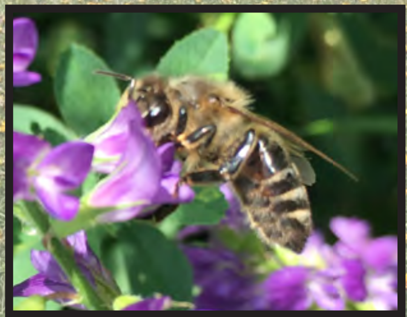
Prepared in cooperation with the U.S. Department of Agriculture

Forage and Habitat for Pollinators in the Northern Great Plains—Implications for U.S. Department of Agriculture Conservation Programs








Open-File Report 2020–1037

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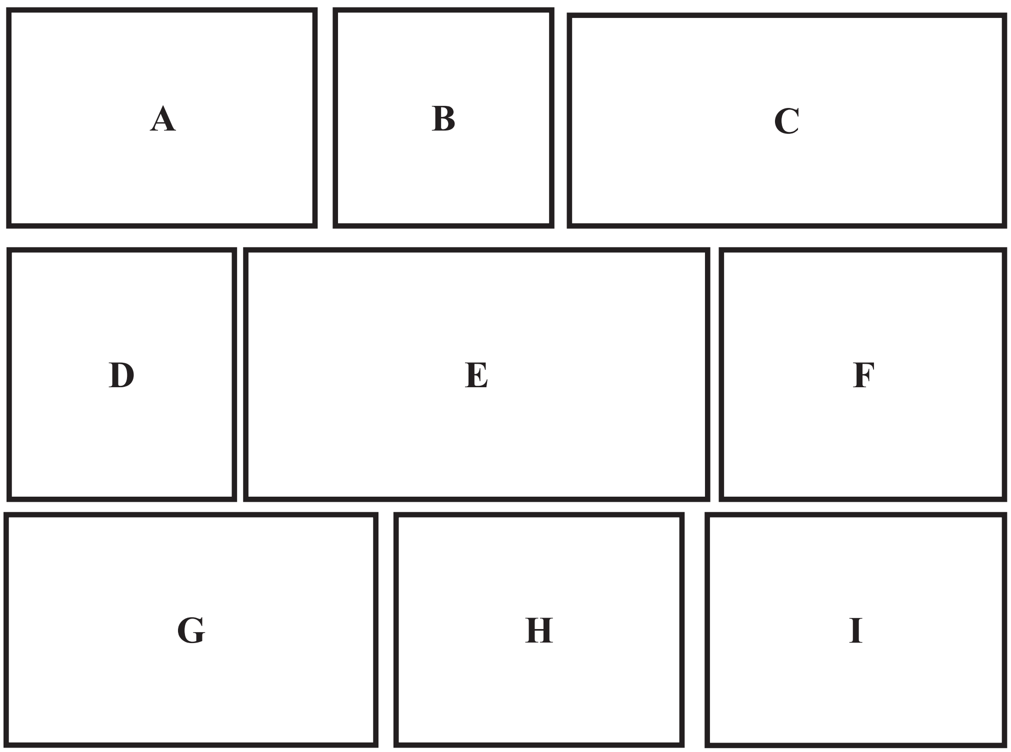

Cover. *A*, Bumble bee (*Bombus* sp.) visiting a locowood flower. Photograph by Stacy Simanonok, U.S. Geological Survey (USGS). *B*, Honey bee (*Apis mellifera*) foraging on yellow sweetclover (*Melilotus officinalis*). Photograph by Sarah Scott, USGS. *C*, Two researchers working on honey bee colonies in a North Dakota apiary. Photograph by Elyssa McCulloch, USGS. *D*, Purple prairie clover (*Dalea purpurea*) against a backdrop of grass. Photograph by Stacy Simanonok, USGS. *E*, Conservation Reserve Program pollinator habitat in bloom. Photograph by Clint Otto, USGS. *F*, Prairie onion (*Allium stellatum*) along the slope of a North Dakota hillside. Photograph by Mary Powley, USGS. *G*, A researcher assesses a honey bee colony in North Dakota. Photograph by Katie Lee, University of Minnesota. *H*, Honey bee foraging on alfalfa (*Medicago sativa*). Photograph by Savannah Adams, USGS. *I*, Bee resting on woolly paperflower (*Psilostrophe tagetina*). Photograph by Angela Begosh, Oklahoma State University. Front cover background and back cover, A USGS research transect on a North Dakota Conservation Reserve Program field in full bloom. Photograph by Mary Powley, USGS.

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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square kilometer (km^2)	247.1	acre
square meter (m^2)	10.76	square foot (ft^2)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Mass	
kilogram (kg)	2.205	pound avoirdupois (lb)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Supplemental Information

Some areas are supplemented with or given in acres because the U.S. Department of Agriculture often uses acres and pounds of pure live seed (PLS) as the primary units of measure.

Abbreviations

CP–42	Conservation Practice 42, “Pollinator Habitat”
CRP	Conservation Reserve Program
DNA	deoxyribonucleic acid
EQIP	Environmental Quality Incentives Program
EQIP–327	Environmental Quality Incentives Program conservation practice, “327-Conservation Cover”
EQIP–512	Environmental Quality Incentives Program conservation practice, “512-Forage and Biomass Planting”
EQIP–550	Environmental Quality Incentives Program conservation practice, “550-Range Planting”
FSA	Farm Service Agency
>	greater than
<	less than
NASS	National Agricultural Statistics Service
NPWRC	Northern Prairie Wildlife Research Center
NRCS	Natural Resources Conservation Service
OTU	operational taxonomic unit
PLS	pure live seed
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

Forage and Habitat for Pollinators in the Northern Great Plains—Implications for U.S. Department of Agriculture Conservation Programs

By Clint R.V. Otto,[1] Autumn Smart,[1,2] Robert S. Cornman,[1] Michael Simanonok,[1] and Deborah D. Iwanowicz[1]

Abstract

Managed and wild pollinators are critical components of agricultural and natural systems. Despite the well-known value of insect pollinators to U.S. agriculture, *Apis mellifera* (Linnaeus, 1758; honey bees) and wild bees currently face numerous stressors that have resulted in declining health. These declines have engendered support for pollinator conservation efforts across all levels of government, private businesses, and nongovernmental organizations. In 2014, the U.S. Department of Agriculture (USDA) and the U.S. Geological Survey initiated an interagency agreement to evaluate honey bee forage across multiple States in the northern Great Plains and upper Midwest. The long-term goal of this study was to provide an empirical evaluation of floral resources used by honey bees, and the relative contribution of multiple land covers and USDA conservation programs to bee health and productivity. Our multi-State analysis of land-use change from 2006 to 2016 revealed loss of grassland and increases in corn and soybean area in North and South Dakota, representing a significant loss of bee-friendly land covers in areas that support the highest density of summer bee yards in the entire United States. Our landscape models demonstrate the importance of the Conservation Reserve Program in providing safe locations for beekeepers to keep honey bees during the summer and highlights how land use in the northern Great Plains has a lasting effect on the health of honey bee colonies during almond pollination the subsequent spring. Our multiseason, multi-State genetic analysis of honey bee-collected pollen revealed *Melilotus* spp., Asteraceae, *Trifolium* spp., Fabaceae, *Sonchus arvensis, Symphyotrichum cordifolium*, and *Solidago* spp. were the top taxa detected; *Melilotus* spp. represented 42 percent of all detected taxa. *Symphyotrichum cordifolium*, *Solidago* spp., and *Grindelia* spp. were the top native forbs detected in honey bee-collected pollen. We also conducted plant and bee surveys on private lands enrolled in the Conservation Reserve Program and Environmental Quality Incentives Program. In general, we found significant variability in floral resources and pollinator utilization across USDA programs and practices. On average, greater than 75 percent of honey bee flower observations on private lands enrolled in a USDA conservation program were on non-native forbs, whereas 33 percent of wild bee flower observations were on non-native forbs. *Melilotus officinalis* and *Medicago sativa* were the most visited by honey bees, wherease M*edicago sativa* and *Helianthus maximiliani* were the most visited by wild bees. Our analysis of nectar dearth periods in June and September for honey bees revealed that although *Melilotus officinalis* and *Medicago sativa* were highly visited, less common native forb species such as *Ratibida columnifera*, *Agastache foeniculum*, and *Gaillardia aristata* were preferred species. However, these preferred species were relatively rare on the landscape and are, therefore, unlikely to make up a sizable part of the honey bee diet. In addition to our empirical results, we also showcase how the U.S. Geological Survey Pollinator Library, a decision-support tool for natural resource managers, can be used to design cost-effective seeding mixes for pollinators. Collectively, the results of this research will assist USDA with maximizing the ecological impact and cost-effectiveness of their conservation programs on pollinators in the northern Great Plains.

Introduction

European *Apis mellifera* (Linnaeus, 1758; honey bees) and wild bees (that is, undomesticated, native bees) support agriculture and ecosystem function throughout the United States. Globally, insects pollinate 85 percent of all flowering plants (Ollerton and others, 2011). Insect pollination services in the United States are valued at $15 billion, annually (Calderone, 2012). Honey bees provide most of the U.S. crop pollination needs, a service valued at $12 billion, annually. Annual losses of honey bee colonies of 30 percent or higher have been consistently reported by U.S. beekeepers over the past decade (for example, vanEngelsdorp and others, 2012, Spleen and others, 2013; Kulhanek and others, 2017).

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Concurrent with elevated honey bee losses, emerging evidence suggest wild bee fauna are in jeopardy as well (Cameron and others, 2011; Koh and others, 2016). Wild bees facilitate essential pollination of numerous crops and native wildflowers (Ollerton and others, 2011; Calderone, 2012). Declining bee populations place considerable strain on food security and the U.S. beekeeping industry (Spivak and others, 2011). It is widely accepted that bee losses or declines do not have a single cause; however, plausible causal factors include parasites and diseases, pesticide exposure, and the interacting effects of land-use change, land conversion, and bee forage loss (Goulson and others, 2015; Hellerstein and others, 2017; Spivak and others, 2017).

