3), and *B. impatiens* had the highest PSI value (0.68), which is likely due to its high abundance (70). At meadows, only one *B. impatiens* may be considered a keystone species. In this habitat, it is the most influential pollinator with highest abundance (123), floral host breadth (10) and PSI value (0.72). At organic farm sites, two bees were instrumental to the structure of the community. *Bombus impatiens* was most fundamental to the community with the most abundance (195), while *Halictus ligatus* Say (Hymenoptera: Halictidae) had the broadest floral breadth (16) and highest PSI (0.77). The organic farm sites had the highest number (59%) of generalist pollinators, categorized herein as a species associated with more than one flower species, contributing to the community. Generalist pollinators at

Table 4. Community level statistics. High values from this study in bold. Statistics from previous studies evaluating overall community networks are included for comparison. N/A indicate unavailable data or statistics.

Land use type	Weighted nestedness	Connectance	Number of bee species	Number of plant species	Unique species interactions	Total community size
Conventional farm	0.42	0.32	24	5	38	29
Organic farm	0.42	0.13	38	23	111	61
Meadow	0.39	0.14	33	13	62	46
Previous studies						
Seacoast NH (Tucker & Rehan 2016)	0.51	0.09	63	34	197	99
Agricultural farm PA (Russo et al. 2013)	N/A	0.16	64	25	261	89
Forest/grassland CO (Clements & Long 1923)	0.59	0.07	83	93	536	176
Deciduous forest NC (Moffen 1982)	0.48	0.25	35	13	143	48
Woodland IL (Schemske et al. 1978)	0.61	0.29	23	6	40	29
Shrublands Spain (Bartomeus et al. 2008)	0.59	0.26	16	23	97	39

Table 5. Community level statistics. Results from New Hampshire are divided into three land use types. Each land use type for the study is partitioned by season. High values from this study in bold. N/A indicates areas where input values were too low accurately calculate statistical value. Statistics from Russo et al. (2013) evaluating community network by season in Pennsylvania are in italics and included for comparison. Asterisks indicate unweighted results where weighted was unavailable.

Land use type	Season	Weighted nestedness	Connectance	Number of bee species	Number of plant species	Total community size
Conventional farm	Early	N/A	0.33	6	3	9
	Mid	0.26	0.48	22	3	25
	Late	N/A	N/A	2	1	3
Organic farm	Early	N/A	0.50	4	2	6
	Mid	0.38	0.14	36	16	52
Meadow	Late	0.59	0.29	14	8	22
	Early	0.53	0.57	7	2	9
	Mid	0.05	0.32	19	9	28
Agricultural farm PA (Russo et al. 2013)	Late	0.90	0.31	13	4	17
	Early	<i>2.80*</i>	0.23	<i>23</i>	8	<i>31</i>
	Mid	13.05*	<i>0.17</i>	<i>46</i>	<i>20</i>	66
	Late	<i>7.89*</i>	<i>0.16</i>	<i>34</i>	<i>19</i>	<i>53</i>

Table 6. Bee species statistics for each land use type. Only specimens from sweep samples are included. Highest values are in bold. Asterisks indicate non-native species (Droege 2015).

Land use type	Family	Bee Species	Abundance	Degree/ floral hosts	Normalized degree	PSI
Conventional farm	Andrenidae	<i>Andrena commoda</i>	2	2	0.40	0.02
		<i>Andrena confederata</i>	1	1	0.20	0.11
		<i>Andrena cressonii</i>	3	2	0.40	0.04
		<i>Andrena dunningi</i>	2	2	0.40	0.26
		<i>Andrena hiliaris</i>	1	1	0.20	0.03
		<i>Andrena nivalis</i>	2	2	0.40	0.07
		<i>Andrena perplexa</i>	3	2	0.40	0.20
		<i>Andrena regularis</i>	1	1	0.20	0.03
		<i>Andrena wilkella</i> *	8	2	0.40	0.18
		<i>Calliopsis andreniformis</i>	3	2	0.40	0.03
		<i>Bombus bimaculatus</i>	7	2	0.40	0.06
		<i>Bombus impatiens</i>	70	2	0.40	0.68
		<i>Ceratina dupla</i>	1	1	0.20	0.01
		<i>Agapostemon virescens</i>	1	1	0.20	0.01
		<i>Augochloropsis metallica</i>	1	1	0.20	0.33
		<i>Halictus confusus</i>	4	2	0.40	0.11
		<i>Halictus ligatus</i>	1	1	0.20	0.01
<i>Halictus rubicundus</i>	1	1	0.20	0.03		
<i>Lasiglossum abanci</i>	1	1	0.20	0.11		
<i>Lasiglossum cressonii</i>	7	3	0.40	0.60		
<i>Lasiglossum paradmirationum</i>	1	1	0.20	0.01		
<i>Lasiglossum versatum</i>	3	3	0.60	0.15		
<i>Heriades carinata</i>	1	1	0.20	0.03		
<i>Osmia inspergens</i>	1	1	0.20	0.03		
	Megachilidae					

Table 6. Continued.

