

IDENTIFICATION OF PLANT SPECIES FOR CROP POLLINATOR HABITAT ENHANCEMENT IN THE NORTHERN PRAIRIES

Diana B. Robson*

The Manitoba Museum, 190 Rupert Avenue, Winnipeg, MB Canada R3B 0N2

Abstract—Wild pollinators have a positive impact on the productivity of insect-pollinated crops. Consequently, landowners are being encouraged to maintain and grow wildflower patches to provide habitat for important pollinators. Research on plant-pollinator interaction matrices indicates that a small number of “core” plants provide a disproportionately high amount of pollen and nectar to insects. This matrix data can be used to help design wildflower plantings that provide optimal resources for desirable pollinators. Existing interaction matrices from three tall grass prairie preserves in the northern prairies were used to identify core plant species that are visited by wild pollinators of a common insect-pollinated crop, namely canola (*Brassica napus* L.). The wildflower preferences of each insect taxon were determined using quantitative insect visitation and floral abundance data. Phenology data were used to calculate the degree of floral synchrony between the wildflowers and canola. Using this information I ranked the 41 wildflowers that share insect visitors with canola according to how useful they are for providing pollinators with forage before and after canola flowers. The top five species were smooth blue aster (*Symphyotrichum laeve* (L.) A. & D. Löve), stiff goldenrod (*Solidago rigida* L.), wild bergamot (*Monarda fistulosa* L.), purple prairie-clover (*Dalea purpurea* Vent.) and Lindley’s aster (*Symphyotrichum ciliolatum* (Lindl.) A. & D. Löve). By identifying the most important wild insects for crop pollination, and determining when there will be “pollen and nectar gaps”, appropriate plant species can be selected for companion plantings to increase pollinator populations and crop production.

Keywords: canola, core plants, insect visitors, pollination, restoration, wildflower plantings

INTRODUCTION

Many crop plants require or benefit greatly from pollination by insects, mainly bees and flies (Kevan et al. 1990; Klein et al. 2007). Worldwide wild pollinators are responsible for most crop pollination (Klein et al. 2007; Garibaldi et al. 2011; Garibaldi et al. 2013) although managed pollinators like honey bees can play an important role in areas where wild pollinator habitat is rare (Southwick & Southwick 1992). Unfortunately, wild pollinator populations are in decline due to numerous causes including land use intensification and pesticide use, climate change, the introduction of alien species, and the spread of pests and pathogens (Kevan 1999; Carvell et al. 2006; Vanbergen & the Insect Pollinators Initiative 2013). Researchers have found a link between landscape diversity, species richness and the abundance of wild pollinators in agroecosystems (Klein et al. 2009; Kennedy et al. 2013). This is likely because many crops, such as canola, do not provide adequate pollen and nectar resources for pollinators with life spans longer than the blooms (Morandin & Winston 2005). The general consensus is that patches of wild grassland and pasture, hedgerows, tree bluffs, windbreaks, grassy ditches (Lagerhög 1992; Kells et al. 2001; Morandin et al. 2007;

Korpela et al. 2013; Kovács-Hostyánszki et al. 2013; Morandin & Kremen 2013) and even the presence of some flowering non-native ‘weeds’ (Carvalho et al. 2011, 2012) provides habitat for pollinators when crops are not in flower, which improves their survival and abundance. The process whereby floral species facilitate each other’s persistence by supporting shared pollinators is called sequential mutualism (Waser & Real 1979). The more floral resources that are present in these natural and semi-natural areas, the better the habitat is for pollinators (Pywell et al. 2005) and the more stable the system will be (Winfree & Kremen 2009). The resulting increase in pollinator abundance can subsequently increase the productivity of insect-pollinated crops by reducing pollen limitation (Morandin & Winston 2006; Carvalho et al. 2011, 2012; Blaauw & Isaacs 2014).

As a result, some landowners are preserving natural and semi-natural habitats for pollinators. Active restoration of pollinator habitat, such as roadside wildflower plantings, can significantly increase wild pollinator abundance (Hopwood 2008; Haaland et al. 2011; Tarrant et al. 2012). Government programs to help support such initiatives are also forthcoming (Carvell et al. 2007; Tuell et al. 2008; Decourtye et al. 2010). The greatest improvements in pollinator richness will likely be in areas that have been the most intensively cultivated (Tscharrntke et al. 2005; Kennedy et al. 2013; Scheper et al. 2013). The positive impact of wildflower plantings may be even greater when combined with organic farming methods (Morandin & Winston 2005; Winfree 2010; Kennedy et al. 2013) and/or methods to

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*Corresponding author: drobson@manitobamuseum.ca;
Phone 204-988-0653

preserve or increase nesting habitat for pollinators (Barron et al. 2000; Kremen et al. 2002; Williams & Kremen 2007).

In Canada, the native tall grass prairie in the Red River Valley of Manitoba has been almost completely cultivated with less than 1% remaining, leaving very little natural habitat for pollinators. Research suggests that growing some wildflowers adjacent to field margins in agricultural regions such as this is likely to increase pollinator populations and reduce the pollen deficit of crops (Tschardt et al. 2005; Kennedy et al. 2013; Stanley et al. 2013; Blaauw & Isaacs 2014; Klatt et al. 2014). Native wildflowers are reported to be more attractive to wild pollinators than non-native ones (Williams & Kremen 2007; Menz et al. 2011; Morandin & Kremen 2013; Gill et al. 2014). Although appropriate wildflower mixtures have been identified for many regions in the United States (The Xerces Society 2014), many of the suggested species are not native to or particularly abundant in the northern prairies of Canada. Since native plants are adapted to grow in certain regions, the optimal wild plant species for attracting crop pollinators will vary depending on the local climate and soils. Several different methods to select the wild plants that are most attractive to pollinators have been suggested. Isaacs et al. (2009) recommend growing a selection of candidate plants together in 1-m² plots and monitoring the insect visitation using vacuum sampling when the plants are in flower to identify highly desirable species. Menz et al. (2011) suggest selecting plant species based on the number of insect taxa that they attract, as these “core” species appear to be more important for ecosystem maintenance than species that attract fewer pollinators (Mommott et al. 2004; Saavedra et al. 2011). However, Johnson (1980) cautioned that resource usage by animals is influenced by abundance; an animal may actually prefer a species that is less common. Kells et al. (2001) used Johnson’s index to calculate the preference index (PI) of bees for different floral species found along uncropped field margins. They found that the plants that were most numerous were not necessarily the species that were preferred by honey bees (*Apis* spp.) and bumblebees (*Bombus* spp.) (Kells et al. 2001).

Plant-pollinator interaction data from three tall grass prairie preserves in south eastern Manitoba were obtained over a five year discontinuous period (Robson 2008, 2010, 2013). Using these previously collected data, I determined whether abundance of the plants in the plots was correlated with the number of insect visits. Then I ranked each plant species according to both the number of insect taxa visiting it and the mean insect PI to see if there were differences in the ranks using these methods. I also used data on floral synchrony and existing literature documenting the pollinators of canola in Canada to identify wild plant species that bloom either before or after the crop, and that attract its known pollinators. Using these three kinds of data (i.e. number of shared insect visitors, PI and floral synchrony) I was able to identify suitable wild plant species for crop pollinator habitat enhancement near canola fields.

MATERIALS AND METHODS

Study Sites

Data from previously published research in three tall grass prairie preserves were used for the calculations: Birds Hill Provincial Park (BHPP), Living Prairie Museum (LPM) and the Tall Grass Prairie Preserve (TPP) (Robson 2008, 2010, 2013). Birds Hill Provincial Park, located north of Winnipeg, MB (50.0167° N 96.8833° W), is a 35-km² protected area in the Lake Manitoba Plain ecoregion of the Prairie ecozone (Ecological Stratification Working Group 1995) containing some tall-grass prairie and oak savannah. The soils are well-drained, glaciofluvial deposits that consist of gravel, sand and silt. There are at least 492 vascular plant species that occur in the park (Manitoba Naturalists Society 1996).