Loss of bee forage and land-use change, driven by the expansion of commodity crop production, has been of particular concern in the northern Great Plains region of the United States where 30–40 percent of the commercially pollinating national pool of honey bee colonies reside throughout the growing season, from June through October (U.S. Department of Agriculture, National Agricultural Statistics Service [USDA, NASS], 2017). Beekeepers have transported their honey bee colonies to this region during the summer to not only make a honey crop, valued at $343 million (USDA, NASS, 2017), but also to bolster the health of their colonies so they can survive the overwintering period and the stresses associated with the migratory pollination circuit. During the growing season in the northern Great Plains, honey bees forage on nectar and pollen resources available in the landscape; this foraging facilitates colony growth and productivity as well as sets the stage for overwintering success and crop pollination the subsequent spring (Gallant and others, 2014; Durant, 2019). However, increasing acreages of row crops, such as corn and soybeans, across the region over the past two decades have decreased the area of land suitable for supporting managed honey bee colonies (Hellerstein and others, 2017; Durant and Otto, 2019) and wild bees (Koh and others, 2016). As a result, core beekeeping areas in the northern Great Plains have substantially shifted toward land use unfavorable for supporting managed honey bees and wild pollinators alike (Evans and others, 2018).

In response to concerns about declining pollinators and bee forage loss, the USDA began a concerted effort to improve floral resource conditions in working landscapes. Within specific programs, the USDA also launched a series of practices and initiatives to bolster bee habitat, with a primary focus in the northern Great Plains and upper Midwestern States. These practices and initiatives incentivized landowners to enhance private lands in agricultural areas for pollinators. In 2014, the USDA (Farm Service Agency [FSA] and Natural Resources Conservation Service [NRCS]) and U.S. Geological Survey (USGS) initiated a co-funded, interagency agreement to evaluate USDA conservation programs and collect biological data needed for the USDA to improve forage for honey bees and other pollinators throughout the northern Great Plains. The long-term goal of this study was to provide an empirical evaluation of floral resources used by honey bees and of the relative contribution of multiple land covers and USDA conservation programs to bee health and productivity. Although our USGS team collected data on multiple land-use types as part of our research project, the primary focus for this report is the FSA's Conservation Reserve Program (CRP) and NRCS's Environmental Quality Incentives Program (EQIP).

The scope of this research necessitated interdisciplinary collaboration and an integrated science approach. In 2014, our team of USGS scientists developed and modified monitoring protocols for a regional pollinator assessment to be done from 2015 to 2017. Upon completion of the pilot study in 2014, USGS started a three-State research project to quantify bee forage and pollen diets. This report describes the status of the honey bee forage research by the USGS Northern Prairie Wildlife Research Center (NPWRC) under interagency agreements 16IAMRECRPHBTA1 (FSA) and 673A7514178 (NRCS). This final report highlights several key research areas from May 2015 to September 2018 including the following:

1. Bee health and productivity in relation to land use. (See the "Landscape Suitability for Supporting Honey Bees," "Honey Bee and Land-Use Pilot Study," and "Land-Use Effects on Honey Bee Colony Health and Services" sections.)

2. Pollen deoxyribonucleic acid (DNA)—What pollen do honey bees collect? (See the "Genetic Analysis of Bee-Collected Pollen Across the Northern Great Plains" section.)

3. Plant-pollinator interactions on private lands enrolled in the CRP and EQIP. (See the "Plant-Pollinator Interactions on Private Lands Enrolled in the Conservation Reserve Program or Environmental Quality Incentives Program" section.)

4. Bee-flower interactions, resource availability, and honey bee floral preference. (See the "Floral Resource Limitations and Honey Bee Preference" section.)

5. The USGS Pollinator Library—A decision support tool for natural resource managers. (See the "The Pollinator Library—A Decision-Support Tool for Enhancing Pollinator Habitat" section.)

We discuss the status of each core research area and highlight the relevance of USGS research to USDA program delivery. We also discuss opportunities for future investigations to improve conservation delivery of USDA programs. Several of the deliverables established in the original USGS–USDA interagency agreement have already been reported in peer-reviewed publications. For deliverables already published, we provide an executive summary of the publication in this report and briefly discuss its relevance to the USDA. Data figures from previous publications have been reprinted in this report, with permission from the publishers.

Landscape Suitability for Supporting Honey Bees

Loss of bee forage and habitat has been implicated in pollinator declines (Goulson and others, 2015). Loss of forage lands for honey bees is of primary concern in the northern Great Plains, a region that supports about 40 percent all U.S. honey bee colonies during the summer (Hellerstein and others, 2017). For the initial phase of our research, we conducted multiple analyses to determine how land use and land-use change in the northern Great Plains affects landscape suitability for supporting commercial apiaries.

Methods and Results

This work (Otto and others, 2016, 2018) has been published in peer-reviewed journals, and below we provide an executive summary of the published work. Our research to date has shown that predominant land-use trends over the past decade in the northern Great Plains have shifted decidedly toward intensive row crop production in parts of the northern Great Plains that also contain a significant presence of commercial beekeeping operators. In Otto and others (2016) we quantified changes in row crop and grassland which totaled 18,363 registered apiary locations in North and South Dakota between 2006 and 2014. We then developed beekeeper “habitat selection models” to identify land-cover and land-use features that affected beekeeper sites selection in areas experiencing substantial land-use change (Otto and others, 2016). Our analysis indicated that corn and soybeans near registered apiaries in North Dakota and South Dakota (fig. 1) increased 1.2 million (M) hectares (ha; 3M acres). This amounts to an increase of 9 ha (22.2 acres) of corn and soybeans per apiary, annually. In general, the frontier of corn and soybeans expanded west and northward across the study region, into areas that support the highest density of registered apiaries.

Concurrent with the increases in corn and soybeans, we determined that CRP areas near registered apiaries systematically decreased from 2006 to 2016 (Otto and others, 2018). The area of the Dakotas experiencing the highest rate of land-use change was within the Prairie Pothole Region, which also contained the greatest number of registered apiaries. Average annual gains in corn and soybean area were four times greater among apiaries in the Prairie Pothole Region compared to apiaries west or south of the Missouri River. Of the apiaries that had a high annual increase in corn and soybeans (greater than [>] 30 ha), 98 percent were in the Prairie Pothole Region. Likewise, of the apiaries that had a substantial annual decrease in grasslands (>10 ha loss), 81 percent were in the Prairie Pothole Region. Our beekeeper “habitat selection models” estimated the probability of a site being used as a commercial apiary was negatively related to the area of row crops in the local landscape. Conversely, the probability of a site being used as a commercial apiary was positively related to the area of grassland, alfalfa, wetland, and CRP. Our models indicated that commercial beekeepers favor CRP land when selecting locations to keep their honey bee colonies. For example, commercial beekeepers were 95 percent more likely to use apiary sites with >500 ha (1,235 acres) of CRP land surrounding them compared to sites with no CRP land nearby.

We ran a series of landscape simulations to determine how alterations to the CRP national acreage cap would affect landscape suitability for supporting apiaries in the Dakotas (Otto and others, 2018). Our models indicated that reducing the CRP cap to 19 M acres would reduce the number of apiaries in the Dakotas that meet key bee forage criteria by 28 percent. However, increasing the national cap to 37 M acres would increase the number of apiaries that met key bee forage criteria by 155 percent. The benefits of the CRP can be extended further by strategically locating USDA conservation covers in areas of high apiary density.

Relevance to the U.S. Department of Agriculture

This represents the first regional assessment of how land-use change affects landscape suitability for managed honey bees. Although we were unable to incorporate EQIP enrollments in our analysis, our research suggested CRP lands were favored by beekeepers when selecting apiary locations. Similar to past work that highlights the benefits of the CRP to waterfowl (Reynolds and others, 2001) and upland birds (Johnson and Igl, 1995), our pollinator research demonstrates the importance of the CRP to managed honey bees and the commercial beekeeping industry. Our research indicated beekeepers were more likely to select an area to keep honey bees if USDA conservation covers were present in the local landscape. This is important considering that our research has also revealed a pressing need for pollinator-friendly land covers in areas of high apiary density in the central parts of North Dakota and South Dakota. The models we developed can be used by USDA to prioritize areas in the northern Great Plains for conservation delivery for a variety of USDA programs. For example, figure 1 shows the counties in North Dakota and South Dakota that support the highest number of honey bee apiaries and that have also undergone the highest rates of land-use change. Our models suggest these would be the most cost-effective areas to target for future conservation plantings to support honey bees. By establishing conservation covers in these areas, the USDA maximizes the chance of providing forage for multiple apiaries, thereby benefiting multiple beekeepers and their honey bees.
The cost-effectiveness of USDA conservation programs can be improved by focusing funding for conservation programs in areas that have undergone the greatest loss in pollinator-friendly land covers and support the highest density of registered apiaries.

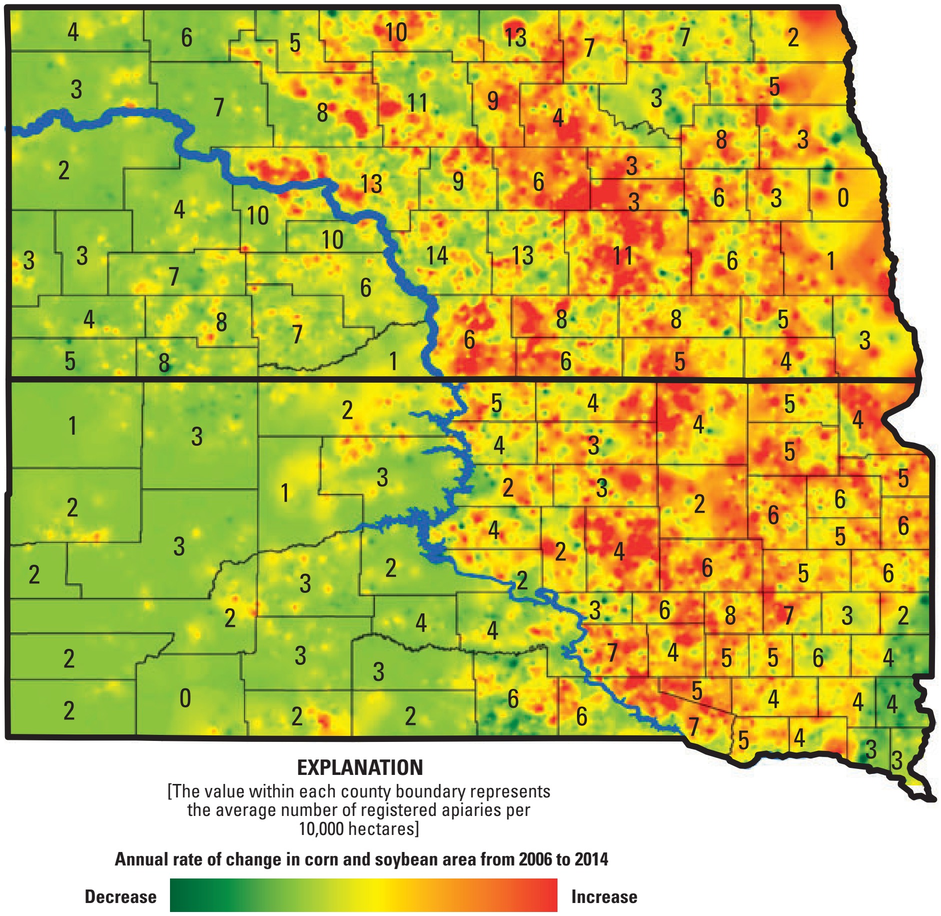


Figure 1. Annual rate of change in the corn and soybean area around 18,363 honey bee apiaries from 2006 to 2014, North and South Dakota. Modified from Otto and others (2016); used with permission.

