AGRICULTURAL PRACTICES ON BOULDER COUNTY OPEN SPACE: IMPLICATIONS FOR POLLINATOR CONSERVATION

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Abstract
Declines and local extinctions of insect pollinators have been reported around the globe. This phenomenon is of great concern as insects, in particular bees, are important pollinators of native plants and agricultural crops. We are interested in examining the bee populations on land used for agriculture. Boulder County Parks and Open Space (BCPOS) owns approximately 25,000 acres of crop land in Boulder, and it is entrusted with managing these properties for both public and private use. Ensuring the conservation of bee communities is one component of its land-use policy. Our proposed study will compare bee communities on open space lands using conventional agricultural practices with open space lands using organic cultivation practices. As part of our investigations, we will explore factors important in bee abundance and diversity.

Introduction

Agriculture is a significant part of Boulder County's history, but urbanization has dramatically changed the county's landscape. Boulder County Parks and Open Space (BCPOS) owns nearly 100,000 acres, 25,000 of which are agricultural properties. BCPOS' mission is conserving "natural, cultural, and agricultural resources and providing public uses that reflect sound resource management and community values" (Boulder County 2015a). BCPOS seeks to manage its agricultural properties in an environmentally-friendly way (Boulder County 2015b). One aspect of this management is the conservation of pollinators on these lands.

Pollinator declines have been documented around the globe since the 1990s (Allen-Wardell et al. 1998, Kearns et al. 1998). As farmland covers over 35% of the earth's ice-free land-mass (Garibaldi et al. 2014), loss of pollinators in these habitats is of concern to ecologists and farmers alike due to significantly reduction in biodiversity. The dependence of crop plants on pollinators also makes pollinators economically important.

Over time, agricultural practices have shifted from small, diversified farms to large-scale, mechanized monocultures using pesticides, chemical fertilizers and herbicides that can harm pollinators (Kremen et al. 2012, Kearns et al. 1998). While flowering monocultures (but not wind-pollinated crops) may provide resources for a limited number of pollinator species during their short flowering seasons, they cannot provide food necessary to maintain pollinators throughout the entire growing season. Before the advent of mechanized agriculture, crop fields were surrounded by hedgerows or untended habitat that provided floral resources over months when crops were not flowering (Roulston and Goodell 2011, Kearns et al. 1998). In addition, uncultivated patches provided pollinator nesting sites (Roulston and Goodell 2011). As semi-natural habitats were brought into cultivation, the loss of floral diversity further reduced pollinator diversity (Garibaldi et al. 2014) and altered the remaining pollinator community composition such that common, wide-ranging taxa were most abundant (Carré et al. 2009). Loss of native bee species can lead to loss of native plants that rely on them for reproduction. In addition, with fewer native pollinators present, farmers come to depend on commercially available honeybees that are transported to crops when they are flowering. Honeybee declines from colony collapse disorder have reduced the number of honeybees available for crop pollination, which has focused attention on the loss of native bees.

In recent years, scientists have begun studying what practices produce environmentally-friendly farms. Several of these studies focus on maintaining pollinator diversity and enhancing crop pollination (Garibaldi et al. 2014, Kremen et al. 2012). Bees are the most important group of pollinators, especially for crops (Morandin and Kremen 2012, Kremen et al. 2007). Native bee abundance and diversity on agricultural lands appears to be a function of both farm management practices and the quality of the landscape around crop fields (Kennedy et al. 2013; Kremen et al. 2007).

Several types of agricultural practices appear to encourage bee diversity on farms. Reestablishing patches of natural habitat can increase pollinator diversity, as well as provide natural pest control by predatory native insects. In addition, these patches offer floral resources over the course of the entire growing season as well as bee nesting sites (Kremen et al. 2007). Within patches of natural habitat, bees prefer native plants over introduced species, so plans should include this consideration (Morandin and Kremen, 2012). Decreasing or modifying the use of insecticides can positively affect pollinators (Chagnon et al. 2015, Garibaldi et al. 2014, Raulston and Goodell 2011). No-tillage farming may also benefit ground-nesting species whose nests can be destroyed by traditional plowing practices (Roulston and Goodell 2011). Diversified crop fields and organic farms support the greatest abundance and diversity of bees (Kennedy et al. 2013).

BCPOS is interested in managing their agricultural properties to maintain bee diversity. Currently, farms leased by BCPOS are under five different management regimes: conventional, certified organic, organic practices, non-organic and non-traditional, and agritainment (Boulder County 2015b). These regimes provide the opportunity for comparing bee diversity under different agricultural practices in the local Boulder climate. Among the crops grown are alfalfa and grass forage, wheat, barley, corn and sugar beets (Boulder County 2015b). Although alfalfa and sugar beets require bees for seed production, none of these crops require pollinators when grown for market. BCPOS' interest is simply in determining best management practices for maintaining bee diversity.

We propose a pilot project to compare bee diversity and abundance under a subset of the crop management conditions found on BCPOS land. The purpose of this project is to provide insight into management practices that sustain native bees.

Objectives

The primary objective of this study is to establish best land-use practices for promoting pollinator conservation on lands leased by Boulder County Parks and Open Space (BCPOS) for agricultural purposes. To do so, we will compare bee communities on open space lands using conventional and organic cultivation practices, and explore factors driving bee abundance and diversity.

Below, we outline a proposed pilot project to compare bee communities on agricultural properties under six different cultivation practices:

- Organic Corn
- Conventional Corn (with pesticides)
- Conventional Sugar Beets
- Organic Alfalfa
- Conventional Alfalfa
- Undeveloped Land

Hypothesis

Null hypothesis

Bee abundance and diversity will be the same in uncultivated habitat adjacent to each of the five types of farms and in undeveloped land.

Alternative hypotheses

Organic farming practices will promote greater bee diversity than conventional farming practices that employ pesticides.

Undeveloped land will harbor greater bee diversity than natural areas surrounding conventional farms employing pesticides.

Methods

Field Surveys

We will establish three plots in each of the habitats listed above, for a total of eighteen plots. Plots will be established adjacent to crop fields along uncultivated edges and ditches.

Each plot will be sampled every three to four weeks (depending on weather) between April 15, 2015 and August 31, 2015. Sampling will involve setting out pan traps for 24 hours and hand-netting in each plot for 30 minutes. Hand-netting will be divided among multiple collectors (e.g., three collectors hand-net for 10 minutes, for a total of 30 minutes). Sampling will be conducted in uncultivated areas adjacent to crop fields (e.g., ditches and hedgerows with wild vegetation).