Living Prairie Museum is located within the city limits of Winnipeg, MB (49.8844° N 97.1463° W). It is a 0.12-km² remnant of tall-grass prairie set aside by the City of Winnipeg in 1971. The park is part of the Lake Manitoba Plain ecoregion (Ecological Stratification Working Group 1995). The soils are moderately well-drained, glaciofluvial in origin and consist of a mixture of clay, silt and sand. Approximately 160 vascular plant species occur in the park.

The Tall Grass Prairie Preserve is located near Gardenton, MB (49.1167° N 96.6667° W). The TPP is a 22-km² site located in the Lake Manitoba Plain ecoregion (Ecological Stratification Working Group 1995), about 100-km south of Winnipeg. The soils are highly calcareous glacial till deposits containing a mixture of gravel, sand, silt and clay. The preserve is hydric in many places, holding water well into summer during wet years. Approximately 475 native vascular plant species occur in the preserve.

Vegetation Surveys

I established 16 plots in BHPP, and 6 plots each in LPM and TPP. At BHPP each plot was 2.5 m² in size, and at LPM and TPP the plots were 5-m². The plots were at least 5-m apart. Sampling in BHPP was conducted for 37 non-consecutive days: 6 days in June (2011), 12 days in July (2010 and 2011), 11 days in August (2008 and 2010), and 8 days in September (2008). Sampling at LPM and TPP occurred from June to September on four non-consecutive days each month in both 2004 and 2005 for a total of 32 days at each site. The number of flowering stems in the plots was recorded each sampling day. The percentage of all flower stems contributed by each species was determined.

Floral Visitor Surveys

Flower-visiting insect sampling at BHPP occurred for 37 non-consecutive days from mid-June to mid-September (99 h total sampling time at each site), thus covering the main period of insect activity. At LPM and TGPP sampling occurred for 32 non-consecutive days from mid-June to mid-September (96 h total sampling time at each site). Thus the total number of sampling hours was similar at each site. As foraging activity is generally low in the early morning when temperatures are cooler (Kevan and Baker 1983), surveys were conducted between 10 am and 5 pm. The order in

which the plots were visited was varied each day by using a random number table to determine the plot visitation sequence. Some of the flower-visiting insects may have also been predators of other flower-visiting insects. Regardless of whether insects were foraging for pollen, nectar, or other insects, all were considered potential pollinators with the exception of ambush bugs (*Phymata* spp.) and crab spiders (*Misumena* spp.) as they tend to remain stationary on one flower stem for a long period of time. More detailed vegetation and floral visitor survey methods and results are described in Robson (2008, 2010, 2013).

A direct observation technique was used to sample the insects. The first time an insect was observed on an inflorescence, the specimen was netted, placed in a killing jar and then transferred to a container with a unique reference number. When the same (or a very similar) species was observed later on, the reference number was used to link the insect visit to the plant. Although this technique does not allow for complete identification "on the wing" (resulting in an underestimate of insect taxa) it does enable evaluation of insect visitation frequency (Parachnowitsch and Elle 2005). All insect voucher specimens were identified by qualified zoologists using reference specimens at The Manitoba Museum (TMM) and the Wallis Roughley Museum, University of Manitoba in Winnipeg, Manitoba; the specimens were deposited in TMM's zoology collection.

The data from BHPP, LPM and TPP was used to create one large plant-insect visitor matrix consisting of 54 native plant species and 169 insect taxa in four orders: six Coleoptera, 85 Diptera, 62 Hymenoptera and 16 Lepidoptera. This matrix was used to determine how many insect taxa visited each plant species. To determine which wild plant species the various pollinators preferred, an index from Kells et al. (2001) was used to calculate the preferences of each insect taxon for each plant species present:

$$PI = \frac{(V_k/V_t)}{(A_k/A_t)}$$

Where V_k is the number of foraging visits of those insect taxa to plant species k , V_t is the total number of visits of those insect taxa to all plant species, A_k is the total number of flowers of species k , and A_t is the total number of flowers of all species. Thus the PI measures the relative attractiveness of plants to specific insect taxa. A plant with a high mean PI is visited frequently even when there are other flowering plants nearby. The PI ranges for *Bombus* and *Apis* species are reported to be between 0.1 and 13 (Kells et al. 2001). The PI was calculated for each plant species for each survey day. If a plant species was in bloom in a plot but not visited by any insect taxon that was observed, it received a PI of zero for that day. The mean PI and standard error (SE) of this mean for all days the plant species was in bloom to each insect taxon was then calculated. Additionally, the mean PI and SE of each plant species was also calculated for just the three insect genera noted to be most abundant on canola fields in Canada, as well as for all insect taxa. The sample sizes (N) varied depending on the number of days each plant was in flower and how many insect taxa were active on each sampling day. Both the number of visiting taxa and the PI

have been suggested as ways to identify highly attractive species to pollinators (Kells et al. 2001; Menz et al. 2011). To determine if these two methods selected similar plant species, I ranked them relative to each other and compared the rank differences using Spearman's rank correlation.

A literature search was conducted to determine which genera and species of insects typically pollinate canola in southern Canada (Turnock et al. 2006; Morandin et al. 2007; Gavloski et al. 2011; Zink 2013). Native plant species that are visited by the same insect taxa as canola were identified using the plant-insect visitor matrix. Supplemental observation data to determine the total number of plant-insect interactions that are likely for each plant species was obtained from existing literature (Robertson 1929; Reed 1993; Petersen 1996; Hilty 2002; Colla & Dumesh 2010).

In southern Canada, canola was noted to bloom from approximately June 20 to July 20, assuming late May seeding (Clay 2009). The exact flowering dates will of course vary slightly from year to year depending on the weather. To determine if the wild plant species were flowering during the same time as canola, the flowering synchrony was calculated from a method modified from Primack (1980). The index of synchrony (X) for a plant species (i) and canola (j) is given by:

$$Xi = (1/f) ej \neq i$$

Where f is the total number of days individual i was in flower, and ej is the number of days individual i and j overlapped in their flowering. Any date when individual i had flowered in any year when it was studied was marked as being in flower. Thus the phenological data from other sites represents summed data across several years. A species with $X = 0$ does not overlap at all with canola while species with $X > 0$ overlaps to some degree.

Data Analysis

I used linear regression analysis to determine the relationship between number of flower stems and insect visits to each plant species. Spearman's rank correlation was used to determine if the insect taxa ranks were significantly different from the PI ranks. These statistical tests were performed using Analyze-It software.

RESULTS

The percentage of flowering stems each plant species contributed to the plots and the percentage of insect visits received by it were not significantly correlated ($y = 0.094x + 1.436$, $R^2 = 0.018$, $P = 0.283$) (Fig. 1). Thus plants with a large number of flowering stems in the plots did not necessarily receive the most insect visits and *vice versa*. This implies that factors other than abundance influence insect choice.