Honey Bee and Land-Use Pilot Study

In the previous section we highlighted how recent land-cover trends have affected landscape suitability for supporting commercial apiaries. The studies referenced above were based on geographic information system analyses and remotely sensed data. Field studies in the northern Great Plains are needed to better understand how honey bee health is affected by the land cover surrounding the colonies. In 2014, the USDA requested that NPWRC develop a pilot study to develop sampling methods for investigating land-cover associations with bee health, forage, and nutrition. We published the results of this pilot study (Smart and others, 2017a) and used them to develop a three-State assessment of honey bee colonies across a distribution of row crop and grassland land covers in 2016 and 2017. In the pilot study we also report on baseline pesticide exposure levels of honey bees throughout a growing season. This pesticide exposure analysis fulfilled multiple deliverables established by the NRCS in the 2014 interagency agreement (673A7514178).

Methods and Results

In this section we provide an executive summary of the 2014 pilot study that was published by Smart and others (2017a). For the pilot study, biweekly pollen samples were screened for 23 common insecticides, herbicides, fungicides, and metabolites. Five insecticides in three classes (pyrethroid, organophosphate, and neonicotinoid), eight fungicides, and five herbicides comprised 63, 30, and 6 percent, respectively, of the pesticide residues detected in honey bee-collected pollen over the growing season. Neonicotinoids (clothianidin, imidacloprid, thiamethoxam) were detected only between May and early July, whereas chlorpyrifos, an organophosphate insecticide, was detected in early July through mid-September. Herbicides were detected in May through early July, and fungicides were detected in early July through early August. These data provide a preliminary investigation into pesticide exposure profiles for honey bee colonies in the northern Great Plains. Additional details on pesticides detected in honey bee-collected pollen are provided in Smart and others (2017a).

Land-Use Effects on Honey Bee Colony Health and Services

Results from the pilot study (Smart and others, 2017a) were used to inform the design of a three-state research project. While the goals of this project were multi-faceted, one of our principle objectives was to investigate how land use affects honey bee colony size and pollination services elsewhere in the country. By quantifying how summer habitat in the northern Great Plains affects colony population size, which in-turn affects beekeeper economics, we were able to quantify spatial subsidies—how different regions provide ecosystem service values across the migratory range of a species (Bagstad and others, 2019). Typically, the concept of spatial subsidies has been applied to naturally migrating species such as waterfowl (Bagstad and others, 2019), but here we extended this concept further to the migratory honey bee industry. We published the result of our three-State land-use assessment project in 2018 and provide an executive summary of the results in this section.

Methods

In Smart and others (2018) we selected 36 apiary locations across a grassland to row crop landscape gradient in North Dakota, South Dakota, and Minnesota (fig. 2). In 2015 and 2016 we did spring and fall colony health assessments at each research apiary (fig. 3) to determine how within-season colony growth was affected by land use surrounding the research apiaries. We also marked individual colonies and assessed their population size in California almond orchards the subsequent spring. Our hypothesis was that honey bee colonies in grassland landscapes would grow larger or more rapidly during the summer and be larger during almond crop pollination the subsequent spring. In turn, larger colonies grown in grassland landscapes would generate additional revenue for beekeepers through increased pollination service payments and colony splits (that is, beekeepers separating a large colony into two small colonies).

Results

In Smart and others (2018) we demonstrated that a greater presence of non-bee friendly agricultural crops (corn, soy, and small grains) around apiaries in North Dakota, South Dakota, and Minnesota resulted in colonies that grew at a slower rate throughout the growing season (fig. 4). Colonies of a smaller population size in the autumn were also smaller for almond pollination the following spring (fig. 5); thus, the beekeeper had a reduced per-colony rental fee for pollination services and reduced potential for splitting large colonies. For example, we determined that apiaries in grassland landscapes generated $4,100 in additional revenue in colony splits and pollination service payments compared to those situated in row crop landscapes. This paper highlighted the downstream effects of factors driving land-use decisions in the northern Great Plains on the ability of beekeepers to grow robust honey bee colonies and support the pollination industry at a national scale.

Relevance to the U.S. Department of Agriculture

Our colony health work shows the direct linkages between land cover in the northern Great Plains, bee health, and pollination services rendered elsewhere in the United States. Thus, almond growers and beekeepers in California are partly subsidized by grasslands and USDA conservation plantings in the northern Great Plains because these lands help to produce more robust honey bee colonies. Grassland conservation programs can have a positive effect on honey bee colony health, which in turn benefits agricultural producers outside the northern Great Plains.

Future Work

Our published work demonstrated the linkage between grassland habitat and honey bee colony health. However, the mechanism by which grasslands, and the forbs that bloom there, confer nutrition to honey bee colonies is still unclear. Ongoing work by the USGS is investigating the physiological mechanisms by which grasslands and other bee-friendly land covers affect worker bee nutritional physiology including glycogen, total sugar, lipids, and protein levels in bees across the row crop agriculture to grassland gradient. Using these nutritional biomarkers to infer land-use quality and predict colony population size will improve our understanding of how honey bee colonies respond to changing land-use conditions and allow us to better quantify the effect of USDA conservation covers on honey bee colony health. Smart and others (2019) provides valuable insight into how grasslands confer nutrition to individual worker bees and how the improved health of individual bees culminates in improved colony health.

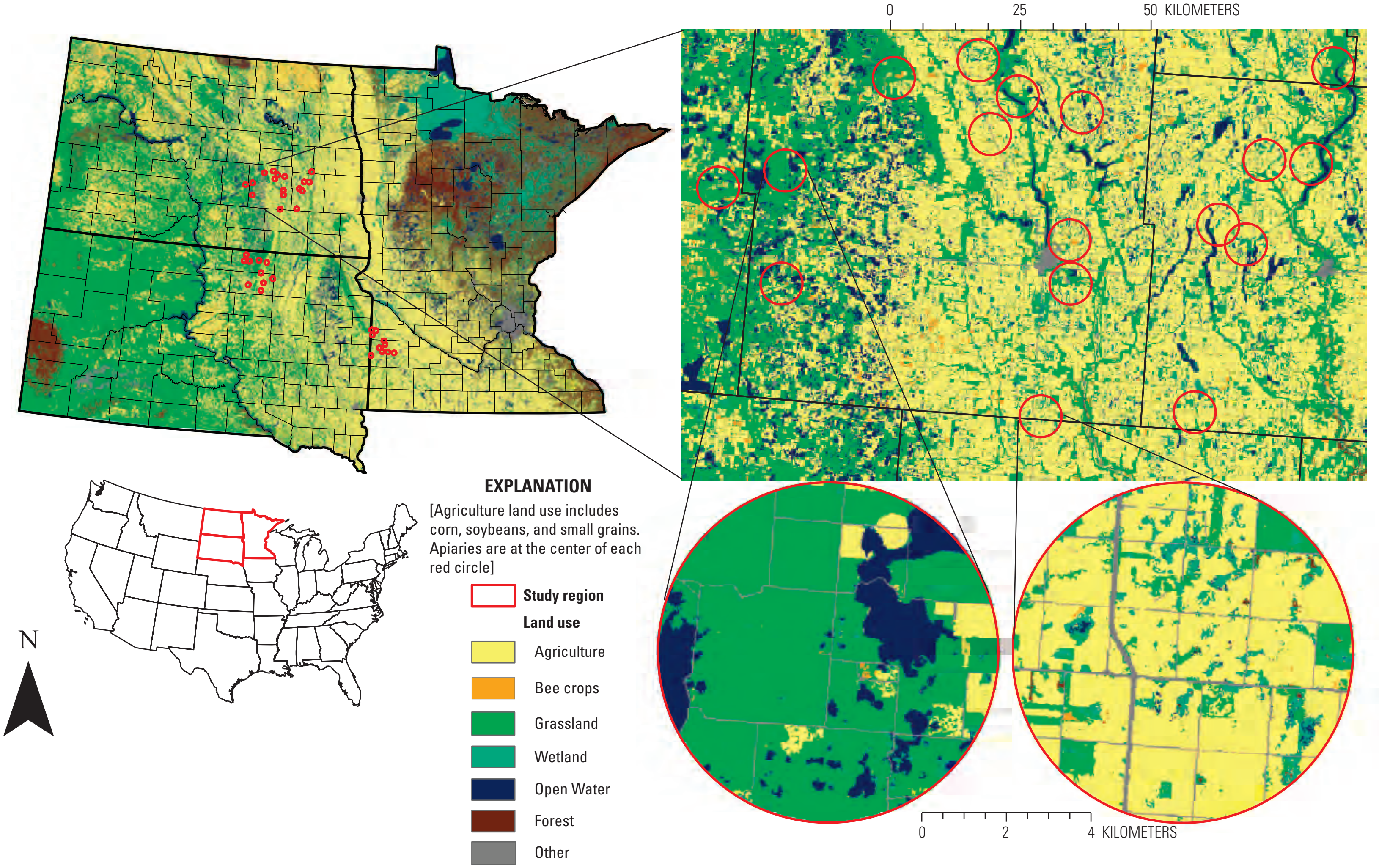


Figure 2. Study region land use in 2015–16; locations of apiaries in North Dakota, South Dakota, and Minnesota; and two example North Dakota apiaries. Modified from Smart and others (2018); used with permission.

Figure 3. U.S. Geological Survey biologist doing health assessments on a honey bee colony in South Dakota, 2016. Photograph by Sarah Scott, U.S. Geological Survey.