Land use type	Family	Bee Species	Abundance	Degree/ floral hosts	Normalized degree	PSI
Organic farm	Andrenidae	<i>Andrena crataegi</i>	2	1	0.04	0.10
		<i>Andrena cressonii</i>	2	2	0.09	0.05
		<i>Andrena erigeniae</i>	1	1	0.04	0.20
		<i>Andrena imitatrix</i>	1	1	0.04	0.05
		<i>Andrena miserabilis</i>	3	2	0.09	0.25
		<i>Andrena nivalis</i>	2	1	0.04	0.04
		<i>Andrena perplexa</i>	1	2	0.09	0.09
		<i>Andrena signumidi</i>	1	1	0.04	0.05
		<i>Andrena vicina</i>	2	2	0.09	0.13
		<i>Andrena wilkella*</i>	1	2	0.09	0.09
		<i>Anthophora terminalis</i>	3	3	0.13	0.03
		<i>Bombus bimaculatus</i>	26	5	0.22	0.29
		<i>Bombus grisecollis</i>	3	2	0.09	0.05
		<i>Bombus impatiens</i>	195	13	0.57	0.71
		<i>Bombus vagans</i>	28	9	0.39	0.19
		<i>Ceratina calcarata</i>	4	3	0.13	0.41
		<i>Ceratina dupla</i>	2	2	0.09	0.03
<i>Ceratina mikmaqi</i>	2	2	0.09	0.22		
<i>Melissodes subillata</i>	4	3	0.13	0.11		
<i>Xylocopa virginica</i>	21	7	0.30	0.16		
Colletidae		<i>Hylaeus mesillae</i>	1	1	0.04	0.05
		<i>Hylaeus modestus</i>	3	1	0.04	0.15
Halictidae		<i>Agapostemon virescens</i>	10	7	0.30	0.14
		<i>Augochlorella aurata</i>	2	2	0.09	0.02
		<i>Halictus confusus</i>	2	2	0.09	0.06
		<i>Halictus ligatus</i>	166	16	0.70	0.77

Table 6. Continued.

Land use type	Family	Bee Species	Abundance	Degree/ floral hosts	Normalized degree	PSI
		<i>Lasioglossum albipenne</i>	1	1	0.04	0.05
		<i>Lasioglossum cinctipes</i>	2	2	0.09	0.06
		<i>Lasioglossum cressonii</i>	8	2	0.09	0.48
		<i>Lasioglossum fuscipenne</i>	1	1	0.04	0.03
		<i>Lasioglossum leucozonium*</i>	4	1	0.04	0.40
		<i>Lasioglossum pectorale</i>	1	1	0.04	0.03
		<i>Lasioglossum pilosum</i>	4	5	0.22	0.18
		<i>Lasioglossum tegulare</i>	1	1	0.04	0.07
		<i>Lasioglossum versatum</i>	1	1	0.04	0.10
	Megachilidae	<i>Heriades carinata</i>	1	1	0.04	0.03
		<i>Megachile centuncularis</i>	1	1	0.04	0.10
		<i>Megachile inermis</i>	2	2	0.09	0.09
Meadow	Andrenidae	<i>Andrena braccata</i>	2	1	0.08	0.03
		<i>Andrena carlini</i>	1	1	0.08	0.14
		<i>Andrena commoda</i>	1	1	0.08	0.14
		<i>Andrena cressonii</i>	2	2	0.15	0.06
		<i>Andrena dunningi</i>	1	1	0.08	0.20
		<i>Andrena erigeniae</i>	1	1	0.08	0.20
		<i>Andrena hirticincta</i>	1	1	0.08	0.02
		<i>Andrena krigiana</i>	1	1	0.08	0.14
		<i>Andrena sigmundi</i>	1	1	0.08	0.14

Table 6. Continued.