There were 54 native plant species that were visited by at least one insect taxon. An additional ten plants occurred in the plots but were not observed being visited by any insects: ground-plum (*Astragalus crassicaarpus* Nutt.), lesser yellow lady's-slipper (*Cypripedium parviflorum* Salisb.), white prairie-clover (*Dalea candida* Michx. ex Willd.), silverberry

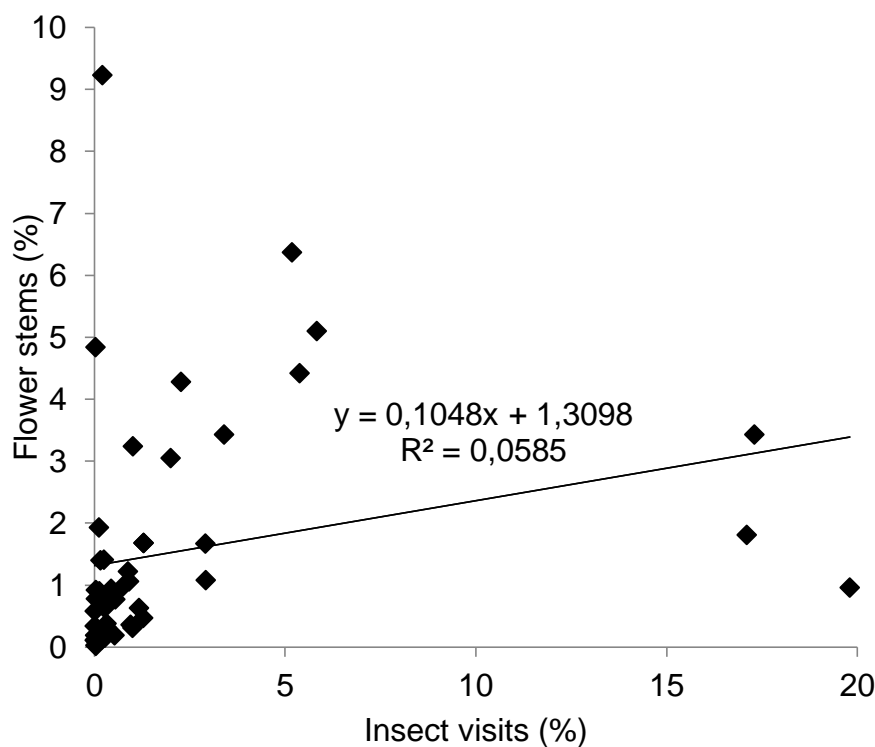


FIGURE I. Relationship between the percentage of flowering stems in the plots and the percentage of insect visits observed to each of 54 wild plant species.

(*Elaeagnus commutata* Bernh. ex Rydb.), fringed gentian (*Gentianopsis crinita* (Froel.) Ma), prairie smoke (*Geum triflorum* Pursh), selfheal (*Prunella vulgaris* L.), veiny peavine (*Lathyrus venosus* Muhl. ex Willd.), whorled loosestrife (*Lysimachia quadrifolia* L.) and Indian breadroot (*Pediomelum esculentum* (Pursh) Rydb). Most of these species were observed for only a few days because they were less abundant in the plots than the other species. The total number of insect taxa that visited each plant species and the mean PI for all of them was calculated (Tab. 1). The ranks were significantly different from each other (Spearman's $r_s = 0.36$; $P = 0.008$). There were 19 species with a signed difference (i.e. = insect taxa rank – PI rank) greater than zero and 35 species with a signed difference lower than zero. Among the 19 species with a positive signed difference, 11 had SE's greater than two, indicating small sample sizes; therefore the PI values for these plant species are less reliable and additional data are needed to assess the species' attractiveness. Species with negative signed differences (i.e. a high insect taxa rank but low PI rank) may have been generalists attractive to many different generalist insects with low fidelities to a single species. The low SE (< 1) of most of the species with negative signed differences indicates that this data is generally more reliable.

Because the purpose of wildflower plantings adjacent to cropland is to provide wild and managed pollinators with floral resources when the crop is not in flower, plant species that are highly attractive to the most common pollinators of crop plants are particularly important to identify. There are 28 bee genera known to visit canola in Alberta; *Lasioglossum* (sweat bees) is the most abundant genus followed by *Bombus* and *Andrena* (Andrenid bees) (Morandin et al. 2007; Zink 2013). The only data from Manitoba was

collected on *Bombus* abundance only. Turnock et al. (2006) indicates that there are at least 13 species of *Bombus* found in canola fields in Manitoba with the red-belted bumblebee (*B. rufocinctus* Cresson, 1863) being the most abundant one followed distantly by the northern amber bumblebee (*B. borealis* Kirby, 1837). Zink (2013) discovered two additional *Bombus* species in canola fields in Alberta but the most abundant ones observed were also *B. rufocinctus* and *B. borealis*. Wildflower visitation data on 11 of the bee genera and 12 of the species from these three studies (Turnock et al. 2006; Morandin et al. 2007; Zink 2013) are summarized in Tab. 2; however, only the taxa that were also observed in Manitoba's tall grass prairies during my research (Robson 2008, 2010, 2011) were listed. My data indicate that at least 41 species of wildflowers are visited by these bees in tall-grass prairie (Appendix I). Seven species of plants shared ten or more insect visitor taxa with canola when data from other sources (i.e. Robertson 1929; Reed 1993; Petersen 1996; Hilty 2002; Colla & Dumesh 2010) were included: *D. purpurea* with 18 insect visitor taxa, gray goldenrod (*S. nemoralis* Ait.) and *S. rigida* each with 17, Canada goldenrod (*Solidago canadensis* L.) with 15, and *Monarda fistulosa*, *Symphotrichum laeve* and western silvery aster (*S. sericeum* (Vent.) G.L. Nesom) each with 11. Five insect taxa visit more than ten wild plant species: *Lasioglossum pruinosum* (Halictidae) visited 20 species, orange-belted bumblebee (*Bombus ternarius* Say, 1863) visited 19, half-black bumblebee (*B. vagans* Say, 1837) visited 16, green metallic sweat bee (*Agapostemon texanus texanus* Cresson, 1872) visited 12 plant species and broad-handed leaf cutter bee (*Megachile latimanus* Say, 1823) visited 11 species. The only fly species that has been confirmed as a visitor to canola is the introduced drone fly (*Eristalis tenax* (L. 1758) (Jauker

TABLE I. Number of visiting insect taxa and mean preference indices (PI) of all insects observed for 54 Manitoba wildflowers ordered according to the signed difference¹. The ranks were significantly different ($r_s = 0.36$, $P = 0.008$) using Spearman's rank correlation.