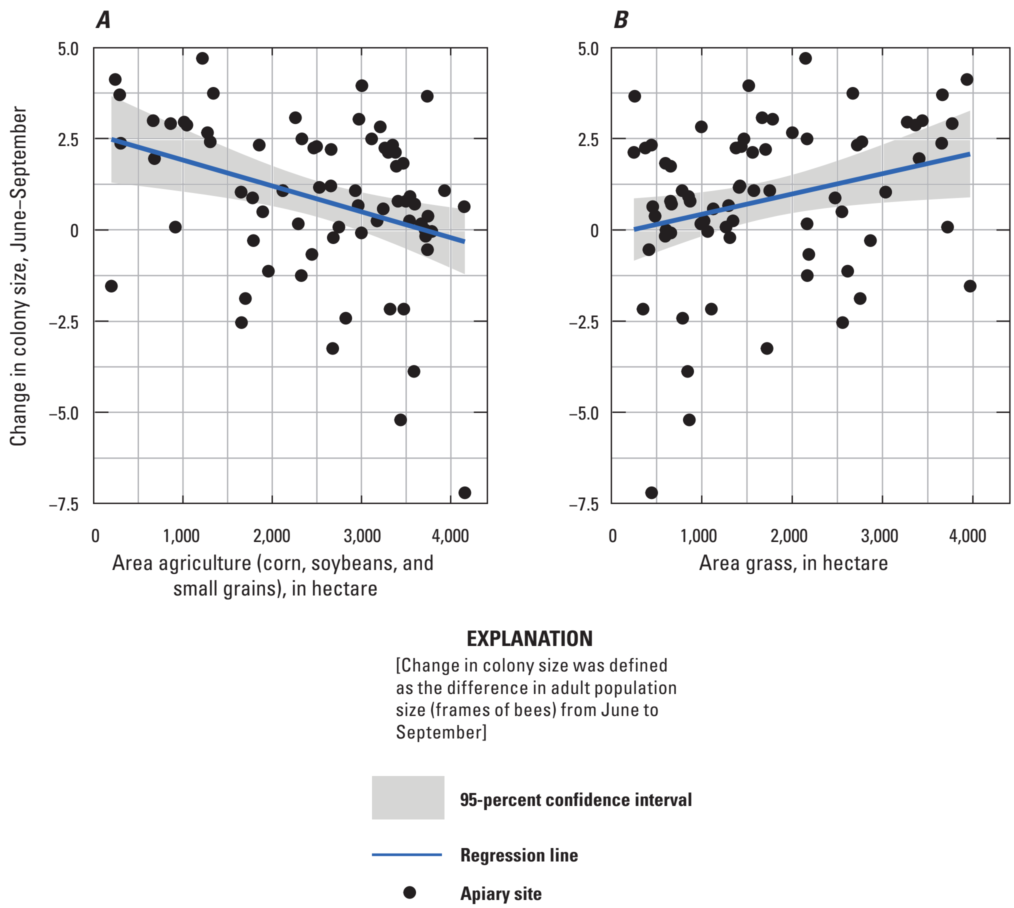


Figure 4. Relation between the area of, *A*, agriculture (corn, soybeans, and small grains) and, *B*, grassland and the colony population change during the growing season in North Dakota, South Dakota, and Minnesota in 2015–16. Modified from Smart and others (2018); used with permission.

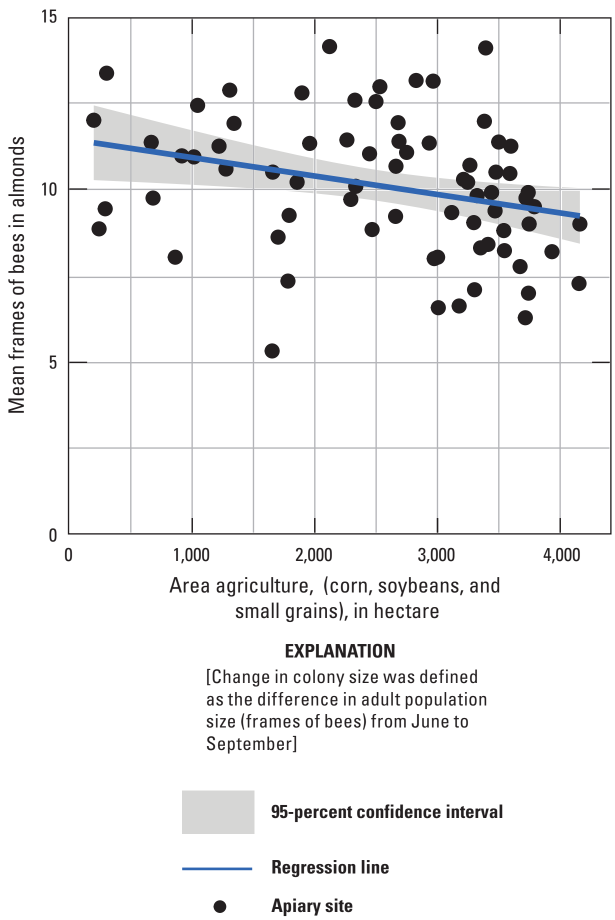


Figure 5. Relation between the area of agriculture (corn, soybeans, and small grains) surrounding honey bee colonies in the summer and the sizes of those colonies during almond pollination in California the subsequent spring. Modified from Smart and others (2018); used with permission.

Genetic Analysis of Bee-Collected Pollen Across the Northern Great Plains

Quantifying pollen diets of honey bees is important for improving bee nutrition and designing pollinator friendly seeding mixes (Kleijn and Raemakers, 2008). Taxonomic identification of bee-collected pollen allows researchers to quantify honey bee floral resource use across landscapes. Honey bee workers can fly as far as about 10 kilometers, covering a 314 square kilometer area, in search of flowering plants harboring pollen and nectar (Seeley, 1995). Foraging honey bees, therefore, serve as useful data collectors for quantifying and characterizing available floral resources on the landscape. Quantifying bee forage at large scales has proven challenging because taxonomic identification of bee-collected pollen has historically required highly specialized skill in light microscopy, takes considerable time, and may lack specificity. In 2014, as part of an initial deliverable to USDA, the USGS developed a high-throughput genetic barcoding strategy to identify samples of bee-collected pollen (Cornman and others, 2015). The techniques we developed provided us with sufficient precision and taxonomic recovery to quantify pollen foraging patterns of individual honey bee colonies throughout the growing season and to relate foraging patterns to land cover surrounding the colonies (Smart and others, 2017b). Smart and others (2017b) determined *Melilotus* spp., *Sonchus* spp., *Brassica* spp., *Grindelia* spp., *Helianthus* spp., and *Solidago* spp., represented 62 percent of the bee pollen collected by honey bees from six apiaries in North Dakota in 2010 and 2011. Genera containing plant species native to the region, *Amorpha* spp., *Alisma* spp., *Anemone* spp., *Dalea* spp., and *Monarda* spp. represented 12 percent of bee-collected pollen. In 2015, we expanded the scope of our pollen genetic analysis to encompass North Dakota, South Dakota, and Minnesota because the USDA had targeted those States for pollinator forage enhancement efforts. We highlight the methods and results of this expanded work in the following “Methods” and “Results” sections.

Methods

We partnered with commercial beekeepers in the northern Great Plains to collect samples of bee-collected pollen from 36 apiaries across our study region (fig. 3). Smart and others (2018) provided a complete list of apiaries included in this study. From early June to mid-September our teams activated pollen traps (fig. 6) within each apiary every other week to collect pollen from foraging honey bees during a 72-hour period.

Pollen samples were stored in a freezer at −20 degrees Celsius before analysis. A subsample of pollen was dried and homogenized to prepare for genetic sequencing (fig. 7). Methodology for extracting, amplifying, and sequencing pollen DNA are provided in Cornman and others (2015) and Smart and others (2017b). DNA extraction was carried out at USGS Leetown Science Center, Kearneysville, West Virginia. Operational taxonomic unit (OTU) reads were given assignments based on taxonomic reference sequences in the National Center for Biotechnology Information (NCBI, https://www.ncbi.nlm.nih.gov/) database. The OTUs can be interpreted as a relative measure of the abundance of a particular plant DNA signature in a sample of bee-collected pollen. We report taxonomic assignments for the most commonly detected plant taxa across North Dakota, South Dakota, and Minnesota for 2015 and 2016. We also provide State-specific forage calendars that show what pollen bees were collecting on a biweekly basis. We also considered an analysis where all OTUs were pooled at the genus or familial level; however, the results did not appreciably change, so we report results at the species, genus, or familial level (that is, lowest achieved taxonomic level). Data for this section are publicly available in Otto and others (2020a).

Figure 6. Two honey bee colonies fitted with pollen traps. Photograph by Clint Otto, U.S. Geological Survey.

Figure 7. Sample of bee pollen collected from a pollen trap before homogenization. Photograph by James Weaver, U.S. Geological Survey.

Results

We analyzed 1,295 samples of bee-collected pollen, from early June to mid-September during 2015 and 2016. We detected 342 different plant taxa, including 148 unique plant species (appendix 1). More than 64 percent of the OTUs detected belonged to *Melilotus* spp., Asteraceae, *Trifolium* spp., Fabaceae, *Sonchus arvensis, Symphyotrichum cordifolium*, and *Solidago* spp. (fig. 8).

Melilotus spp. was the most commonly detected plant taxon across all States and years (42.6 percent of total OTUs). Asteraceae constituted more than 5.0 percent of the OTUs detected in our analysis, but we were unable to achieve species or genus resolution for these reads. *Melilotus* spp. was consistently the top taxon across all States and years; however, we did observe State and year differences across other top taxa (table 1). Although table 1 shows the most commonly detected plant taxa, it is important to note these taxa constituted 60–90 percent of the total OTUs detected; numerous other taxa constituted the remaining 10–40 percent OTU reads (appendix 1). Caution should be used when interpreting data for taxa with exceptionally low OTU counts (less than [<] 1,000 OTU counts) because some of these are unlikely to be true detections. Current metabarcoding techniques lack formal methods for dealing with rarely detected taxa. We chose to report all OTU counts >50 but stress the focus of these results should be on commonly detected taxa.

Across all States, the top-ranking, native forb genera and species included *Symphyotrichum cordifolium* (blue wood-aster), *Solidago* spp. (goldenrod), and *Grindelia* spp. (gumweed). Honey bee pollen collection changed considerably throughout the growing season (fig. 9; appendix 1). From June to mid-July, honey bees in North Dakota collected a variety of woody (for example, *Salix* spp., *Elaeagnus* spp., and *Acer* spp.), wetland (for example, *Anemone canadensis* and *Sparganium eurycarpum)*, and upland (for example, *Melilotus* spp., *Taraxacum* spp., and *Hesperis* spp.) plant pollen (fig. 9). Mid-season pollen consisted mostly of plants in Fabaceae (for example, *Melilotus* spp., and *Trifolium* spp.) and Brassicaceae (for example, *Brassica* spp.). During the late season, honey bees collected pollen from multiple asters including *Sonchus arvensis*, *Symphyotrichum* spp. and *Solidago* spp. *Medicago sativa* (alfalfa), an important nectar plant, made up just 0.001 percent of all OTU reads. Notable wetland plants detected in our analysis are listed in table 2.