Land use type	Family	Bee Species	Abundance	Degree/ floral hosts	Normalized degree	PSI
		<i>Andrena simplex</i>	1	1	0.08	0.02
		<i>Andrena wilkella</i> *	1	1	0.08	0.25
		<i>Calliopsis nebraskensis</i>	2	1	0.08	0.03
	Apidae	<i>Bombus bimaculatus</i>	11	4	0.31	0.48
		<i>Bombus impatiens</i>	123	10	0.77	0.72
		<i>Bombus perplexus</i>	1	1	0.08	0.13
		<i>Bombus vagans</i>	9	6	0.46	0.20
		<i>Ceratina calcarata</i>	1	1	0.08	0.02
		<i>Ceratina dupla</i>	2	1	0.08	0.03
		<i>Ceratina mikmaqi</i>	2	1	0.08	0.03
		<i>Xylocopa virginica</i>	3	2	0.15	0.07
	Colletidae	<i>Hylaeus affinis</i>	1	1	0.08	0.02
	Halictidae	<i>Agapostemon virescens</i>	2	2	0.15	0.16
		<i>Augochlorella aurata</i>	3	2	0.15	0.38
		<i>Halictus confusus</i>	2	2	0.15	0.10
		<i>Halictus ligatus</i>	7	4	0.31	0.10
		<i>Halictus rubicundus</i>	1	1	0.08	0.25
		<i>Lasioglossum albipenne</i>	2	1	0.08	0.25
		<i>Lasioglossum coriaceum</i>	1	1	0.08	0.13
		<i>Lasioglossum cressonii</i>	4	2	0.15	0.14
		<i>Lasioglossum imitatum</i>	1	1	0.08	0.07
		<i>Lasioglossum lineatulum</i>	1	1	0.08	0.07
		<i>Lasioglossum versatum</i>	13	4	0.31	0.21
	Megachilidae	<i>Anthidium oblongatum</i> *	1	1	0.08	0.20

conventional farm sites comprised half (50%) of the bee species and organic farm sites contained many more specialist than general pollinators (30%).

Degree, normalized degree, and PSI were also used to assess the importance of flower species (Table 7) at each land use type. For conventional farm sites, red clover had the greatest pollinator breadth (15), however white clover had the highest PSI value (0.79). At organic farm sites, *Rubus* sp. (berry brambles) in this community appears to be paramount to current function with the most pollinator species (11) and highest PSI (0.75). At meadow sites, *Solidago canadensis* (Canadian goldenrod) had the greatest breadth of pollinators, while *Lotus corniculatus* (Bird's-foot trefoil) was most essential to ecosystem functioning (PSI = 0.72). Only three flower species were specialists, *Coreopsis lanceolata*, *Erigeron philadelphicus* and a species of *Syringa*, all found on organic farm sites (Table 7).

Discussion

Bee abundance and species richness. Seasonal differences appear to have less influence on overall bee abundance and richness than land use type. Abundance was significantly greater mid-season than early season, but not significantly different than late season. Despite the number of species present only being significantly different between mid and early season, the specific species composition was highly varied among all seasons.

Land use type did strongly influence the bee community. While it may have been expected that meadow sites would have higher bee abundance and species richness, both metrics were significantly highest in organic farm sites. One reason that bee abundance and species richness were greater in organic farm sites may be the higher diversity of floral resources as has often been correlated with larger bee communities (Andersson et al. 2013, Rutgers-Kelly & Richards 2013, Ellis & Barbercheck 2015). Our results correspond with previous studies showing that the impact of agriculture on bees is often dependent on the habitat or region studied (Hernandez et al. 2009, Hoehn et al. 2010, Cariveau & Winfree 2015, Gill et al. 2016). These data also support the theory that managed habitat areas are not necessarily detrimental to bees and some agricultural practices may help promote bee abundance (Jackson & Jackson 2002, Rosenzweig 2003, Westphal et al. 2003, Carre et al. 2009, Winfree et al. 2009).

Common and rare species. We found that *B. impatiens* was the most abundant and common bee species found at all sampling sites. *Bombus impatiens* is recurrently the most abundant species in studies of agricultural ecosystems of Pennsylvania (Russo et al. 2013) and urban gardens of New York (Matteson et al. 2008). Four additional halictid bee species, *A. virescens*, *A. aurata*, *L. coriaceum*, and *L. versatum*, were also found at all sites in abundance, though they were not necessarily the most abundant of the species sampled. The abundance of halictid species is consistent with findings from other studies in the northeast (Richards et al. 2011, Rutgers-Kelly & Richards 2011, Hinners et al. 2012, Russo et al. 2013, Lerman & Milam 2016).