Specimens that are easily recognizable in the field (such as bumblebee queens of known species) will be netted, chilled, identified and released. All other netted specimens will be euthanized in ethyl acetate collecting jars, pinned and labeled. Pan trapped specimens will all be collected, washed and dried, pinned, and labeled. Unfortunately, the difficulties in species- and in some instances even generic-level identifications within bees (Apoidea) necessitate the euthanasia and preservation of specimens. We will mitigate any effects of sampling on bee populations by surveying only once per month, allowing us to survey across multiple flight seasons without oversampling bees in any one month.

Sampling Locations

BCPOS has active farms on the following lands: Ertl/Keith and Leggit properties (organic corn); AHI property (organic alfalfa); Gaynor, Sisters of St. Francis, and Denzel properties (conventional beets); Sisters of St. Francis and Denzel properties (conventional corn); Agricultural Center property (conventional alfalfa). Sampling will take place on a subset of these farms. In addition, natural, non-agricultural grasslands will also be sampled. All sampling sites are located within Boulder County, Boulder, Colorado, USA and are located between CO state highways 66 and 52 (north-south) and between 75th St. and East County Line Road (west-east).

Specimen Identifications

All specimens will be initially identified to the genus level during the summer and fall of 2015. Genus-level identifications will be used for statistical analyses. Ultimately, we will attempt to provide species identifications. However, due to the difficulty in identifying several genera to the species level (Megachile, Perdita, Lasioglossum/Dialicts, Melissodes, etc.), additional funding would be required to pay for the services of the few taxonomic experts qualified for this work.

All specimens will be barcoded, and vouchered at the University of Colorado Museum of Natural History or as part of a BCPOS reference collection.

Statistical Analyses

Bee abundance will be compared within (the three plots per habitat) and between (the six) habitat types using standard analysis of variance techniques. Total species richness will be extrapolated in each habitat type. Diversity indices will be calculated and compared, and similarity among habitat types will be calculated. Genus lists (and species where possible) will be prepared for each habitat type. Differences in representation of the functional groups of bees present in different habitats will be examined.

Project Schedule

Specimen collection and preparation will begin in mid-April 2015 and continue until late August 2015. If necessary, specimen preparation will continue into the fall of 2015. Data analysis will begin in August 2015.

Anticipated Value

Results from this study will help BCPOS make decisions on management of its agricultural properties for bee pollinator conservation. Management decisions might include: limiting lease options to specific crops; encouraging specific methods of crop production; limiting pesticide use; expanding irrigation ditch corridors; reducing cultivated areas to increase adjacent natural habitat; revegetating uncultivated habitat adjacent to crop fields with native plant species.

Qualifications of Principle Investigators

CVs of the principle investigators are attached.

For the past 15 years, Oliveras and Kearns have been monitoring bee populations in undeveloped areas in Boulder County, Colorado. Our results indicate that on these properties, the number of bee species in Boulder has remained little changed compared to the number reported from the early 1900s. We are currently in the process of analyzing data from a five-year bumblebee monitoring project conducted across an elevation range of 1700m – 3350m.

Oliveras and Kearns are faculty at the University of Colorado. Kearns has co-authored two books about pollinators. Carper is a postdoctoral research associate whose current work in Colorado focuses on the growth and reproduction of bees across an agricultural gradient and the responses of native bees to the Colorado flood. His doctoral work focused on pollination in suburban environments.

Budget

Budget Request from BCPOS:

Materials	
1. Insect pins –7000 pins of various sizes; 1000 at $55	$ 400
2. Insect labeling paper - 100 sheets at $23	$ 23
3. Waterproof ink pens - 5 at $2.50	$ 12
4. Printer cartridge	$ 50
5. Fumigant strips for insect boxes	$ 15
6. Large plastic bags for insect boxes - 100 at $52	$ 52
7. Insect boxes - 15 at $16	$ 240
9. U.S. National Museum specimen drawers - 10 at $66	$ 660
Materials Total:	$1,452
Stipends	
1. Student internship	
Requesting BCPOS internship for one student	$ 2,000
2. P.I. honorarium	
Requesting BCPOS honorarium of $4000 for two PIs	$ 8,000
Stipends Total:	$10,000
Total requested from BCPOS	
1. Materials total	$ 1,452
2. Stipends total	$10,000
Total funding from BCPOS:	$11,452

Budget Request from University of Colorado:

Alternative Student Funding	
1. Undergraduate Research Opportunities (UROP) team grant	
Three students at $1000 each	$3,000
2. Individual UROP grant	
One senior undergraduate	$2,400
Total student funding University of Colorado:	$5,400
Additional PI funding	
Supervising and mentoring students	
Two PIs at $2000 each	$4,000

Total requested from University of Colorado

1. Student funding	$5,400
2. PI funding	$4,000
Total funding from University of Colorado:	$9,400

Budget Justification

Materials
The University of Colorado Museum of Natural History Entomology Collection is donating bee traps for this project. The three PIs already possess nets that they will use to capture specimens. However, the Entomology Collection does not have equipment or supplies that it can donate to this study. The three PIs also do not have the necessary equipment or supplies. We request that BCPOS purchase the materials necessary for specimen storage in a reference collection.

Two of the PIs (Kearns and Oliveras) are teaching faculty at the University of Colorado and have nine-month academic appointments. They are not funded for any work performed in the summer. The third PI (Carper) is a research associate currently being funded for another pollination project. We request BCPOS monies to support the summer work conducted by Kearns and Oliveras.

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Table 1.				
Property	management	crop*	coordinates	elevation (m)
AHI	organic	alfalfa	N 40°1456 W -105°1882	1549.0
ERTL	organic	corn	N 40° 1249 W-105° 0966	1560.0
Clark	conventional	sugar beets	N 40°2191 W -105°1351	1560.0
Distel	conventional	alfalfa	N 40° 1275 W -105° 1152	1504.6
Dougherty	conventional	corn, fallow, alfalfa	N 40° 1250 W-105° 0967	1548.0
Sisters	conventional	barley	N 40° 1437 W-105°0881	1518.3
Wambsganns	conventional	corn	N 40° 1006 W -105° 0751	1525.9
Zimdahl1	organic	corn	N 40° 2121 W -105° 0882	1560.5
Zimdahl3	organic	alfalfa	N 40° 2067 W -105° 0876	1560.5
ChCrkS	organic	mixed crops	N 40° 0297 W-105°1053	1550.0
Montgomery	organic	corn	N 40°1911 W -105°0559	1514.0
Puma	revegetated	flowers	N 40° 2251 W -105° 1143	1563.9
RuthRoberts	revegetated	flowers	N 39° 9481 W-105°0876	1625.0
Peck	organic	mixed crops	N 40°1337 W -105°1338	1521.0
*crop in field closest to sampling site				

Table 1. Sampling site characteristics.