Relevance to the U.S. Department of Agriculture

Pollen is the essential source of protein, lipids, vitamins, and minerals for bees; thus, including flowers in seed mixes that honey bees use as pollen sources supports honey bee health, brood production, and immune system function. Our multi-State, multi-season analysis of bee-collected pollen provides the USDA with a suite of potential plants that could be included in seed mixes to provide honey bees access to pollen. Although most pollen collected by honey bees was from non-native plant species, we also detected numerous native plant species and genera. Beekeepers have long sought patches of clover for honey production; our analysis shows that *Melilotus* spp. and *Trifolium* spp. are also important providers of pollen to honey bees. Although it is widely known that *Medicago sativa* (alfalfa) is an important nectar plant for honey bees, our genetic analysis indicates honey bees are reluctant collectors of *M. sativa* pollen. Thus, large plantings of alfalfa may contribute to honey production within a colony but do little to support brood production without supplemental pollen from other sources. Conservation plantings where alfalfa is the dominate forage plant for honey bees may not provide bees with nutritious pollen for brood production.

Based on data reported here, and by Smart and others (2017b), it seems wetland plants serve as an understudied source of pollen for honey bee colonies. Honey bee and wetland plant associations unsurprisingly have not been reported because field researchers studying plant-pollinator interactions are more likely to sample foraging bees in upland habitat than in wetlands. Indeed, all plant-pollinator interaction data we collected via fieldwork were gathered in upland habitat (see the "Plant-Pollinator Interactions on Private Lands Enrolled in the Conservation Reserve Program or Environmental Quality Incentives Program" section). Science demonstrating the value of wetlands to pollinators is limited; however, emerging science suggests these areas provide important forage for honey bees (Gallant and others, 2014; Otto and others, 2016) and nesting and forage resources for native bees (Vickruck and others, 2019). Our pollen analysis suggests conservation programs that protect or restore wetlands in the Prairie Pothole Region will provide forage lands for honey bees. Enhancing the value of wetlands to pollinators can be achieved through management activities that increased forb abundance within terrestrial buffers and even within the wetlands themselves.

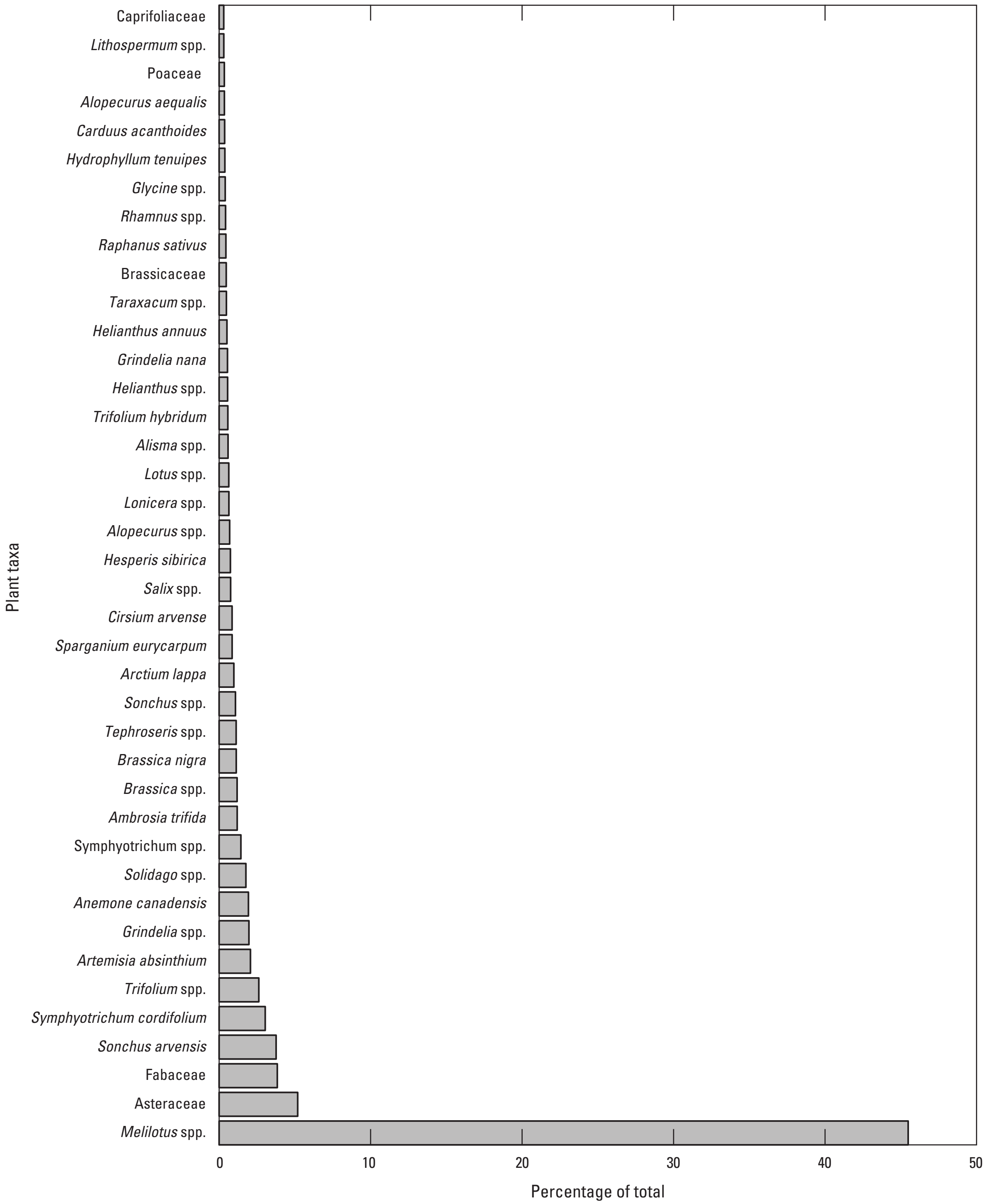


Figure 8. Operational taxonomic units detected in 1,295 samples of bee-collected pollen from North Dakota, South Dakota, and Minnesota from 2015 and 2016.

Table 1. Top-five flowering plant species and genera detected in 1,295 samples of bee pollen collected in North Dakota, South Dakota, and Minnesota from 2015 and 2016.

[OTU, operational taxonomic unit]

North Dakota		South Dakota		Minnesota	
Taxon	Percentage of total OTUs	Taxon	Percentage of total OTUs	Taxon	Percentage of total OTUs
2015					
Melilotus spp.	46.08	*Melilotus* spp.	51.57	*Melilotus* spp.	35.83
Sonchus arvensis	8.70	*Symphyotrichum cordifolium*	8.58	*Trifolium* spp.	9.76
Symphyotrichum cordifolium	3.59	*Sonchus arvensis*	6.41	*Solidago* spp.	5.28
Grindelia spp.	2.64	*Grindelia* spp.	4.37	*Ambrosia trifida*	4.50
Brassica nigra	2.49	*Artemisia absinthium*	3.65	*Arctium lappa*	3.25
2016					
Melilotus spp.	63.5	*Melilotus* spp.	82.98	*Melilotus* spp.	55.39
Tephroseris spp.	4.57	*Artemisia absinthium*	3.20	*Symphyotrichum* spp.	4.61
Brassica spp.	2.86	*Cyclachaena xanthiifolia*	1.90	*Trifolium* spp.	3.71
Symphyotrichum spp.	2.29	*Grindelia hirsutula*	1.48	*Solidago* spp.	2.54
Rhamnus spp.	2.20	*Cirsium arvense*	0.98	*Lotus* spp.	2.45

Table 2. Wetland plant taxa detected in samples of honey bee-collected pollen from North Dakota, South Dakota, and Minnesota, 2015 and 2016.

[Wetland plants were listed as obligate or facultative wetland plants in the U.S. Department of Agriculture PLANTS database (https://plants.sc.egov.usda.gov/index.html)]

Taxon	Family	Percentage of total
Alisma spp.	Alismataceae	0.561
Amaranthus tuberculatus	Amaranthaceae	0.132
Ambrosia trifida	Asteraceae	1.279
Anemone canadensis	Ranunculaceae	1.734
Lythrum salicaria	Lythraceae	0.403
Nuphar variegata	Nymphaeaceae	0.001
Nymphaea odorata	Nymphaeaceae	0.018
Phalaris arundinacea	Poaceae	0.118
Phleum alpinum	Poaceae	0.001
Ranunculus repens	Ranunculaceae	0.008
Rudbeckia laciniata	Asteraceae	0.020
Silphium perfoliatum	Asteraceae	0.005
Sium suave	Apiaceae	0.188
Sparganium eurycarpum	Typhaceae	0.767
Viburnum opulus	Adoxaceae	0.001
Total		5.236