Plant Species	Insect taxa visiting (#)	Insect taxa rank	PI of all insects (mean \pm SE) ²	PI rank	Signed difference	Days surveyed (#)
<i>Symphoricarpos occidentalis</i>	10	16	0.28 \pm 0.13	44	-28	12
<i>Dalea purpurea</i>	19	6	0.84 \pm 0.23	33	-27	38
<i>Campanula rotundifolia</i>	12	12	0.57 \pm 0.17	38	-26	29
<i>Galium boreale</i>	11	14	0.46 \pm 0.31	40	-26	17
<i>Symphyotrichum sericeum</i>	21	5	1.36 \pm 0.12	29	-24	13
<i>Heterotheca villosa</i>	15	10	0.83 \pm 0.22	34	-24	25
<i>Symphyotrichum ericoides</i>	11	14	0.75 \pm 0.35	35	-21	17
<i>Symphyotrichum ciliolatum</i>	15	10	1.18 \pm 0.64	30	-20	8
<i>Solidago nemoralis</i>	45	1	2.55 \pm 0.70	20	-19	34
<i>Solidago rigida</i>	42	2	2.41 \pm 0.41	21	-19	20
<i>Solidago canadensis</i>	34	3	2.57 \pm 0.97	19	-16	16
<i>Erigeron glabellus</i>	17	8	2.05 \pm 0.44	23	-15	25
<i>Solidago ptarmicoides</i>	16	9	1.86 \pm 0.85	24	-15	15
<i>Lithospermum canescens</i>	8	24	0.56 \pm 0.28	39	-15	20
<i>Astragalus agrestis</i>	9	20	0.92 \pm 0.34	32	-12	13
<i>Lobelia spicata</i>	2	40	0.02 \pm 0.01	51	-11	12
<i>Vicia americana</i>	9	20	1.18 \pm 0.29	30	-10	16
<i>Erigeron strigosus</i>	10	16	1.84 \pm 0.70	25	-9	24
<i>Helianthus subrhomboides</i>	3	35	0.28 \pm 0.16	44	-9	6
<i>Sisyrinchium montanum</i>	3	35	0.37 \pm 0.25	43	-8	12
<i>Parnassia palustris</i>	1	46	0.01 \pm 0.01	54	-8	6
<i>Houstonia longifolia</i>	2	40	0.06 \pm 0.04	47	-7	9
<i>Prunella vulgaris</i>	1	46	0.01 \pm 0.01	53	-7	5
<i>Rudbeckia hirta</i>	19	6	4.21 \pm 1.63	12	-6	28
<i>Symphyotrichum laeve</i>	12	12	2.84 \pm 1.03	18	-6	13
<i>Fragaria virginiana</i>	4	31	0.60 \pm 0.27	37	-6	8
<i>Anemone cylindrica</i>	2	40	0.12 \pm 0.08	46	-6	13
<i>Zizia aptera</i>	31	4	6.04 \pm 0.97	9	-5	8
<i>Pediomelum argophyllum</i>	1	46	0.02 \pm 0.02	51	-5	4
<i>Viola nephrophylla</i>	1	46	0.03 \pm 0.03	50	-4	3
<i>Achillea millefolium</i>	8	24	1.79 \pm 0.92	27	-3	35
<i>Hypoxis hirsuta</i>	1	46	0.04 \pm 0.03	49	-3	6
<i>Monarda fistulosa</i>	8	24	1.80 \pm 0.76	26	-2	15
<i>Astragalus adsurgens</i>	1	46	0.05 \pm 0.05	48	-2	8
<i>Dasiphora fruticosa</i>	10	16	3.00 \pm 2.26	17	-1	9
<i>Amorpha nana</i>	2	40	0.60 \pm 0.42	36	4	1
<i>Euthamia graminifolia</i>	9	20	3.62 \pm 2.14	15	5	7
<i>Polygala senega</i>	1	46	0.39 \pm 0.39	41	5	8
<i>Penstemon gracilis</i>	1	46	0.39 \pm 0.39	41	5	8
<i>Helianthus maximilliani</i>	6	29	2.29 \pm 1.71	22	7	7
<i>Liatris ligulistylis</i>	10	16	6.48 \pm 3.30	7	9	8
<i>Zizia aurea</i>	8	24	4.21 \pm 0.97	12	12	14
<i>Allium stellatum</i>	2	40	1.38 \pm 1.00	28	12	3
<i>Rosa blanda</i>	6	29	3.38 \pm 1.83	16	13	7
<i>Zygadenus elegans</i>	8	24	6.18 \pm 2.66	8	16	4
<i>Cirsium flodmanii</i>	4	31	3.72 \pm 1.86	14	17	6
<i>Packera plattensis</i>	9	20	11.09 \pm 6.30	2	18	7
<i>Comandra umbellata</i>	4	31	4.59 \pm 4.20	11	20	4
<i>Gaillardia aristata</i>	3	35	5.36 \pm 4.01	10	25	10
<i>Asclepias ovalifolia</i>	4	31	10.46 \pm 9.01	3	28	15
<i>Crepis runcinata</i>	3	35	7.83 \pm 7.39	6	29	4
<i>Agoseris glauca</i>	3	35	38.64 \pm 30.85	1	34	2
<i>Potentilla arguta</i>	2	40	9.84 \pm 6.56	4	36	2
<i>Heuchera richardsonii</i>	1	46	7.93 \pm 7.93	5	41	2

¹Signed difference = Insect taxa rank - PI rank.

²Sample sizes (N) for each species ranged from 8 to 368 (mean $N = 111$).

TABLE 2. Bee taxa observed visiting canola in western Canada. Values are the percentage of all bees collected during the course of the study.

Bee taxa	Zink (2013) Bees collected (%)	Morandin et al. (2007) Bees collected (%)	Turnock et al. (2006) ¹ Bees collected (%)
<i>Agapostemon</i>	2.39	0.30	-
<i>Andrena</i>	16.99	14.30	-
<i>Bombus</i> spp.	23.09	26.10	-
<i>B. borealis</i>	1.66	-	9.37
<i>B. fervidus</i>	0.46	-	0.16
<i>B. perplexus</i>	-	-	0.47
<i>B. rufocinctus</i>	9.69	-	80.80
<i>B. ternarius</i>	1.66	-	0.51
<i>B. vagans</i>	-	-	0.38
Other <i>Bombus</i> spp.	9.62	-	4.73
<i>Coelioxys</i> spp.	0.20	-	-
<i>C. rufitarsis</i>	0.20	-	-
<i>Colletes</i>	2.39	3.40	-
<i>Epeolus</i>	0.40	0.45	-
<i>Hylaeus</i>	0.86	0.15	-
<i>Lasioglossum</i> spp.	34.64	42.5	-
<i>L. leucozonium</i>	3.52	-	-
<i>L. pruinatum</i>	1.73	-	-
<i>L. succipenne</i>	0.13	-	-
Other <i>Lasioglossum</i> spp.	29.26	-	-
<i>Megachile</i> spp.	1.13	1.20	-
<i>M. frigida</i>	0.13	-	-
<i>M. melanophaea</i>	0.13	-	-
Other <i>Megachile</i> spp.	0.87	-	-
<i>Melissodes</i>	2.19	0.61	-
<i>Nomada</i>	1.53	0.30	-
<i>Osmia</i>	0.27	0.45	-
<i>Perdita</i>	0.19	0.30	-
<i>Pseudopanurgus</i>	0.79	-	-
<i>Sphex</i> spp.	0.66	2.60	-
Other bee genera	12.28	7.34	-

¹Turnock et al. (2006) only collected data on *Bombus* spp.

& Wolters 2008; Jauker et al. 2012), which has also been observed visiting five wild plant species in Manitoba.

Most of the plant species that were visited by the pollinators of canola were in the Asteraceae (51%) followed by the Fabaceae (16%) (Tab. 3). Four plants were woody and the remainder perennial. Most of the species possessed yellow flowers (37%) followed by purple (24%), white (15%), pink (2%), orange (2%) and blue (2%); some of the Asteraceae species (17%) possessed yellow disk flowers with various colours of ray flowers (e.g. white, purple or pink). The inflorescences were mostly capitula with regularly symmetrical flowers owing to the abundance of Asteraceae species. The calyx/corolla tubes ranged from zero to 25 mm so a wide range of flower types were visited.

The mean PI of canola pollinator taxa to various wild plant species was calculated. Six of the *Bombus* species that visit canola were also observed visiting 25 wild plant species (Tab. 4). The high SE of some mean PI values indicates a relatively small sample size for that insect species. One plant species was visited by all six *Bombus* spp. (i.e. *Solidago rigida*) and two plants (i.e. purple milkvetch (*Astragalus agrestis* Dougl. and *S. canadensis*) were visited by four each.

The *Bombus* sp. most abundant in canola fields (Turnock et al. 2006) was the relatively short tongued *B. rufocinctus*; this insect was observed visiting six wildflowers in Manitoba but it preferred American vetch (*Vicia americana* Muhl. ex Willd.). The second most commonly seen species in canola fields, namely *B. borealis*, has a relatively longer tongue, visited eight plant species and also preferred *V. americana*. *Bombus ternarius*, which has a similar abundance in canola fields in Alberta as *B. borealis*, has a relatively short tongue, was observed visiting 18 plants, and preferred smooth rose (*Rosa blanda* Ait.) and *S. canadensis*.

The wildflower preferences of the three insect genera most commonly found in canola fields (Morandin et al. 2007; Zink 2013), namely *Andrena*, *Bombus* and *Lasioglossum*, were also determined (Fig. 2). Not included in Fig. 2 were four plants with mean PI's of 30 or greater for one of the three insect genera: prairie dandelion (*Agoseris glauca* (Pursh) Raf.), alumroot (*Heuchera richardsonii* R. Br.), dandelion hawkbeard (*Crepis runcinata* James T. & G.), and gaillardia (*Gaillardia aristata* Pursh). These species had high PI's of 243 ± 172 , 143 ± 143 , 111 ± 111 , and 30 ± 30 respectively but the high SE's indicate low reliability;

TABLE 3. Floral characteristics of 41 wildflowers that share insect visitors with canola.