Collected in nets only

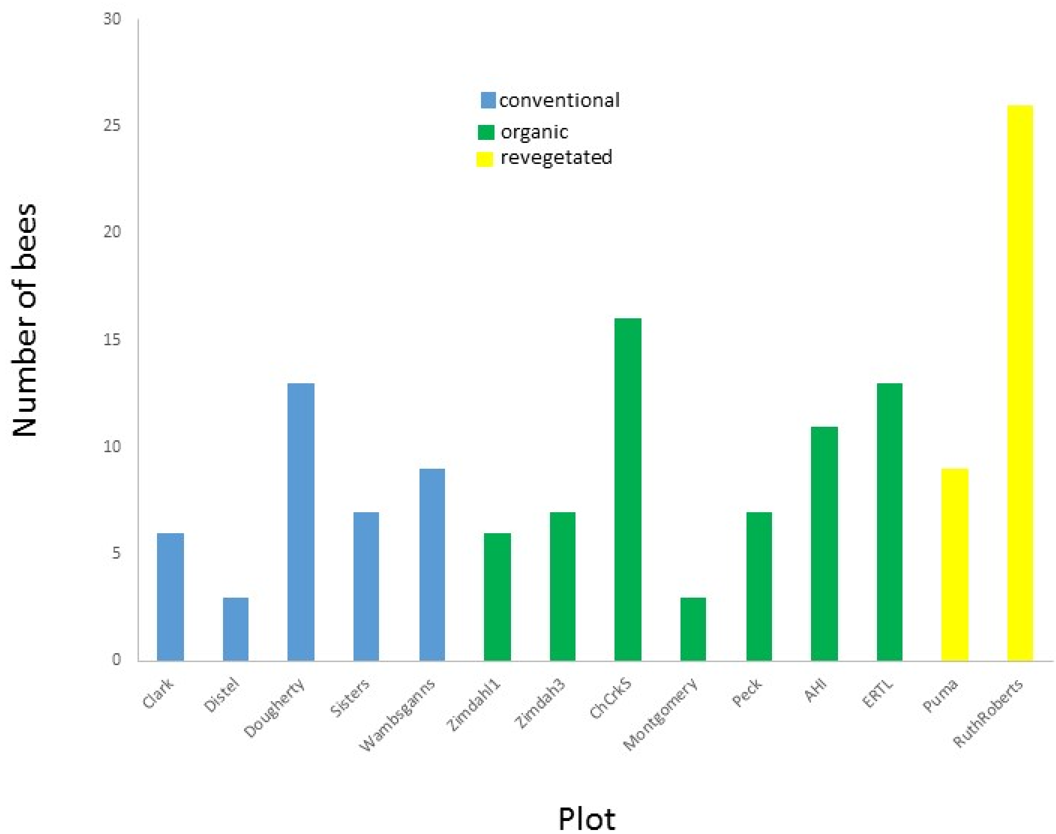
Bombus	*centralis*
Bombus	*nevadensis*
Caliopsis	
Ceratina	
Colletes	sp
Halictus	sp1
Halictus	sp2
Halictus	sp3
Halictus	*tripartitus*
Megachile	sp1
Megachile	sp3
Sphecodes	sp2

Collected in vane traps only

Anthophora	*montana*
Anthophora	*smithii*
Anthophora	*walshii*
Diadasia	sp
Eucera	sp
Hoplitis	sp2
Hoplitis	sp3
Lilthurge	*apicalis*
Megachile	sp2
Melecta	sp
Melissodes	commune-ish
Melissodes	sp1
Nomada	sp
Osmia	
Peponapis	*pruinosa*
Perdita	
Triepeolus	sp1
Xeromelecta	*interrupta*

Table 2. Bee species caught in either nets or vane traps.

a.



30
25
20
15
10
5
0
Number of bees
conventional
organic
revegetated
Clark
Distel
Dougherty
Sisters
Wambsganns
Zimdahl1
Zimdah3
ChCrkS
Montgomery
Peck
AHI
ERTL
Puma
RuthRoberts
Plot

b.