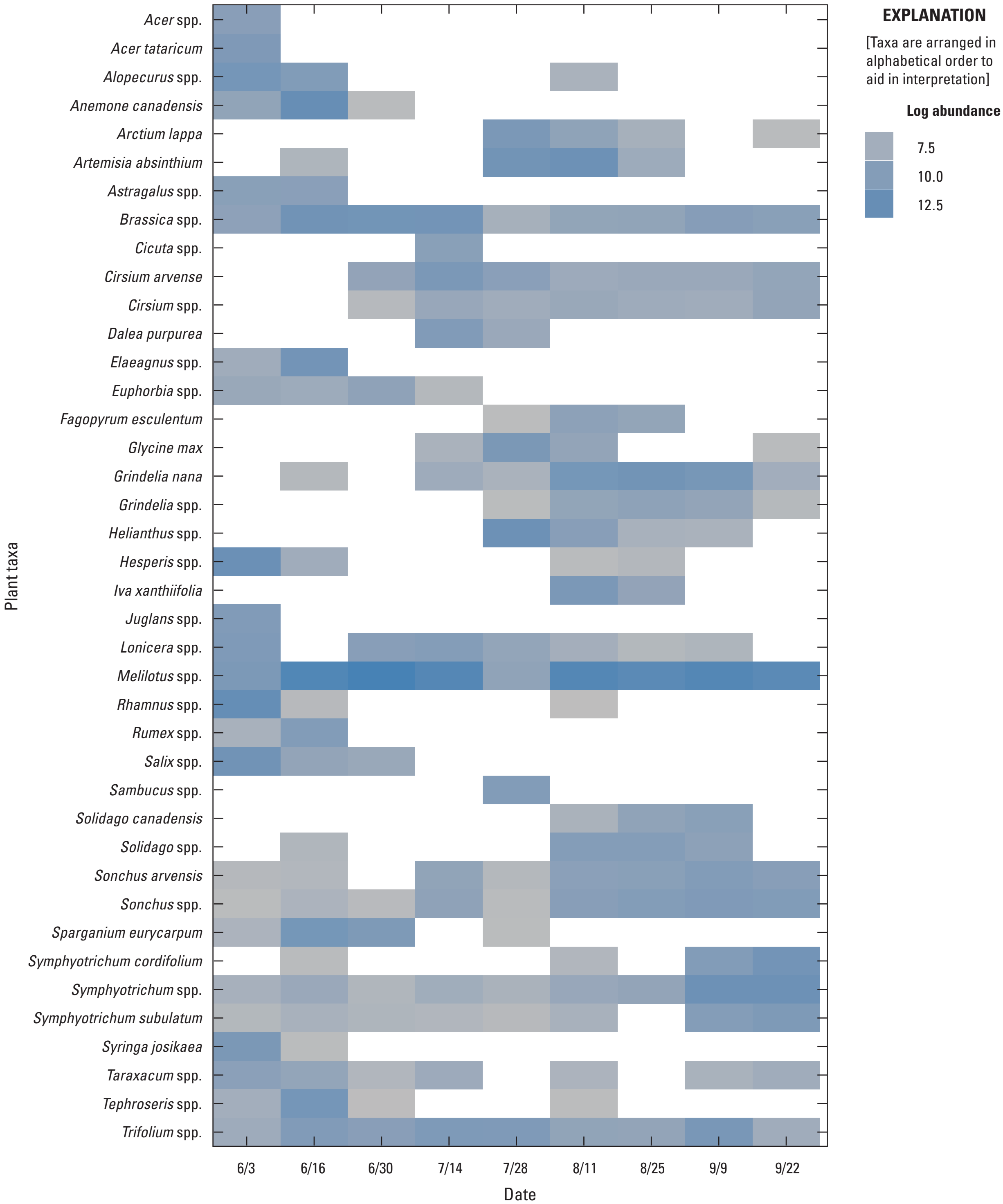


Figure 9. Top 40 most commonly detected plant genera and species (logarithmic summation of operational taxonomic units) across all dates for pollen samples collected from North Dakota apiaries in 2016. Forage calendars for South Dakota and Minnesota are provided in appendix 1, figure 1.1.

Future Work

More than 5.0 percent of total OTUs were classified as Asteraceae but were not assigned to specific species or genera in our analysis. This is likely due to close genetic similarities between Asteraceae taxa and to the limited number of Asteraceae species available as reference DNA in the NCBI database. We have obtained tissue samples from herbarium specimens for several commonly occurring asters in the northern Great Plains and are currently cataloging the DNA sequence of those species in the NCBI database. These new DNA references will allow us to achieve species resolution for multiple aster species and add new insights into honey bee foraging, particularly during the late summer and early fall.

Pollen quality is directly related to honey bee colony health, and pollen diversity supports bee immune system function (Smart and others, 2016). Although the relation between pollen diversity and bee health is clear, less is known about how the composition and configuration of land covers support diverse flower communities that in turn support pollinators. Starting in 2020, we will conduct a formal investigation into how the diversity of land covers surrounding our research apiaries is related to the diversity and quality of pollens collected by the bees. To our knowledge this will be the first ever landscape-scale study of how the composition and diversity of bee-collected pollen is related to surrounding land covers.

Plant-Pollinator Interactions on Private Lands Enrolled in the Conservation Reserve Program or Environmental Quality Incentives Program

Increased societal concern over global pollinator declines has generated interest in pollinator conservation efforts across Government agencies and the private sector. The Pollinator Health Task Force (2015) was commissioned in 2015 to develop a Federal strategy for achieving three goals related to pollinator health: (1) reduce honey bee colony winter losses to <15 percent by 2025, (2) increase the eastern population of monarch butterflies to 225 million by 2020, and (3) restore or enhance 7 million acres of land for pollinators by 2020. Achieving the third goal of the Federal strategy requires a concerted effort between all branches of Government as well as public and private partners to engineer pollinator habitat in working landscapes. Concurrent with the Federal strategy, the USDA unveiled multiple initiatives to create or enhance pollinator habitat across multiple States in the northern Great Plains and upper Midwest. For example, the NRCS launched the EQIP Honey Bee Pollinators Initiative in fiscal year 2014 to promote conservation practices that will benefit honey bee nutrition through improved floral resources. In fiscal year 2010, the FSA launched the CRP Pollinator Habitat Initiative and developed Conservation Practice 42, “Pollinator Habitat” (CP–42). Initiatives and practices such as these highlight the active role of the Government in improving refugia for pollinators.

Improving forage for pollinators requires an understanding of flowering plants that are used by these organisms. This information is useful for designing seed mixes to maximize pollinator benefits. The USGS quantified floral resource availability on private lands enrolled in the CRP and the EQIP within the three-State study region (fig. 2) from 2015 to 2017. This assessment of plant-pollinator interactions on CRP and EQIP lands was supported by the FSA and NRCS and was part of a larger effort to quantify the relative role of different land covers in supporting forage for pollinators in the northern Great Plains. Conducting pollinator resource assessments on specific USDA enrollments will assist USDA with determining whether management efforts are having desired outcomes.

Methods

To complete this assessment, our team networked with NRCS and FSA county offices to obtain contact information of landowners who recently enrolled in one or more EQIP or CRP conservation practices. We focused on EQIP conservation practices “327-Conservation Cover,” “512-Forage and Biomass Planting,” and “550-Range Planting” (hereafter EQIP–327, EQIP–512, and EQIP–550, respectively). For the CRP, we focused on all practices for which landowners would grant land access. We quantified flowers and bee visitations along 168, 193, and 58 transects on EQIP fields in 2015, 2016, and 2017, respectively. We sampled 341, 379, and 151 transects on CRP fields across those same years. All transect locations were randomly chosen before sampling. Each transect location was visited once during each period of the growing season; early (June 15–July 15), mid (July 16–August 15), and late (August 16–September 15). Transects were 20 meters long and 2 meters wide (fig. 10). Because of the high number of flowers on some transects, we counted the number of stems supporting one or more inflorescences and used this as an index of flower abundance (hereafter “flower abundance”). Although not a true census of the number of flowers on a given transect, this method provides a reliable index of flower abundance to make comparisons across plant species, land-use types, and seasons. While counting flowering plants, our team also recorded observations of honey bees foraging on specific plants. In 2016 and 2017, we also recorded wild bee visitations during floral resource assessments. After completing the flower counts, an observer spent 5 minutes netting native bees observed foraging on flowers within the transect boundary (2016 and 2017 only). Additional sampling methods are described in Otto and others (2017). In the “Results” part of this section, we provide summary information of flowers and bee use of flowers on the surveyed CRP and EQIP enrollments.

Figure 10. U.S. Geological Survey technicians conducting plant and bee surveys on a field enrolled in the Environmental Quality Incentives Program in 2017. Photograph by Clint Otto, U.S. Geological Survey.

We also provide a comparison of flower abundance and richness to bee observations across multiple CRP and EQIP practices. A data release for this section has been prepared by Otto and others (2020b).

Results

We conducted 1,363 unique transects distributed across multiple land-use types (that is, CRP, EQIP, pasture, roadsides, waterfowl production areas, and so on) in North Dakota, South Dakota, and Minnesota in 2015–17. Across these transects we counted 959,386 flowers, represented by 319 plant taxa. Appendix table 1.2 provides the complete list of scientific and common names of plants and the abundance of flowers for each flower species.

Conservation Reserve Program

Overall, 174 unique plant taxa were observed blooming among CRP transects over 3 years. Of all blooming taxa detected, 113 (65 percent) were native to the northern Great Plains and 61 plants (35 percent) were non-native, based on locality information found in the USDA PLANTS database (https://plants.sc.egov.usda.gov). Native and non-native flowers constituted 17 and 83 percent of total abundance of flowers detected on CRP fields, respectively (fig. 11).

We examined floral abundance among CRP practices on a per transect basis because of the uneven distribution of transects among practices (table 3). Because of the large number of CRP practices sampled, we removed all CRP practices with <10 transects to ease with interpreting results. The number of flowers per transect varied over the season by CRP practice type (fig. 12). Flower abundance (per transect) was highest in the early season and lowest in the late season. CP–42 had the most stems relative to any other practice. Conservation Practice-25, “Rare and Declining Habitat,” had the highest proportion of native flower abundance across the growing season. Forb species richness was highest among CP–42 across all three sampling periods (fig. 13). In most cases, forb species richness declined across the three sampling periods.

A total of 1,740 honey bees were observed among all plant transects conducted on CRP fields. The highest number of honey bees observed per transect occurred on CP–42 followed by Conservation Practice 01, “Permanent Introduced Grass and Legume” (fig. 14). The number of flower-visiting honey bees was comparable in the early and mid-summer but declined in late summer. Honey bees visited 35 (23 native, 12 introduced) different flowering plant species growing on CRP fields (fig. 15). About 80 percent of all observed honey bee visits recorded in CRP fields were on non-native plants, compared with 20 percent on native plants. The three most visited plants by honey bees were *Melilotus officinalis* (yellow/white sweet clover), *Medicago sativa* (alfalfa), and *Dalea purpurea* (prairie purple clover). Collectively, these three species were responsible for 78 percent of all observed honey bee visits on CRP fields.

Wild bees were observed on 31 (21 native, 10 introduced) different flowering plant species on CRP fields (fig. 16). Wild bee visitation was not documented in 2015; thus, wild bee data presented below are with regards to the 2016 and 2017 field seasons only. In contrast to the observed visitation patterns of honey bees, just 31 percent of all observed wild bee visits were on introduced plants, compared with 69 percent on native plants. The top three plants visited by wild bees were *Medicago sativa*, *Cirsium arvense* (Canada thistle), and *Dalea purpurea*. Collectively, these three species were responsible for 38 percent of all observed wild bee visits.

A total of 175 wild bees were observed among all plant transects conducted on private lands enrolled in CRP. Of the netted individuals that were positively identified in the lab, the most abundant wild bee species detected on CRP enrollments were *Halictus confusus* (confusing metallic furrow bee), *Melissodes trinodis* (long-horned bee), followed by *Halictus ligatus* (ligated furrow bee), *Lasioglossum albipenne* (white-winged metallic-sweat bee), *Ceratina* sp. (small carpenter bee), and *Perdita swenki* (Swenk’s miner bee, fig. 17). Among the netted individuals, the most frequently visited flowers on CRP enrollments were *Sonchus arvensis* (field sowthistle), *Cirsium arvense* (Canada thistle), and *Heliopsis helianthoides* (false sunflower). Figure 18 provides a complete network motif of all wild bee and host-plant interactions observed on the CRP from 2016 to 2017.