The prevalence of *Taraxacum* sp. (dandelion) and white clover in all sites is not surprising as both are considered weedy in the northeast and even invasive in some states (USDA 2017). Red clover, while also found at all sites, is not on the USDA's weed list and is often associated with bee surveys (Fussell & Corbet 1992,

Table 7. Flower species statistics for each land use type. Highest values are in bold. Asterisks indicate non-native species.

Land use type	Family	Flower species	Degree/bee visitors	Normalized degree	PSI	
Conventional farm	Asteraceae	<i>Taraxacum</i> sp.	2	0.08	0.42	
	Fabaceae	<i>Trifolium pratense</i> *	15	0.63	0.53	
		<i>Trifolium repens</i> *	13	0.54	0.79	
	Papaveraceae	<i>Chelidonium majus</i> *	5	0.21	0.71	
		<i>Ranunculus</i> sp.	3	0.13	0.53	
	Organic farm	Ranunculaceae	<i>Asclepias tuberosa</i>	7	0.18	0.30
		Apocynaceae	<i>Coreopsis lanceolata</i>	1	0.03	0.20
			<i>Echinacea purpurea</i>	8	0.21	0.19
		Asteraceae	<i>Erigeron philadelphicus</i>	1	0.03	0.07
	<i>Heliopsis helianthoides</i>		4	0.10	0.32	
<i>Heliopsis</i> sp.	5		0.13	0.19		
<i>Hieracium</i> sp.	2		0.05	0.08		
<i>Hieracium</i> sp. 2	4		0.10	0.54		
<i>Rudbeckia hirta</i>	5		0.13	0.44		
<i>Rudbeckia</i> sp.	8		0.21	0.29		
<i>Solidago speciosa</i>	5		0.13	0.23		
Asteraceae	<i>Taraxacum</i> sp.	2	0.05	0.50		
	<i>Vernonia fasciculata</i>	9	0.23	0.11		

Table 7. Continued.

Land use type	Family	Flower species	Degree/bee visitors	Normalized degree	PSI
	Fabaceae	<i>Lupinus sp.</i>	4	0.10	0.24
		<i>Trifolium incarnatum</i> *	3	0.08	0.31
		<i>Trifolium pratense</i> *	7	0.18	0.21
		<i>Trifolium repens</i> *	6	0.15	0.24
	Lamiaceae	<i>Agastache foeniculum</i>	8	0.21	0.23
		<i>Monarda fistulosa</i>	5	0.13	0.32
		<i>Salvia patens</i> *	3	0.08	0.09
	Oleaceae	<i>Syringa sp.</i> *	1	0.03	0.25
	Polygonaceae	<i>Fagopyrum esculentum</i> *	3	0.08	0.02
	Rosaceae	<i>Rubus sp.</i>	11	0.28	0.75
	Apiaceae	<i>Daucus carota</i> *	7	0.21	0.26
Meadow	Apocynaceae	<i>Asclepias sp.</i>	3	0.09	0.61
	Asteraceae	<i>Centaurea jacea</i> *	4	0.12	0.23
		<i>Solidago canadensis</i>	12	0.36	0.49
		<i>Solidago speciosa</i>	1	0.03	0.01
		<i>Taraxacum sp.</i>	6	0.18	0.62
	Caprifoliaceae	<i>Lonicera sp.</i>	2	0.06	0.34
	Caryophyllaceae	<i>Silene latifolia</i> *	4	0.12	0.09
	Fabaceae	<i>Lotus corniculatus</i> *	5	0.15	0.72
		<i>Trifolium pratense</i> *	4	0.12	0.27
		<i>Trifolium repens</i> *	4	0.12	0.39
		<i>Vicia sp.</i>	4	0.12	0.51
	Rosaceae	<i>Potentilla recta</i> *	6	0.18	0.59

Richards et al. 2011, Rundlöf et al. 2014). Even though *Taraxacum* and clovers comprise mostly non-native species, they are central flora in many ecosystems (Tommasi et al. 2004, Richards et al. 2011, Larson et al. 2014, Lerman & Milam 2016, Tucker & Rehan 2016). The importance of these two flowers is evinced in their ability to grow in a wide range of habitats in the northeast, over multiple seasons, while providing floral resources to a diversity of bee species (Larson et al. 2014, Lerman & Milam 2016, Tucker & Rehan 2016).