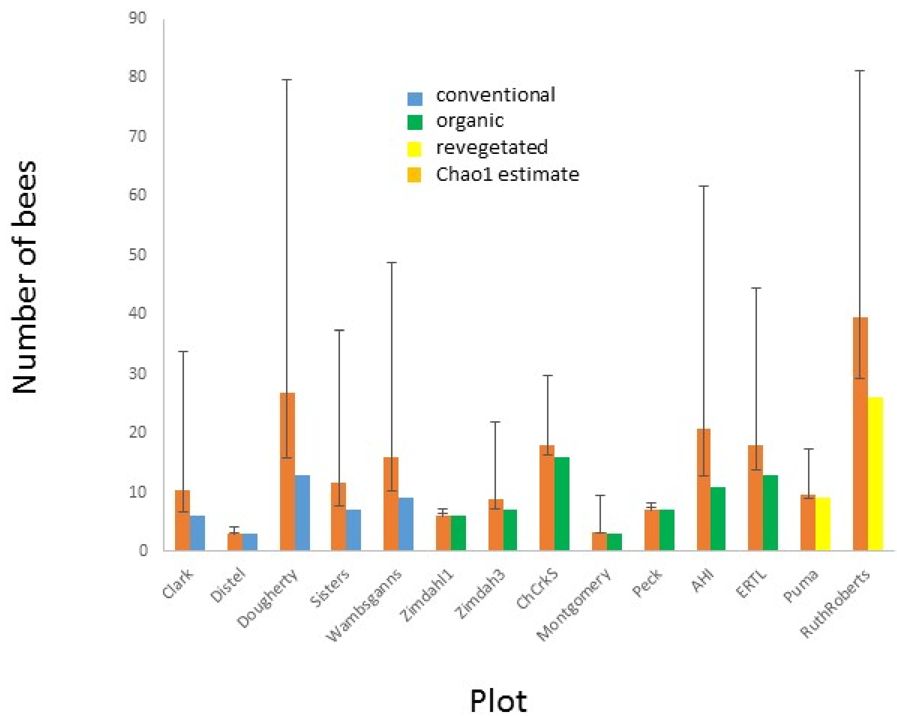
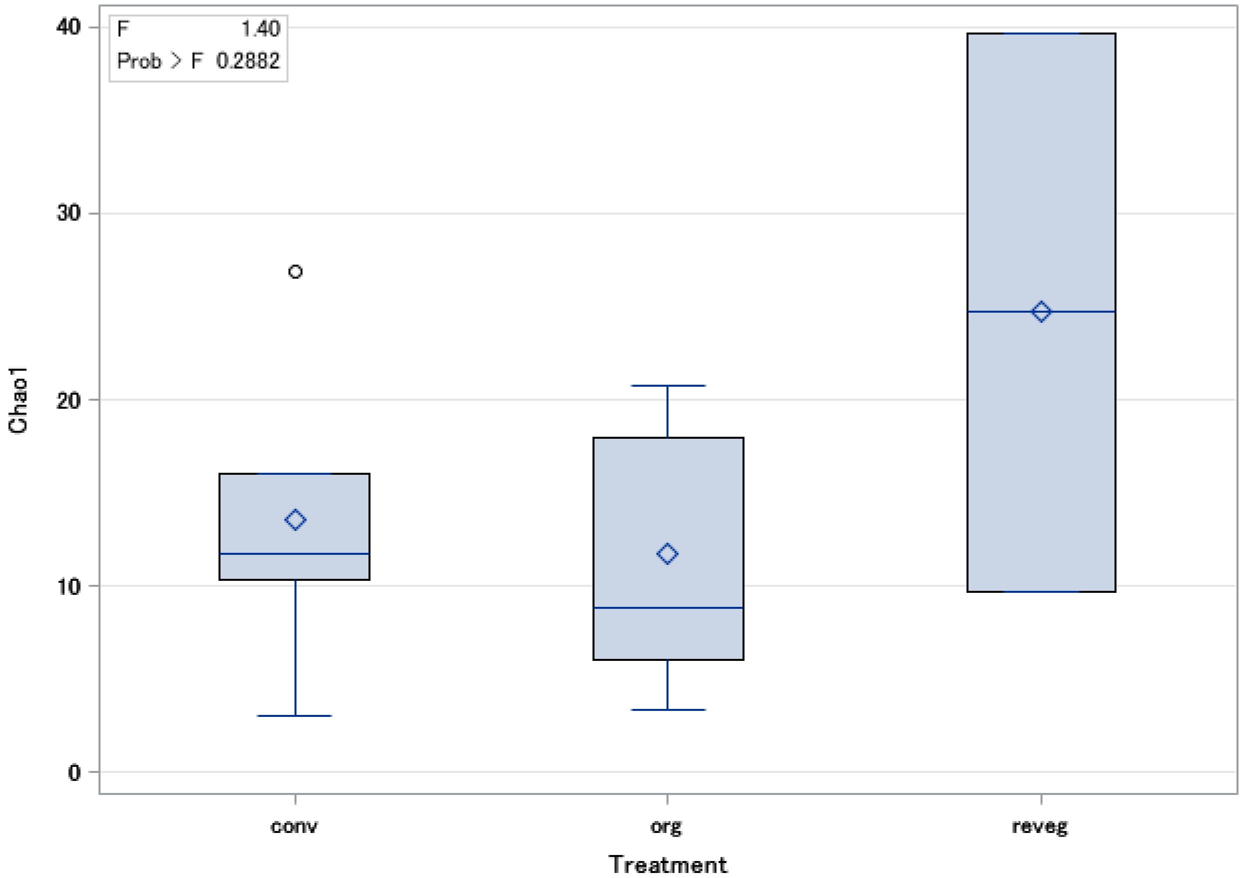


Figure 1. a. Number of species collected in vane traps at each site. b. Chao1 estimates the true value if plots were sampled many, many times and every single species was collected. Bars represent 95% confidence intervals.

a.



.

b.