Table 3. Number of plant and bee transects performed on private lands enrolled in the Conservation Reserve Program in North Dakota, South Dakota, and Minnesota, 2015–17.

Conservation practice	Number of transects
CP–01, Permanent Introduced Grasses and Legumes	16
CP–02, Permanent Native Grasses	31
CP–04D, Permanent Wildlife Habitat	11
CP–05A, Field Windbreak	9
CP–10, Veg Cover, Established Grass	41
CP–11, Veg Cover, Established Trees	4
CP–17A, Living Snow Fence	6
CP–21, Filter Strips	38
CP–22, Riparian Buffer	16
CP–23, Wetland Restoration	43
CP–23A, Wetland Restoration Non–Floodplain	22
CP–25, Rare and Declining Habitat	62
CP–27, Farmable Wetland	7
CP–28, Farmable Wetland Buffer	40
CP–37, Duck Nesting Habitat	35
CP–38E, State Acres for Wildlife Enhancement	28
CP–42, Pollinator Habitat	74

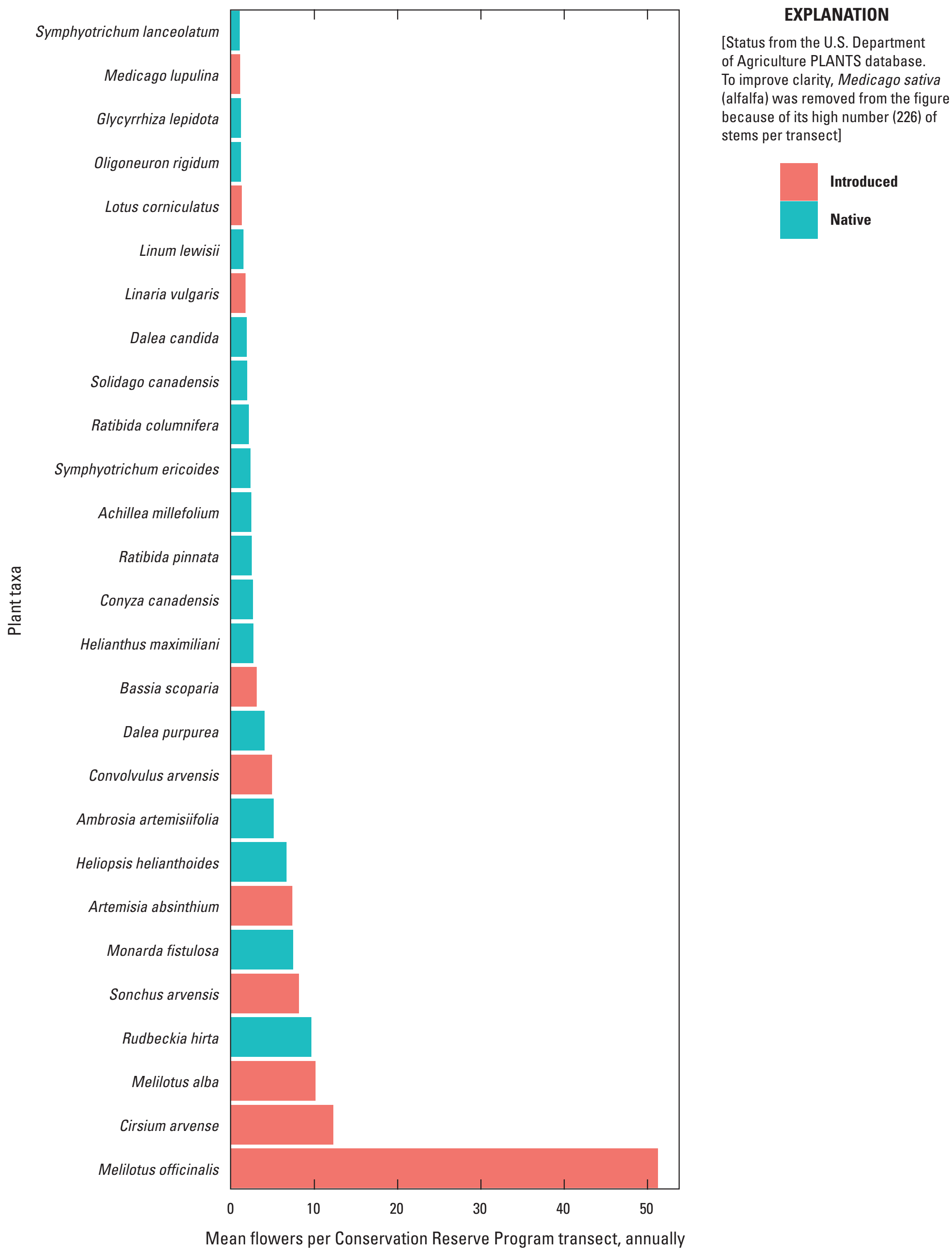


Figure 11. Top flowering plants observed blooming among all transects on Environmental Quality Incentives Program fields, from June through September, 2015–17.

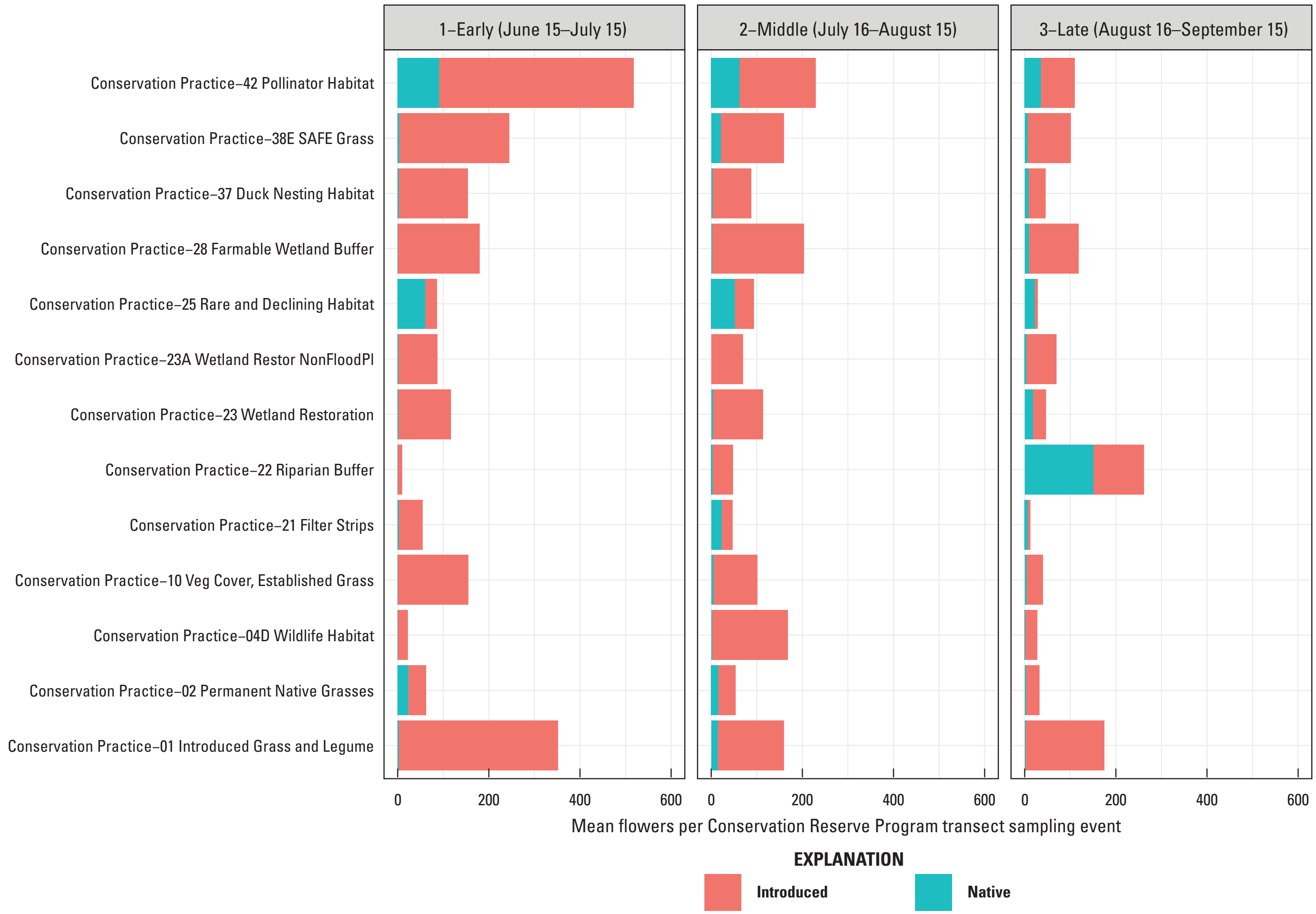


Figure 12. Mean flowering stems per transect sampling event among Conservation Reserve Program practices across the growing season, 2015–17.