Plant species	Family	Rarity status ¹	Life habit	Flower colour	Inflorescence	Floral Symmetry	Calyx/corolla tube length (approx.) ²
<i>Achillea millefolium</i>	Asteraceae	4	P	White	Corymbs of capitula	Regular	2-4.5 mm
<i>Agoseris glauca</i>	Asteraceae	4	P	Yellow	Capitula	Regular	4 mm
<i>Amorpha nana</i>	Fabaceae	4	W	Purple	Raceme	Irregular	2 mm
<i>Astragalus adsurgens</i>	Fabaceae	4	P	Purple	Raceme	Irregular	4 mm
<i>Astragalus agrestis</i>	Fabaceae	4	P	Purple	Raceme	Irregular	5-8 mm
<i>Campanula rotundifolia</i>	Campanulaceae	4	P	Blue	Solitary, raceme or panicle	Regular	5-7 mm
<i>Cirsium flodmanii</i>	Asteraceae	4	P	Purple	Capitula	Regular	12-15 mm
<i>Crepis runcinata</i>	Asteraceae	4	P	Yellow	Capitula	Regular	4-5.5 mm
<i>Dalea purpurea</i>	Fabaceae	4	P	Purple	Spike	Irregular	1.5-3 mm
<i>Dasiphora fruticosa</i>	Rosaceae	4	W	Yellow	Cluster	Regular	n/a
<i>Erigeron glabellus</i>	Asteraceae	4	P	Purple-yellow	Racemes of capitula	Regular	4-5.5 mm
<i>Erigeron strigosus</i>	Asteraceae	4	P	White-yellow	Racemes of capitula	Regular	1.5-2.5 mm
<i>Gaillardia aristata</i>	Asteraceae	4	P	Yellow-red	Capitula	Regular	0.5-1.5 mm
<i>Galium boreale</i>	Rubiaceae	4	P	White	Terminal and axillary cluster	Regular	n/a
<i>Helianthus maximiliani</i>	Asteraceae	4	P	Yellow	Racemes of capitula	Regular	5-7 mm
<i>Helianthus pauciflorus</i> spp.	Asteraceae	4	P	Yellow	Terminal capitula	Regular	6.5-7 mm
<i>Heterotheca villosa</i>	Asteraceae	4	P	Yellow	1-several terminal capitula	Regular	5-6 mm
<i>Heuchera richardsonii</i>	Saxifragaceae	4	P	Orange	Terminal raceme	Irregular	2-3.5 mm
<i>Houstonia longifolia</i>	Rubiaceae	4	P	White	Cyme	Regular	2-2.5 mm
<i>Liatriis ligulistylis</i>	Asteraceae	4	P	Purple	Racemes of capitula	Regular	8-11 mm
<i>Lithospermum canescens</i>	Boraginaceae	4	P	Yellow	Cyme	Regular	7-18 mm
<i>Lobelia spicata</i>	Lobeliaceae	4	P	White	Raceme	Irregular	2 mm
<i>Monarda fistulosa</i>	Lamiaceae	4	P	Purple	Dense terminal and axillary cluster	Irregular	16-25 mm
<i>Packera plattensis</i>	Asteraceae	3	P	Yellow	Corymbs of capitula	Regular	2.5-3.5 mm
<i>Pediomelum argophyllum</i>	Fabaceae	4	P	Purple	Spike	Irregular	3-5 mm
<i>Rosa blanda</i>	Rosaceae	4	W	Pink	Solitary	Regular	n/a
<i>Rudbeckia hirta</i>	Asteraceae	4	P	Yellow	Capitula	Regular	2 mm
<i>Sisyrinchium montanum</i>	Iridaceae	4	P	Purple	Solitary	Regular	n/a
<i>Solidago canadensis</i>	Asteraceae	4	P	Yellow	Panicles of capitula	Regular	2.2-2.8 mm
<i>Solidago nemoralis</i>	Asteraceae	4	P	Yellow	Panicles of capitula	Regular	2.5-4.6 mm
<i>Solidago ptarmicodes</i>	Asteraceae	4	P	White	Corymbs of capitula	Regular	3.8-4.1 mm
<i>Solidago rigida</i>	Asteraceae	4	P	Yellow	Cymes of capitula	Regular	4.3-6.1 mm
<i>Symphoricarpos occidentalis</i>	Caprifoliaceae	4	W	White-pink	Terminal and axillary clusters	Regular	4-5 mm

TABLE 3. continued

Plant species	Family	Rarity status ¹	Life habit	Flower colour	Inflorescence	Floral Symmetry	Calyx/corolla tube length (approx.) ²
<i>Symphotrichum ciliolatum</i>	Asteraceae	4	P	Pink-yellow	Panicles of capitula	Regular	4.3-6.4 mm
<i>Symphotrichum ericoides</i>	Asteraceae	4	P	White-yellow	Panicles of capitula	Regular	2.5-4 mm
<i>Symphotrichum laeve</i>	Asteraceae	3	P	Purple-yellow	Panicles of capitula	Regular	3.5-6.1 mm
<i>Symphotrichum sericeum</i>	Asteraceae	1	P	Pink-yellow	Panicles of capitula	Regular	5-7 mm
<i>Vicia americana</i>	Fabaceae	4	P	Purple	Raceme	Irregular	3.5-5.6 mm
<i>Zizia aptera</i>	Apiaceae	4	P	Yellow	Compound umbel	Regular	n/a
<i>Zizia aurea</i>	Apiaceae	4	P	Yellow	Compound umbel	Regular	n/a
<i>Zygadenus elegans</i>	Liliaceae	4	P	White	Raceme	Regular	n/a

¹ 1 At Risk in Canada, 3 Sensitive in Canada, 4 Secure in Canada, (Canadian Endangered Species Conservation Council 2011).

² Data obtained from Flora of North America Editorial Committee 1993+, and Reaume 2009.

additional data are needed to truly assess the PI of these species. Twelve species that had PI's of less than one were also not included on Fig. 2. In total, there were eight species of plants that insects in all three genera visited, almost all of which were in the Asteraceae: Flodman's thistle (*Cirsium flodmanii* (Rydb.) Arthur), smooth fleabane (*Erigeron glabellus* Nutt.), *S. canadensis*, *S. nemoralis*, *S. rigida*, *Symphotrichum ciliolatum*, *S. laeve* and golden Alexanders (*Zizia aurea* (L.) Koch). Wildflower species with a high PI value for one genus did not necessarily have a high PI for the others; several of the favourite plants of *Bombus* and *Lasioglossum* were not observed being visited by the other genera, although this may be partly due to the small sample size for some of these plants. The only plant with a high (> 5) PI value for more than one genus was *C. flodmanii*, which was highly attractive to both *Andrena* and *Lasioglossum* spp, although the high SE suggests that additional data are needed to confirm its attractiveness.

To determine which wild plant species are most likely to provide the wild pollinators of canola with optimal resources when the crop is not in flower, three factors were taken into account: synchrony, number of shared insect visitor taxa and the PI of canola pollinators (Tab. 5). There were seven species of plants that had a synchrony with canola equal to one; that is complete flowering overlap (Fig. 3). Eight species had a synchrony of zero, indicating no overlap at all. The synchrony of 14 species was greater than zero but 0.5 or less, and that of 12 species greater than 0.5 but less than one. The number of shared insect visitor taxa with canola ranged from 16 to just one: this variation is partially affected by a lack of supplementary data on pollinator visitation for some species. Regarding the PI, eight species had SE's greater than two and so were not ranked due to the unreliability of the data. The top five plant species (excluding those with SE > 2) in decreasing order were: *Monarda fistulosa*, *Solidago canadensis*, heart-leaved Alexanders (*Zizia aptera* (Gray) Fern.), *Symphotrichum laeve* and dwarf false indigo (*Amorpha nana* Nutt.). Each plant species was given a rank

according to how high its' value was for the three indicated factors. The three plants with a synchrony of one were not ranked as they are potential competitors for canola pollinators and likely provide floral resources at a time when it is not lacking. Plants with a synchrony of zero were given the highest rank. Plants that shared the most insect visitors with canola or had the highest PI were given the highest ranks. If two species had the same value, they were given the same rank. I decided to use the average rank for these three values to identify the plant species most likely to provide optimal forage for the crop pollinators of canola. Of the top 20 ranked plants, five species reach their flowering peak in June, four in July, eight in August and three in September.