All three land use types had a relatively high percentage of unique bee species (conventional farm 30%, organic farm 33%, meadow 25%), and even higher percentages of unique flower species (conventional farm 40%, organic farm 83%, meadow 69%). Interestingly, all but three flower species (*C. lanceolata*, *E. philadelphicus* and *Syringa* sp.) received visitations from multiple bee species. Two flowers were visited by *H. ligatus* and the third by *L. cressonii*. The lack of additional species collected on these flowers was likely due to the short flower bloom duration. We found an overall higher percent of generalist pollinators in conventional and organic farms. While most of the specialist bee species collected were categorized as such due to few specimen collections (<3), three confirmed specialist bee species, *Andrena braccata* Viereck, *Andrena hirticincta* Provancher, and *Andrena simplex* Smith (all Hymenoptera: Andrenidae), were collected from *S. canadensis*, which is a known host plant along with other species of *Solidago* (LaBerge 1967, Mitchell 1960). Our findings of a greater species richness of generalist bees is consistent with other studies that suggest generalist species were more resilient and better adapted to agricultural landscapes in comparison to specialist pollinators (Weiner et al. 2014, Winfree et al. 2011). Taken together, our data confirm former studies indicating that a broad range of habitat and land use types are necessary to achieve maximum levels of biodiversity (Carvell 2002, Tscharntke et al. 2005, Mandelik et al. 2012). A diversity of foraging landscapes and the subsequent pollinator species richness may help to ensure the ability of an ecosystem to recover after a major disturbance or local extinction (Tscharntke et al. 2005, Kehinde & Samways 2012, Senapathi et al. 2015).

Plant-pollinator interactions. Previous research, on a broad spectrum of pollinator orders, has examined how plant-pollinator networks change with land use in Africa (Grass et al. 2013), South America (Marrero et al. 2014), and Germany (Weiner et al. 2014). However, bee centric studies are needed to examine plant-pollinator networks at the species level across different land use types and agricultural settings. Here we present the first such study in New England, with continuous sampling of the same locations throughout the collecting season. We found an apparent inverse relationship between connectance and community size (Table 4). This inverse relationship where larger communities have more unique interactions, but less connectance, appears in many plant-pollinator networks (Table 4; Clements & Long 1923, Schemske et al. 1978, Motten 1982, Bartomeus et al. 2008, Russo et al. 2013). The inverse relationship is biologically intuitive since a larger community provides a greater number of potential interactions. However, not all pollinators are compatible with all flowers and vice versa because at the species level bee biology differs as does floral nutritional resources. We also found that plant-pollinator networks in mixed grassland and agricultural ecosystems appear to have greater species richness and unique interactions than forested woodland or scrubland ecosystems (Table 4; Clements and Long 1923, Schemske et al. 1978, Motten 1982, Bartomeus et al. 2008, Russo et al. 2013,

Tucker & Rehan 2016). Our seasonal network characteristics differed slightly from a similar study in Pennsylvania where the plant-pollinator community was both largest and most complex mid-season (Russo et al. 2013), whereas most of our networks were largest mid-season, but most complex late season (Table 5).

Many of the essential bee species reported in our plant-pollinator community across different land use types parallel those reported in other pollinator studies across eastern North America (Table 6; Richards et al. 2011, Kammerer et al. 2015, Lerman & Milam 2016, Mallinger et al. 2016). While none of the floral species we sampled were specific to a single bee species, many floral species were found to be essential to the community (Table 7). The flowers identified in this study correspond with plants identified as central to habitat function in previous studies across the northeast (Table 7; Morse 1980, Ginsberg 1983, Fussell & Corbet 1992, Tommasi et al. 2004, Carvell et al. 2007, Denisow & Wrzesien 2007, Richards et al. 2011, Larson et al. 2014). Here we provide essential regionally specific information on bee habitat across different agricultural settings. The widespread importance of clovers, berry brambles, goldenrods and other weedy species to the bee community suggests the need to promote and maintain areas supporting such habitat.

Determining the impact of agricultural landscapes on the bee community and comparisons across regions is critical to the conservation of wild bees and the indispensable pollination services they provide. New England is an area for which research pertaining to effects of agricultural practices on the pollinator community is sparse. We found bee abundance and species richness to be highest in organic farm sites. We found both a great overlap of bee species among land use types, whereas floral species were largely land use type specific. This suggests a heterogeneous landscape may not only increase floral diversity, but pollinator species richness and community stability as well. This study provides important baseline data to establish the plant-pollinator community dynamics in New England across agricultural landscapes. Additional long-term research is needed to determine the habitat requirements needed for maintaining the most diverse and stable community possible over time. However, based on the findings of this study we recommend conserving both areas of natural weedy flora and semi-natural areas with supplemental flowering plants, especially those that bloom early season. A combination of flowers that bloom across seasons and mixed among or bordering crop areas, along with reduced pesticide use, appears to increase both bee abundance and species richness.

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