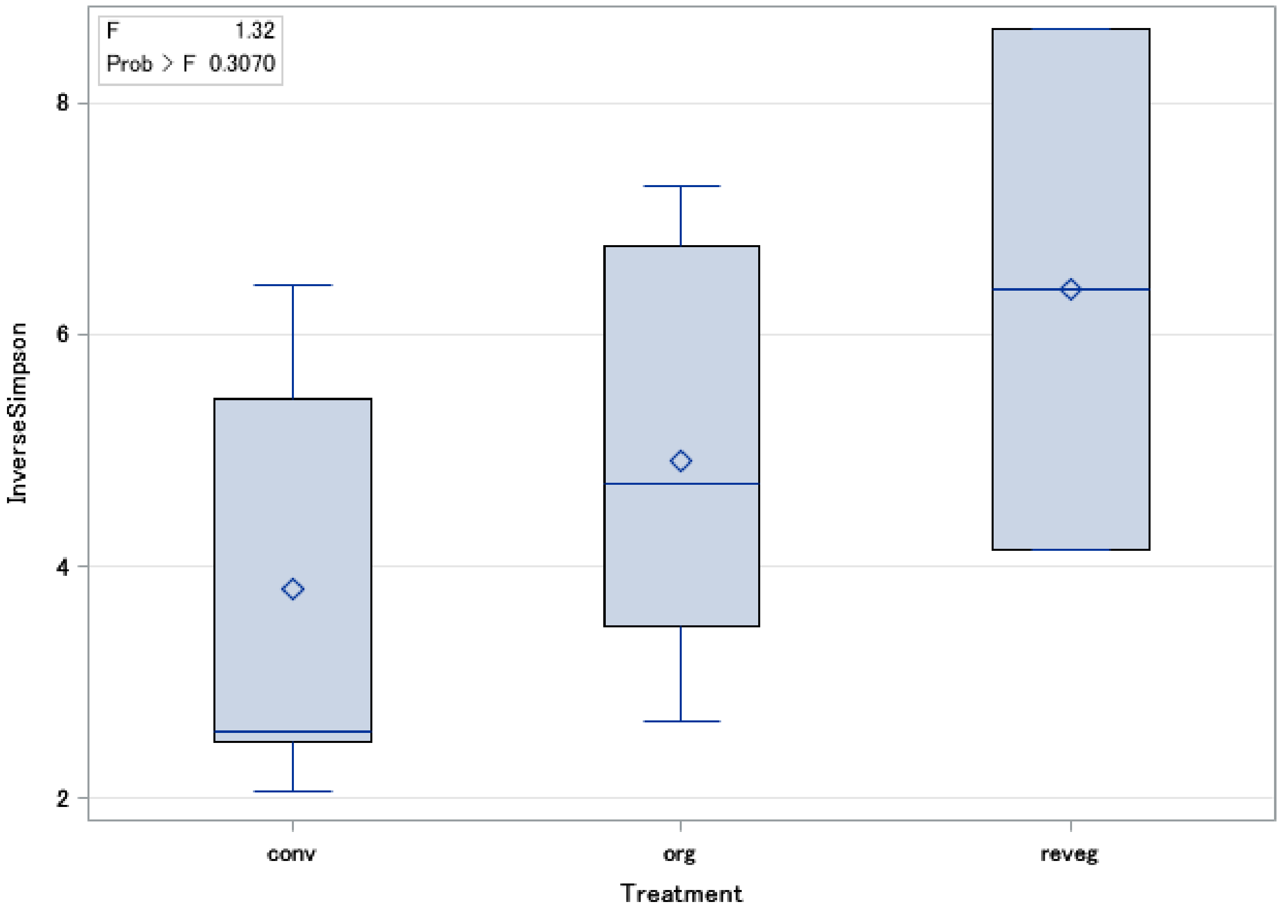
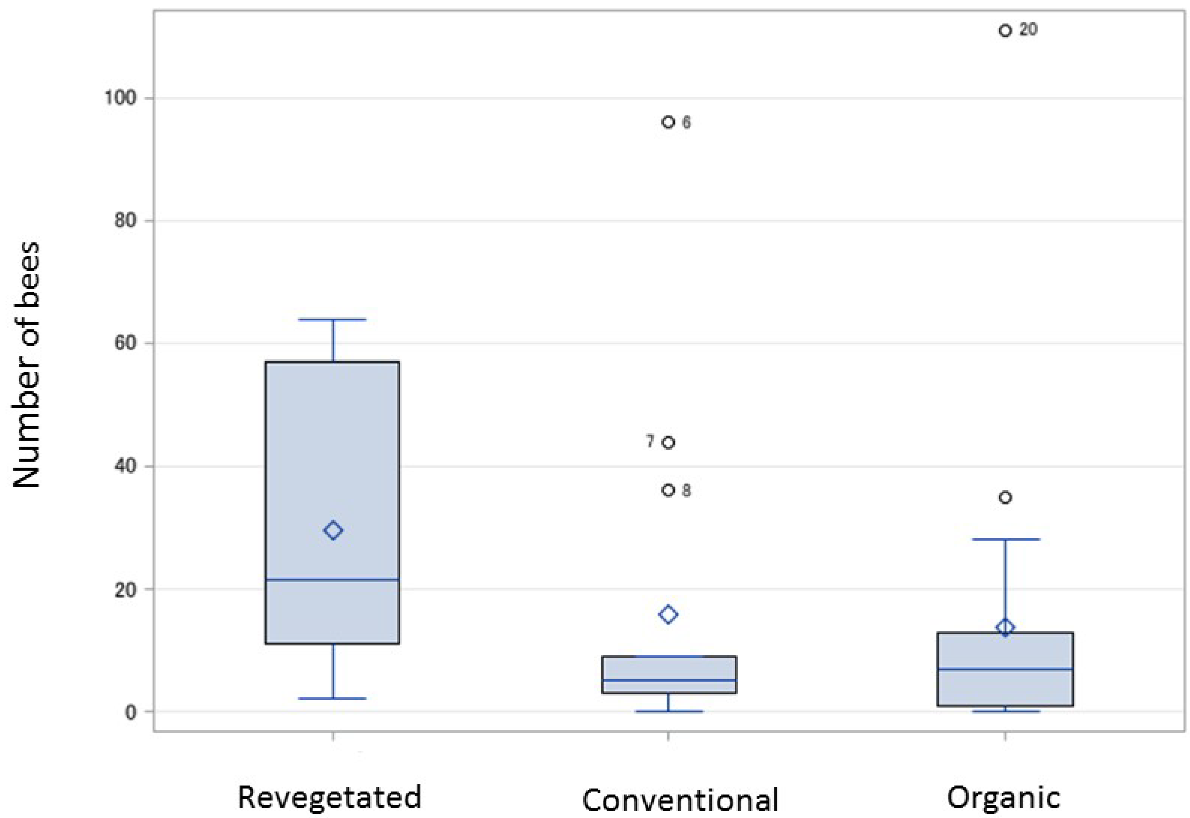


Figure 2. a. Chao1 estimates were not significantly different among farm management treatments. b. Inverse Simpson diversity indices were not significantly different among treatments (p=0.31).

a.


Number of bees
100
80
60
40
20
0
6
7
8
20
Revegetated
Conventional
Organic

b.