DISCUSSION

The purpose of this research was to analyse data on plant-pollinator interactions in the northern prairies to identify wildflowers that support the pollinators of the popular insect-pollinated crop, canola. I found that insect visitation was not strongly correlated with plant abundance, an observation that was not unexpected as previous research indicates that there are many factors that influence foraging behaviour including sensory information, learning ability, and floral rewards (Heinrich 1976; Waddington 1983; Ibanez 2012). Within a species, insects may favour different plants depending on whether they are searching for pollen or nectar (Rasheed & Harder 1997; Elle et al. 2012). Even the presence of pollinator predators, like crab spiders, influences pollinator visitation (Jones & Dornhaus 2011). Thus data on actual pollinator visitations are more valuable for assessing wildflower suitability than data on plant abundance in a community.

Menz et al. (2010) suggest that when creating habitat for pollinators the core species, which are the plants that are visited by the most insect taxa, should be grown as they form the core of the plant-pollinator network. These core species are likely to be actinomorphic-flowered plants that do not restrict nectar access (Elle et al. 2012) rather than species

TABLE 4. Wildflower preference indices (PI) of *Bombus* spp. known to visit canola in Manitoba in order of decreasing importance to canola.¹ Relative tongue length indicated in brackets².

Plant species	Preference Index (mean±SE) ³							Insect taxa visiting (#)	All <i>Bombus</i> (mean PI±SE)
	<i>B. rufocinctus</i> (short)	<i>B. borealis</i> (long)	<i>B. ternarius</i> (short)	<i>B. perplexus</i> (medium)	<i>B. vagans</i> (medium)	<i>B. fervidus</i> (long)			
<i>Solidago rigida</i>	2.21±1.1	0.04±0.04	1.19±0.68	4.91±3.14	1.75±1.75	20.80±0	5	2.54±0.96	
<i>Astragalus agrestis</i>	2.78±2.78	5.09±4.56	0	23.8±0	5.01±3.12	-	4	5.32±2.22	
<i>Solidago canadensis</i>	0.76±0.38	0	10.76±9.36	1.34±0.75	1.33±1.33	0	4	4.82±3.76	
<i>Monarda fistulosa</i>	0	7.25±4.24	3.61±1.93	23.30±0	0	-	3	5.52±2.03	
<i>Vicia americana</i>	6.55±6.55	8.72±3.38	0	0	2.63±1.92	-	3	4.26±1.51	
<i>Liatis ligulisyts</i>	0	3.65±0	3.23±2.01	0	2.80±0	-	3	2.14±0.98	
<i>Dalea purpurea</i>	0	1.04±0.35	1.59±0.71	0	4.94±2.14	-	3	1.48±0.47	
<i>Symphytotrichum laeve</i>	1.20±1.20	0	1.49±1.49	-	-	0	2	1.04±0.76	
<i>Solidago nemoralis</i>	0	0.96±0.96	0.36±0.16	0	0	0	2	0.39±0.22	
<i>Lithospermum canescens</i>	0	0.30±0.30	-	0	0.07±0.07	-	2	0.13±0.10	
<i>Symphytotrichum ciliolatum</i>	0	0	0.21±0.18	0.59±0.49	-	-	2	0.34±0.21	
<i>Zizia aurea</i>	4.28±4.28	0	-	0	-	-	1	0.71±0.71	
<i>Rosa blanda</i>	-	-	22.30±22.19	-	-	-	1	22.3±22.19	
<i>Anorpha nana</i>	-	-	1.82±0	-	-	-	1	1.82±0	
<i>Helianthus pauciflorus</i> ssp. <i>subrhomboides</i>	0	0	1.62±1.62	-	-	-	1	0.97±0.97	
<i>Symphoricarpos occidentalis</i>	-	-	0.97±0.69	0	0	-	1	0.62±0.44	
<i>Erigeron glabellus</i>	-	-	0.52±0.52	0	-	-	1	0.28±0.28	
<i>Rudbeckia hirta</i>	0	0	0.51±0.51	-	-	-	1	0.17±0.17	
<i>Pedimelum argophyllum</i>	-	-	0.23±0.23	0	-	-	1	0.13±0.13	
<i>Helianthus maximiliani</i>	0	-	0.04±0.04	0	-	0	1	0.02±0.02	
<i>Solidago ptarmicoides</i>	0	0	0.03±0.03	0	0	-	1	0.02±0.02	
<i>Symphytotrichum ericoides</i>	0	0	0.01±0.01	0	-	0	1	0.003±0.003	
<i>Campanula rotundifolia</i>	0	0	0	-	3.04±2.10	-	1	0.66±0.49	
<i>Cirsium flodmanii</i>	-	-	0	-	2.86±0.00	-	1	0.57±0.57	
<i>Houstonia longifolia</i>	0	0	-	-	0.37±0.37	-	1	0.15±0.15	

¹Importance of *Bombus* spp. to canola as recorded in Turnock et al. (2006)²Williams et al. (2014)³Sample sizes (*N*) for each species ranged from 1 to 16 (mean *N* = 4).

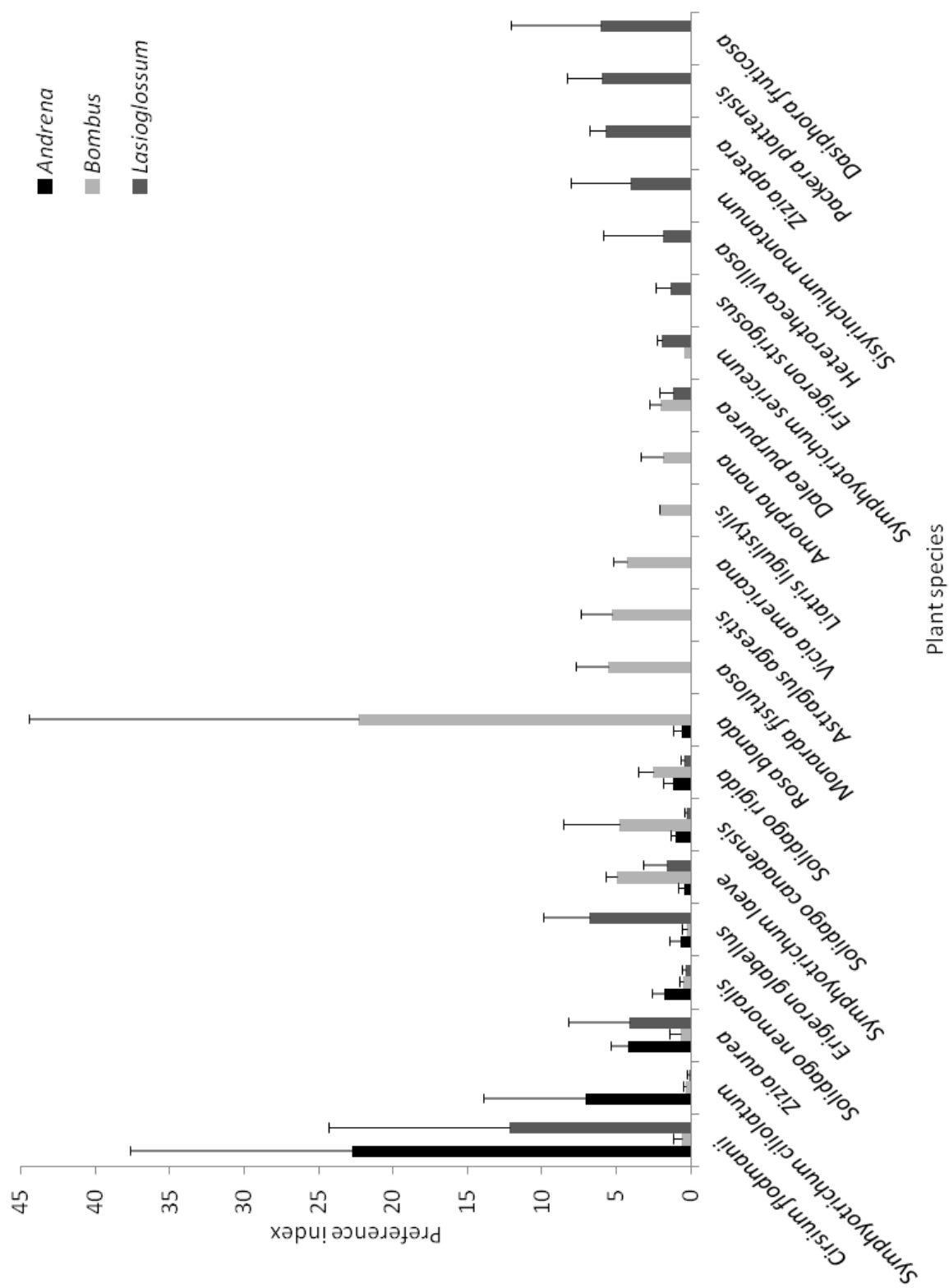


FIGURE 2. Preference indices (PI) of three insect genera to 22 wildflowers. Error bars indicate +SE.

TABLE 5. Data on synchrony, insect visitors and preference index (PI) to 41 plant species that share insect visitors with canola in Manitoba.

Plant species	Suitability rank	Flowering peak (month)	Total synchrony	Shared insect visitor taxa ¹ (#)	PI of shared visitors (mean±SE) ²
<i>Symphotrichum laeve</i>	1	September	0	11	2.71±0.85
<i>Solidago rigida</i>	2	August	0	17	1.60±0.47
<i>Monarda fistulosa</i>	3	July	0.31	11	4.00±1.94
<i>Dalea purpurea</i>	4	August	0.16	18	1.96±0.66
<i>Symphotrichum ciliolatum</i>	5	August	0	5	2.18±1.98
<i>Zizia aurea</i>	6	June	0.14	11	1.86±0.76
<i>Symphotrichum sericeum</i> ³	6	September	0	11	0.38±0.19
<i>Solidago canadensis</i>	8	July	0.55	15	3.51±1.98
<i>Erigeron glabellus</i>	9	July	0.31	9	2.20±0.89
<i>Liatris ligulistylis</i>	9	August	0	4	1.68±0.65
<i>Solidago nemoralis</i>	9	August	0.04	17	0.53±0.13
<i>Symphotrichum ericoides</i>	12	September	0	8	0.23±0.16
<i>Vicia americana</i>	13	June	0.46	7	2.40±0.72
<i>Heterotheca villosa</i>	14	August	0.04	5	0.75±0.36
<i>Helianthus maximiliani</i>	15	August	0.09	3	0.77±0.43
<i>Helianthus pauciflorus</i> ssp. <i>subrhomboides</i>	15	August	0	2	0.32±0.32
<i>Astragalus agrestis</i>	17	June	0.85	6	2.41±0.98
<i>Amorpha nana</i>	18	June	0.5	2	2.48±0.66
<i>Campanula rotundifolia</i>	19	July	0.52	6	0.86±0.41
<i>Zizia aptera</i>	20	June	0.83	2	2.86±1.54
<i>Rudbeckia hirta</i>	21	July	0.52	8	0.27±0.20
<i>Dasiphora fruticosa</i>	22	July	0.3	1	1.14±1.14
<i>Erigeron strigosus</i>	22	July	0.56	7	0.55±0.34
<i>Pedimelum argophyllum</i>	24	August	0	1	0.07±0.07
<i>Solidago ptarmicodes</i>	25	August	0.39	3	0.08±0.05
<i>Sisyrinchium montanum</i>	26	June	0.48	1	0.74±0.74
<i>Lithospermum canescens</i>	27	June	0.56	3	0.12±0.09
<i>Houstonia longifolia</i>	28	June	0.85	3	0.07±0.07
<i>Lobelia spicata</i>	28	August	0.37	1	0.04±0.04
<i>Achillea millefolium</i>	30	August	0.57	2	0.01±0.01
<i>Symphoricarpos occidentalis</i>	n/r ⁴	July	1	6	0.87±0.53
<i>Galium boreale</i>	n/r ⁴	July	1	2	0.07±0.06
<i>Astragalus adsurgens</i>	n/r ⁴	July	1	1	0.15±0.15
<i>Cirsium flodmanii</i>	n/r ⁵	July	0.42	3	9.84±5.63
<i>Packera plattensis</i>	n/r ⁵	June	0.58	2	59.50±54.82
<i>Crepis runcinata</i>	n/r ⁵	June	0.67	1	37.0±37.0
<i>Rosa blanda</i>	n/r ⁵	June	0.7	4	8.80±8.52
<i>Agoseris glauca</i>	n/r ^{4,5}	July	1	2	145.60±111.30
<i>Heuchera richardsonii</i>	n/r ^{4,5}	July	1	1	20.41±20.41
<i>Gaillardia aristata</i>	n/r ^{4,5}	June	1	1	4.33±4.33
<i>Zygadenus elegans</i>	n/r ^{4,5}	July	1	1	3.05±3.05

¹Information on the number of interactions obtained from Robertson (1929), Reed (1993), Petersen (1996), Hilty (2002), Colla & Dumesht (2010), Robson (2008, 2010, 2013).

²Sample sizes (*N*) for each species ranged from 2 to 126 (mean *N* = 36).

³This species is nationally rare in Canada.

⁴Suitability not ranked due to high synchrony with canola.

⁵Suitability not ranked due to high standard error of the PI (i.e. > 2).

with deep, narrow nectar tubes (Stang et al. 2006) as most pollinators have relatively short mouthparts. Using plant-insect interaction matrices from the tall grass prairie in Manitoba I identified these core species. However, Winfree (2010) cautioned that basing flower selection decisions solely on use rather than preference may result in some desirable species being overlooked. By calculating the PI for each species (Johnson 1980; Kells et al. 2011), I was able to determine that some plants that were visited by a small number of insect taxa were actually highly preferred by them. As suggested by previous research (Stang et al. 2006; Elle et al. 2012), these species tended to have relatively deep nectar tubes. *Vicia americana*, for example, has a deep nectar tube and was only visited by nine insect taxa. Species such as this should not be discounted for inclusion in wildflower plantings, especially if they are favoured by a common pollinator of a crop. As both *Bombus rufocinctus* and *B. borealis*, the most common bumblebee pollinators of canola, preferred *V. americana* over all other plants, including it would likely be beneficial. Plants that were visited by many species (e.g. *Solidago nemoralis*) often had a low PI. This is because plants that are visited by many insects may not be highly important to any one species but rather moderately important to many. In summary, looking only at the number of insect visitor taxa may result in highly preferred flowers being overlooked and looking only at the PI may discriminate against species that are utilized by many taxa. Because both methods had shortcomings and both long and short-tongued insects visit canola, I concluded that ranking the plant species relative to each other and then averaging the ranks would likely identify the optimal mixture of species to use for pollinator habitat enhancement.

In western Canada, canola is visited most frequently by *Lasioglossum*, *Bombus* and *Andrena*. The relative efficacy of these three genera in pollinating canola has not been ascertained although *Bombus* tends to be more efficient than most other bee genera (Herrera 1987; Sahli & Connor 2007; Ali et al. 2011). Although these three genera tended to prefer slightly different wildflower species, there was still quite a bit of overlap: eight plants were visited by all three genera and ten species were visited by two of the three genera. The *Bombus* spp. preferred many of the purple, tubular flowers such as *Monarda fistulosa* and Rocky Mountain blazingstar (*Liatris ligulistylis* (A. Nelson) K. Schum.) while *Lasioglossum* preferred many of the asters with large, yellow capitula, such as hairy golden-aster (*Heterotheca villosa* (Pursh) Shin.) and fleabanes (*Erigeron* spp.). Carvell et al. (2007) noted that *Bombus* species were most attracted to a mixture of legumes, a finding also observed by Zink (2013) in Alberta. The legumes *Vicia americana* and *Dalea purpurea* were preferred by several of the *Bombus* spp. in this study as well. Legumes were more attractive to *Bombus* spp. than to *Lasioglossum* or *Andrena* likely because they often have longer mouthparts than the others, an observation also made by Lagerhof et al. (1992). However, because the shorter-tongued bees (i.e. *Andrena* and *Lasioglossum*) were more abundant than the longer tongued bumblebees in canola fields, a mixture of flowers attractive to all three taxa would likely be most effective in provisioning them. Supporting this is the observation that a diverse mixture of wildflowers

attracts more bee species and provides a better continuity of floral resources (Carvell et al. 2007). Plant mixtures with greater functional diversity would also likely provide more stable pollination service over time as insect populations fluctuate from year to year (Kremen et al. 2002; Klein et al. 2009; Albrecht et al. 2012).