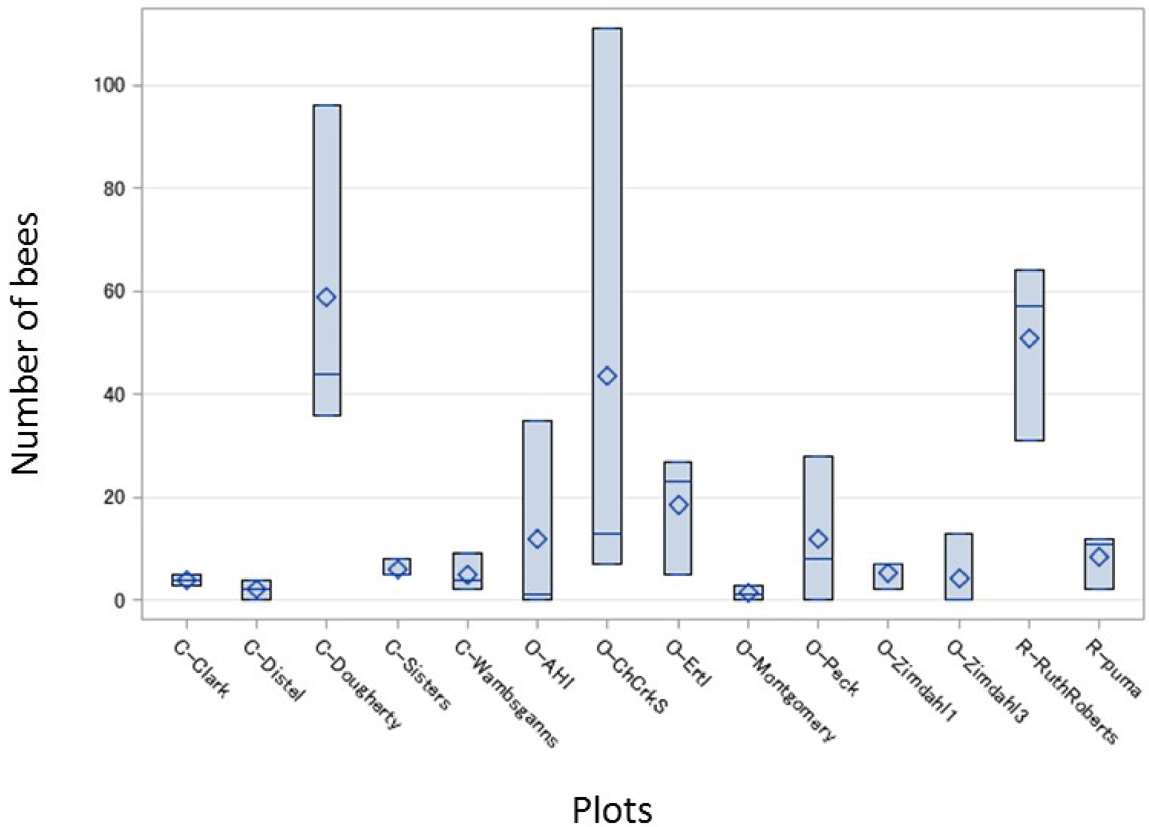


Figure 3. a. Abundance of bees captured in vane traps for different farm management treatments (treatments not significantly different, $p = 0.64$) b. Number of bees captured in vane traps at each site (Sites within treatments were significantly different, $p = 0.009$. Each site was sampled three times.

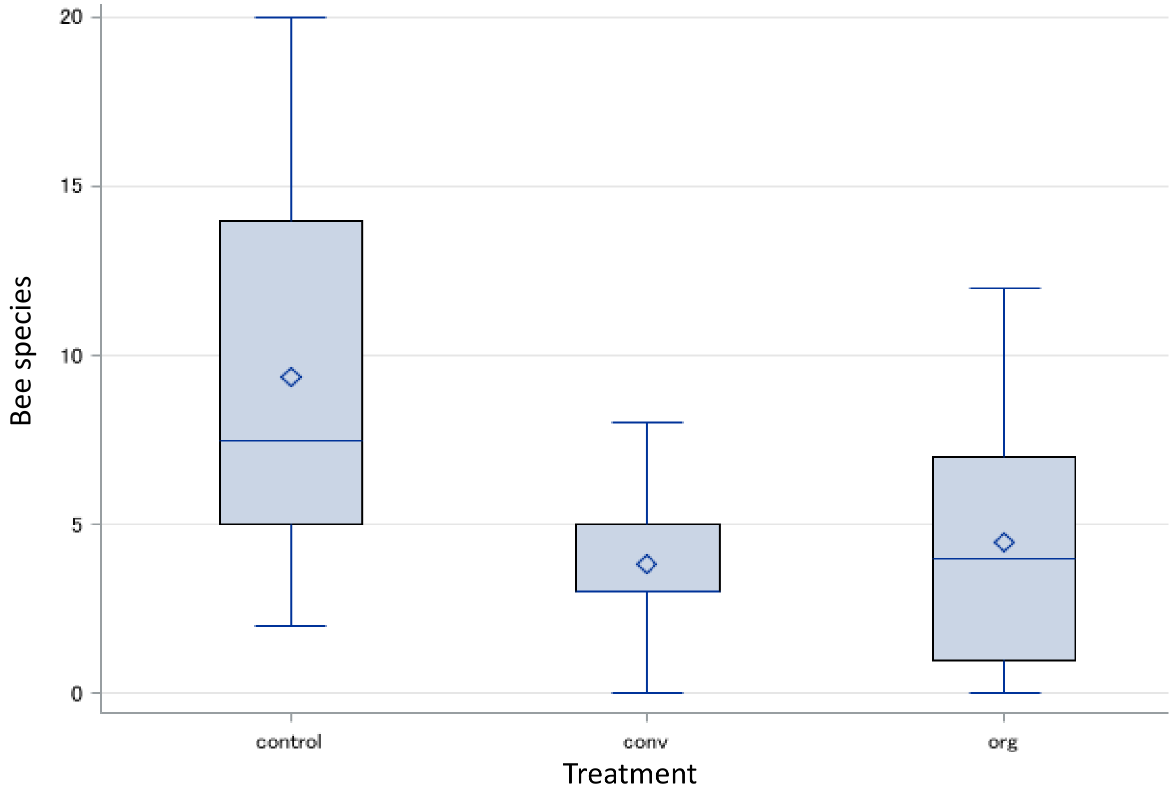
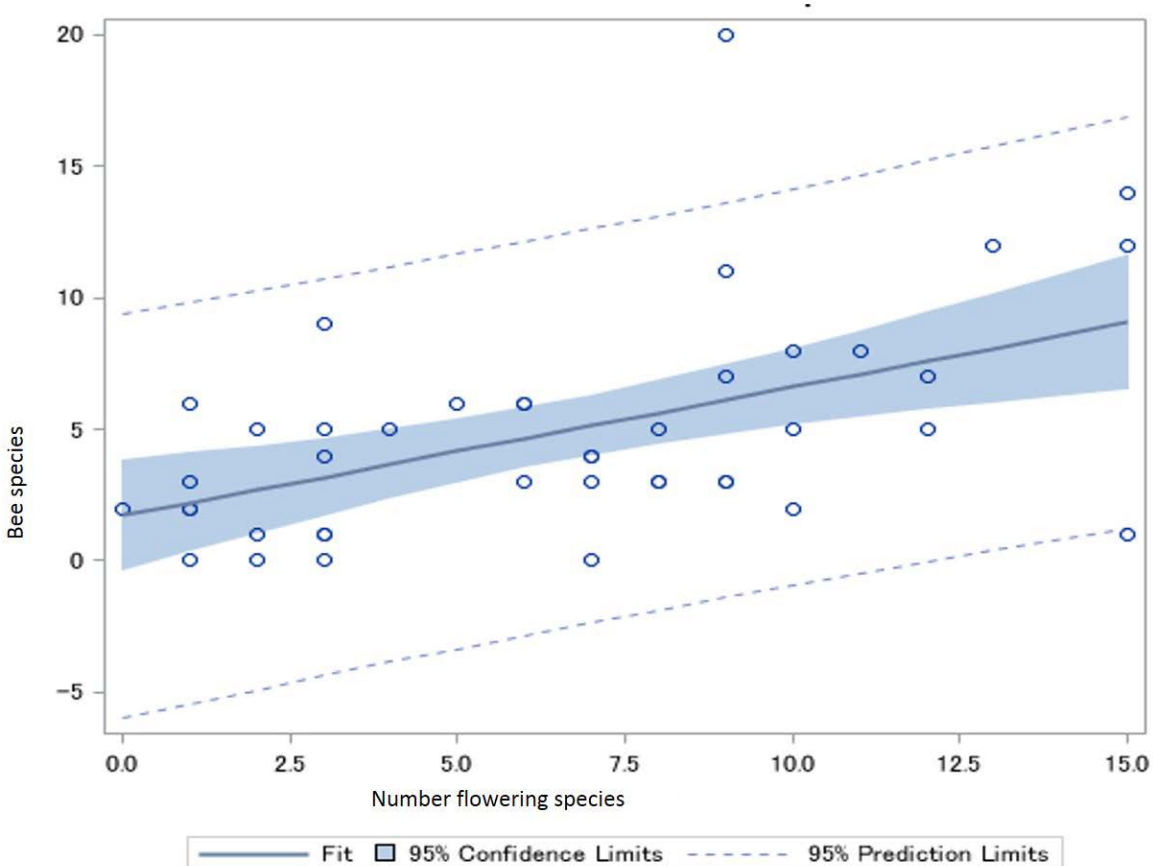


Figure 4. Treatments have significantly different numbers of bee species (log transformed variables, p = .008). Organic and conventional have similar numbers of bee species, lower than for the revegetated control plots.

a.



20
15
10
5
0
−5
Bee species
0.0
2.5
5.0
7.5
10.0
12.5
15.0
Number flowering species
Fit
95% Confidence Limits
95% Prediction Limits

b.

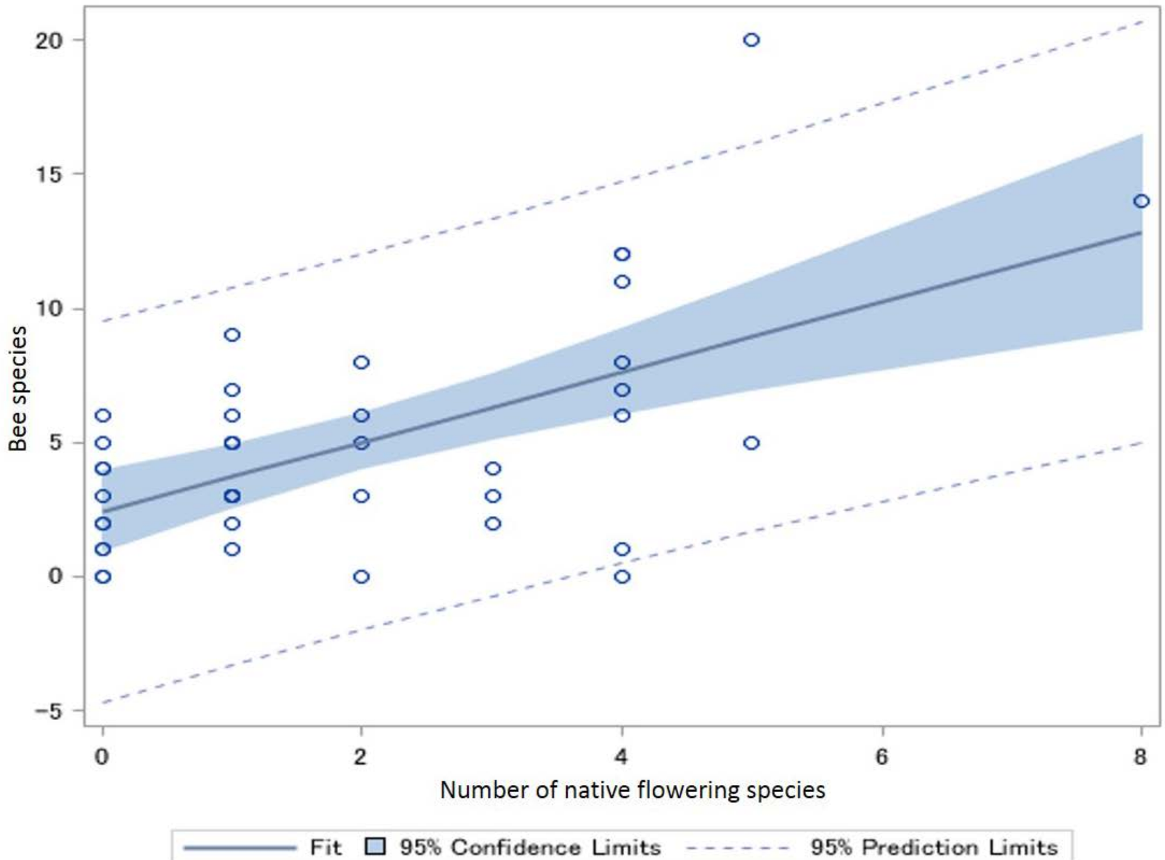


Figure 5a. Relationship between the number of bee species and all flowering plants: r-squared =0.252, p = 0.0007. b. Relationship between the number of bee species and native flowering plant species: r-squared = 0.343, p = 0.0001.