Another factor to consider when selecting plant species for habitat enhancement is whether they supply nectar and pollen during resource limited times (Menz et al. 2010). By assessing the degree of flowering synchrony between canola and the wild plants, I was able to identify seven plant species that may compete with canola for pollinators and should either be grown sparingly or not at all. However, as canola provides mainly pollen, plants that provide primarily nectar may not necessarily compete with canola as much as they would complement it; the possibility of facilitation via resource complementarity (Ghazoul 2006) needs to be examined in more detail. There were 34 plant species that reached their flowering peak either before or after canola typically blooms. If the top 20 plants identified in this study were grown in a wildflower planting there would be a fairly even sequence of blooms throughout the year; five species in early June, four in late July, eight in August and three in September. Thus the objective of providing floral resources throughout the growing season would be achieved. Some of the plants identified were previously noted as being important pollen and nectar sources for pollinators in North America including: milkvetch (*Astragalus* spp.), bluebell (*Campanula rotundifolia* L.), prairie-clover (*Dalea* spp.), shrubby cinquefoil (*Dasiphora fruticosa* (L.) Rydb.), lobelia (*Lobelia* spp.), *Monarda fistulosa*, rose (*Rosa* spp.), ragwort (*Packera* spp.), goldenrod (*Solidago* spp.), western snowberry (*Symphoricarpos occidentalis* Hook.), aster (*Symphotrichum* spp.) and *Zizia aurea* (Isaacs et al. 2009; Mader et al. 2011; Evans 2013). Additionally, plants in the genera *Cirsium*, *Fragaria*, *Helianthus*, *Penstemon*, *Prunella*, *Rudbeckia*, *Vicia* and *Viola* were noted to be attractive to one or more species of *Bombus* (Williams et al. 2014). Although *Symphotrichum sericeum* was one of the top ten plants, this species is actually nationally rare in Canada. Thus even though *S. sericeum* provides good forage for the likely pollinators of canola, it may not be available for wildflower restoration in Canada due its legal protection. However, as this species is more common in the U.S., it may be useful to grow there as it supplies late summer forage. The remaining species are all common and many are already popular plants for wildflower plantings.

There were several assumptions and limitations that must be acknowledged. I assumed that canola would be in flower for about one month from approximately June 20 to July 20 but if spring seeding is impaired by cool or wet weather it may be in flower till the end of July. However, as cool, wet weather also hampers the bloom times of wildflowers by several weeks (Robson 2008), the synchrony between canola and wildflowers may not be significantly different. As well winter seeding of canola followed by an early spring may result in earlier bloom dates than I used. If canola will typically be seeded in August or September, fewer June-flowering plants and more July-flowering plants would be optimal for providing pollinators forage.

Good data on the abundance of wild pollinators in canola fields in Manitoba (aside from *Bombus* spp.) is lacking so I assumed that the genera found visiting canola in Alberta were likely to visit it in Manitoba (Morandin et al. 2006; Zink 2013). This study also assumed that the most important pollinators of canola were bees. This was simply due to a lack of data on the abundance of potentially pollinating fly species of canola in Canada. In Pakistan (Ali et al 2011), Germany (Jauker & Wolters 2008; Jauker et al. 2012) and New Zealand (Rader et al. 2009) some flies, particularly those in the Syrphidae were noted as effective pollinators of canola. However, the only species observed in those studies that is also found in North America is the introduced *Eristalis tenax* (Syrphidae). *Eristalis tenax* has been observed visiting five wildflowers in North America and may visit canola here as well. Gavloski et al. (2011) also noted that bee flies (Bombyliidae) are potential pollinators of canola although no data on their abundance or frequency in Canadian canola crops has been published. Further research is needed to truly understand the role that wild flies play in the pollination of canola and other Canadian crop plants.

Another limitation was the lack of data on pollinator visitation to wild plants. Although the data provided by other sources (Robertson 1929; Reed 1993; Petersen 1996; Hilty 2002; Colla & Dumesh 2010) was valuable and greatly increased the number of confirmed species interactions (49 additional links were added as a result), there were several plant species with no supplemental data (e.g. *Amorpha nana*, ascending purple milk-vetch (*Astragalus adsurgens* Pall.) and *Gaillardia aristata*). Thus some plant species are likely visited by more insect taxa than was reported, which resulted in them receiving a lower suitability rank than if better data were available. As well, many insects and plants were observed infrequently resulting in high SE's. Caution should be used when interpreting the PI of plant species with high SE's as the values may not reflect true attractiveness.

As the plots I selected did not contain any flowering plants in May, data on insect visitations to the earliest flowering plants are lacking. However, I did observe bumble and sweat bees visiting several shrubs growing near my plots in late May, including pin cherry (*Prunus pensylvanica* L.), chokecherry (*P. virginiana* L.), American plum (*P. americana* Marsh), and Saskatoon serviceberry (*Amelanchier alnifolia* Nutt.). Many of these flowering shrubs are popular in windbreaks on the prairies and provide the added benefit of supplying resources to pollinators early in the year. Thus planting later flowering wildflowers, such as *Solidago* and *Symphotrichum*, alongside existing windbreaks of spring flowering shrubs would improve these habitats by providing a more stable supply of floral resources for pollinators.

Lastly, this study was restricted to just 56 species of wild plants common to the tall grass prairies. Visitation data to some of these plant species was inadequate and additional observations are needed to assess their relative importance. Some of these plants are common across the entire Canadian prairies (e.g. *Dalea purpurea*, *Monarda fistulosa*, *Symphoricarpos occidentalis*) while others are limited to Manitoba (e.g. *Liatriis ligulistylis*) although species in the

same genus may be present farther west (e.g. dotted blazingstar (*Liatriis punctata* Hook.)). Many plants that are common in the fescue prairies to the northwest or the drier mixed grass prairies to the southwest, where canola is also a common crop were not evaluated. However, the methodology presented here that integrates plant-insect visitor interaction networks, data on flower preference, and knowledge of crop pollinators and bloom times can be adapted for any crop or ecoregion.

Conclusions

Farmers are being encouraged to provide forage and breeding habitat for the wild pollinators of crop plants to improve crop productivity and resiliency of their agroecosystems. Existing data on crop pollinators, wild plant phenology, plant-insect interactions and quantitative data on insect visitation can be valuable for helping to identify the most appropriate plant species for wildflower plantings in agroecosystems. Using this approach I identified the plant species native to southern Canada that can provide insects with the resources they need for their survival. In particular, late-summer flowering plants like *Solidago* spp. and *Symphotrichum* spp. were identified as excellent candidates for wildflower plantings to support wild pollination service to canola. Good early spring-flowering species include *Zizia* spp., *Vicia americana* and *Astragalus agrestis*. Exactly which of these species are selected for habitat enhancement will require the collection of more complete data on flower preferences by bees and possibly other pollinating insects, the relative importance of individual bee species to canola pollination and information on the degree to which canola competes with other concurrently flowering species for pollinators. As well, wild flower species selection will depend on the availability of seed as well as the local soil conditions as some plants cannot tolerate very dry or moist conditions. Finally, testing of a wildflower seed mixture using these species will be required to determine the impact on bee abundance and crop productivity. Protecting or providing nesting habitat as well as a steady supply of floral resources would likely be even more beneficial.

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APPENDICES

Additional supporting information may be found in the online version of this article:

APPENDIX I. Plant-insect visitor matrix.

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