Appendix 1. Bees species found in each plot

BEE SPECIES	AHI	CHCrkS	Clark	Distel	Dougherty	Ertl	Montgomery	Peck	Puma	RuthRoberts	Sisters	Wambsganss	Zimdahl1	Zimdahl3
Agapostemon angel/tex	X	X	X		X	X	X	X	X	X		X	X	X
Agapostemon virescens										X				
Anthophora montana		X			X		X			X	X	X		
Anthophora walshii						X				X				
Apis mellifera	X	X	X		X	X		X	X	X	X		X	X
Augochlorella aurata		X							X	X				
Bombus appositus	X					X			X					
Bombus bifarius				X										
Bomb centralis											X			
Bombus fervidus	X		X							X				
Bombus griseocollis										X				X
Bombus huntii											X			
Bombus nevadensis									X	X				
Bombus pensylvanicus	X	X		X	X	X	X			X		X		
Calliopsis sp						X								
Ceratina sp.		X												
Colletes sp.								X						
Diadasia			X											
Dialictus		X								X				
Eucera sp				X										
Halictus ligatus	X		X		X					X				
Halictus rubicundus					X									
Halictus sp 1											X			
Halictus sp2													X	
Halictus sp3						X								
Halictus triparitus		X						X	X	X				
Hoplitis sp1										X				
Hoplitis sp2					X					X				
Hoplitis sp3		X												
Lasioglossum sp		X	X		X		X	X	X	X		X	X	
Lasioglossum hudson					X					X				
Lithurge apicalis	X													
Megachile sp1	X													
Megachile sp2	X													
Megachile sp3									X					
Melecta												X		
Melissodes agilis	X	X				X	X	X	X	X		X		X
Melissodes bimaculata		X	X			X					X	X	X	X
Melissodes commune-ish	X	X			X	X			X	X	X	X	X	
Melissodes coreopsis			X											
Melissodes coreop-ISH		X	X		X	X	X	X	X	X	X	X		
Melissodes sp1	X				X					X				
Melissodes sp2	X	X	X			X				X	X			
Nomada sp										X				
Osmia		X												
Peponapis pruinosa		X				X		X		X			X	X
Perdita					X									
Sphecodes sp1										X				
Sphecodes sp2					X									
Svastra obliqua						X				X				
Triepeolus sp			X			X								
Xeromelecta interrupta										X				

Appendix 2. Plant species found in each plot. Highlighted species are non-natives.

Species	Common name	AHI	ChCrkS	Clark	Distel	Dough	Ertl	Montg	Peck	Puma	RuthRob	Sisters	Wambs	Zim1	Zim3
Ambrosia sp	ragweed		X												
Apocynum cannabinum	white/hemp dogbane		X												X
Argemone polyanthemos	poppy thistle;prickly poppy								X						
Artemesia sp	sagewort										X				
Asclepias speciosa	milkweed	X	X			X	X					X	X	X	X
Capsella bursa-pastoris	Shepherd's purse														
Cardaria draba	white top				X		X								
Carduus nutans	musk thistle	X	X	X	X	X	X		X	X	X	X	X		X
Chorispora tenellua	purple mustard														
Chrysothamnus nauseosus	rabbit brush										X				
Cichorium intybus	chickory											X			
Cirsium arvense	Canada thistle	X	X	X	X	X	X	X	X		X	X	X	X	X
Cirsium vulgaris	bull thistle	X													
Convolvulus arvensis	bindweed	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Conium maculatum	poison hemlock	X													
Conyza canadensis	horseweed	X	X			X	X		X		X	X	X	X	
Cucurbita sp	wild cucumber								X						
Cynoglossum officionale	hound's tongue					X								X	X
Dalea purpurea	purple prairie clover										X				
Daucus carota	Queen Anne's lace											X			
Dipsacus sylvestris	teasel				X		X								
Erigeron sp	fleabane		X						X	X	X				
Erodium cicutarium	crane's bill														
Euphorbia sp	spurge		X												
Gaillardia aristata	blanketflower										X				
Gaura coccinea	whirling butterflies														
Gaura parviflora	small beeblossum														
Geranium richardsonii	white geranium	X													
Grindelia squarrosa	gumweed	X									X	X			
Helianthus anuus	sunflower	X		X		X	X				X		X		
Hesperis matronalis	Dame's rocket														
Heterotheca villosa	golden aster							X	X		X				
Lactuca tartarica	blue lettuce						X								
Lactuca sp	wild lettuce						X					X			
Leonorus cardiaca	mint								X						
Lepidium campestre	pepperwort														
Lepidium densiflorum	pepperwort														
Lotus corniculatus	bird-foot trefoil												X		
Lysimachia vulgaris	loosestrife												X		
Malva neglecta	common mallow			X			X		X				X		X
Medicago sp	alfalfa white	X									X				
Medicago sativa	alfalfa purple	X	X	X	X	X	X	X			X	X	X	X	X
Melilotus alba	white sweet clover	X	X		X										
Melilotus officinalis	yellow sweet clover	X									X	X			
Nepeta cataria	catnip			X		X									
Oenothera biennis	evening primrose	X	X		X				X				X		
Oenothera sp	evening primrose														
Penstemon palmeri	wild snapdragon										X				
Penstemon sp	snapdragon								X						
Physalis walteri	ground cherry													X	
Pisum sativum	pea								X						
Plantago lanceolata	plantain													X	
Podospermum laciniatum	salsify														
Polygonum sp	knotweed		X				X								
Portulaca oleracea	moss rose		X												
Potentilla sp	cinquefoil													X	
Ranunculus	buttercup													X	
Raphanus sativus	radish								X						
Ratibida columnifera	prairie coneflower										X				
Rosa arkansana	rose							X							
Rumex crispus	dockweed											X			
Silene vulgaris	bladder campion	X													
Sisymbrium altissimum	Jim Hill mustard		X	X					X	X					
Solanum rostratum	yellow solanum	X													
Solidago sp	goldenrod				X										
Sonchus oleraceus	sow thistle			X		X	X		X				X		
Sphaeralcea sp	orange mallow										X				
Taraxacum officinalis	dandelion			X	X				X				X	X	X
Thlaspi arvense	field pennycress	X													
Tithymalus esula	leafy spurge														
Tragopogon sp	yellow salsify	X		X								X			
Tribulus terrestris	puncture vine											X			
Trifolium hybridum	white clover													X	
Trifolium sp	purple flower	X													
Verbascum thapsus	Indian toilet paper		X			X	X						X	X	
Verbena bracteata	vervain														
Verbena hastata	swamp vervain												X		
Veronica sp	veronica								X						
Vicia villosa	hairy vetch								X						