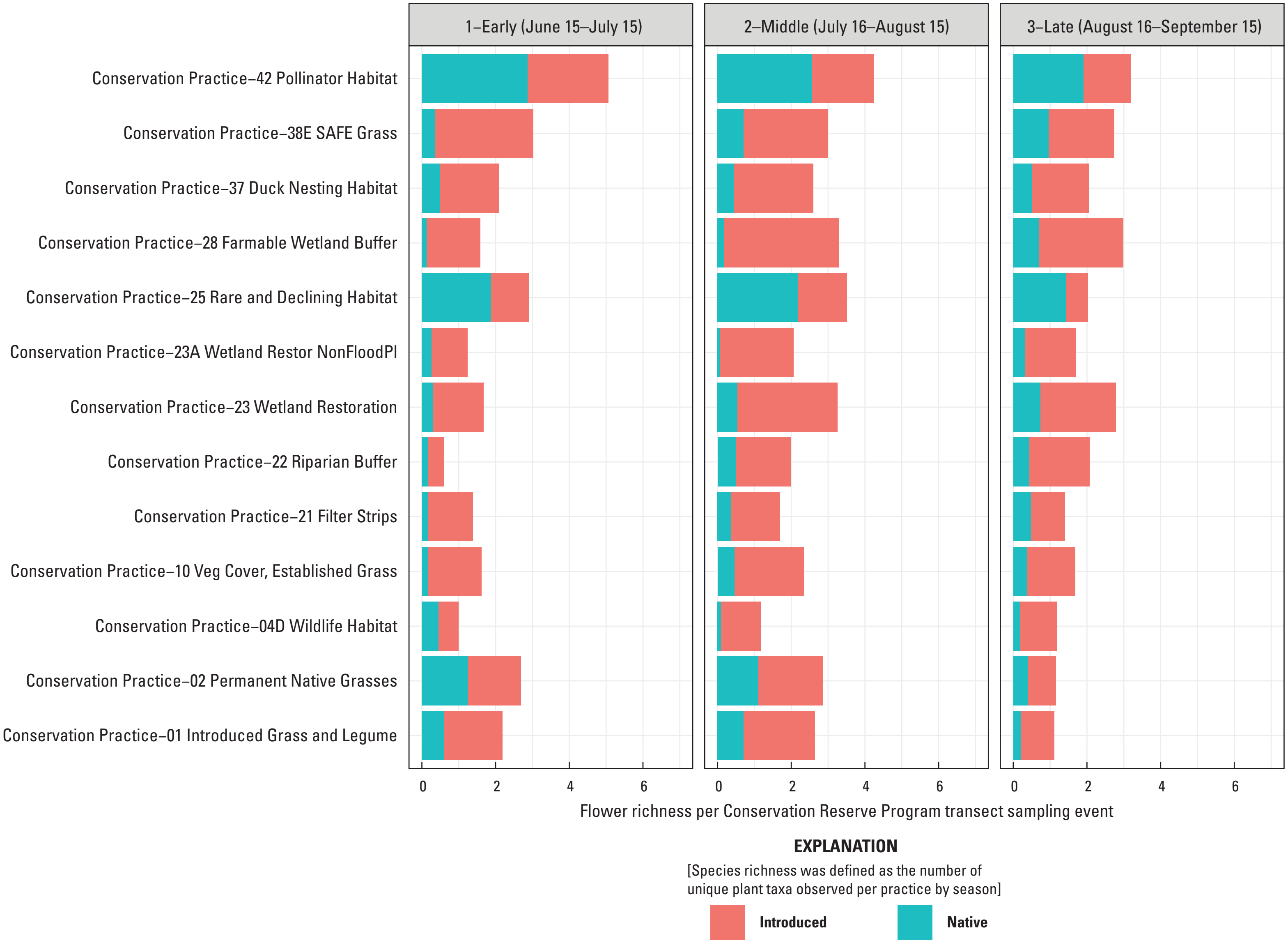


Figure 13. Flowering plant species richness per transect among Conservation Reserve Program practices across the growing season, 2015–17.

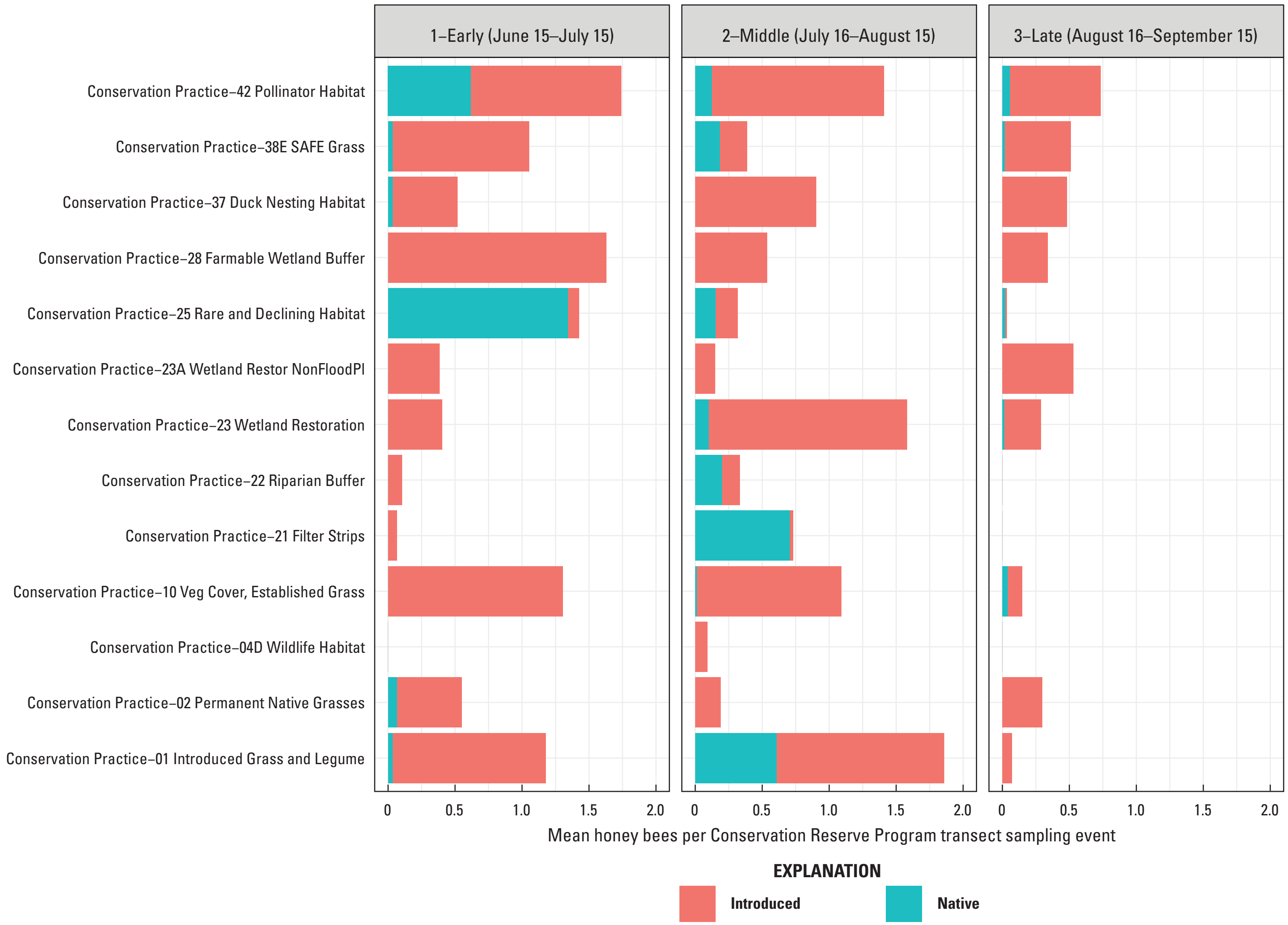


Figure 14. Number of honey bees observed per transect among Conservation Reserve Program practices across the growing season, 2015–17.

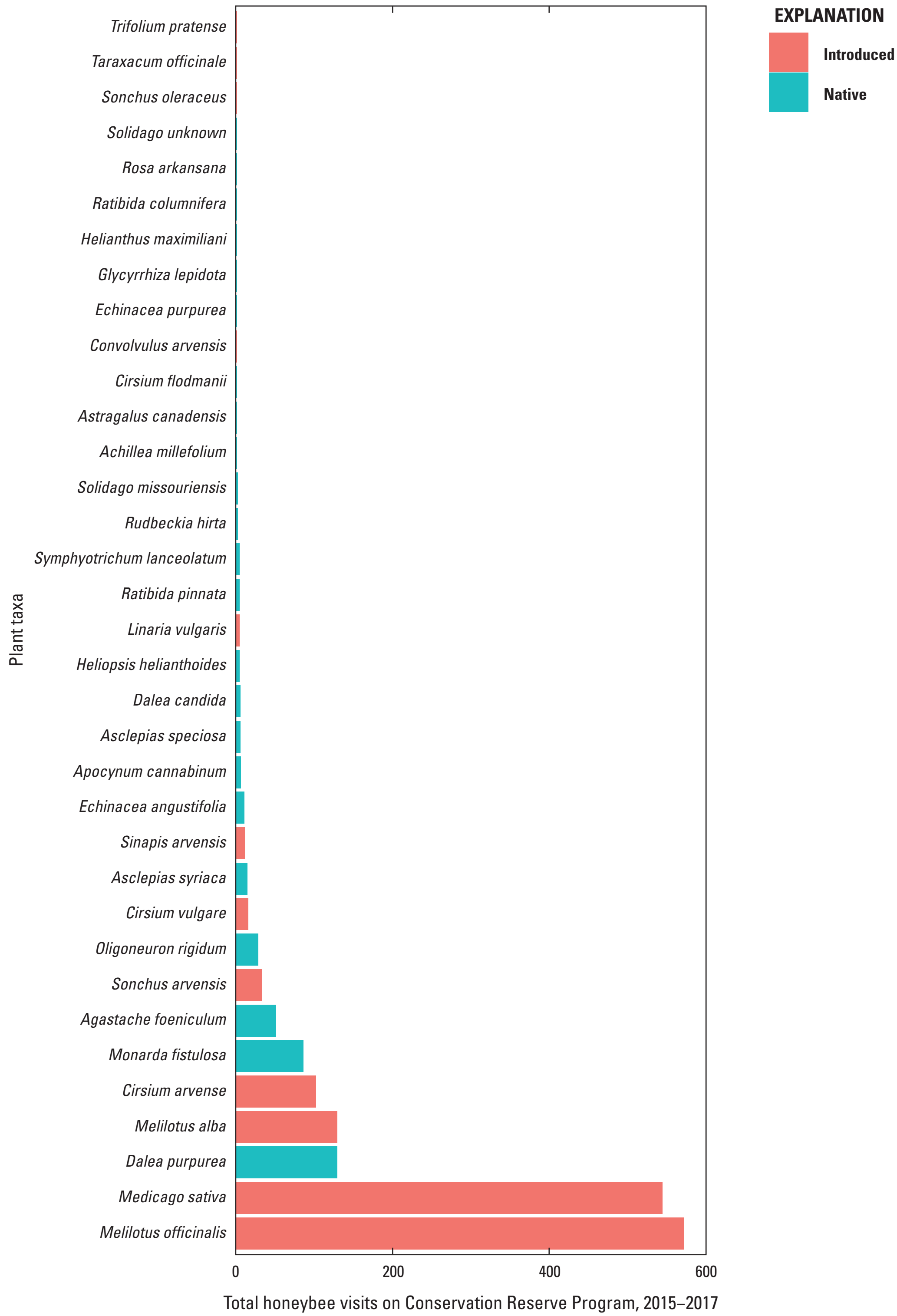


Figure 15. Flowering plants with observed honey bee visitation among all transects conducted on Conservation Reserve Program land, 2015–17.

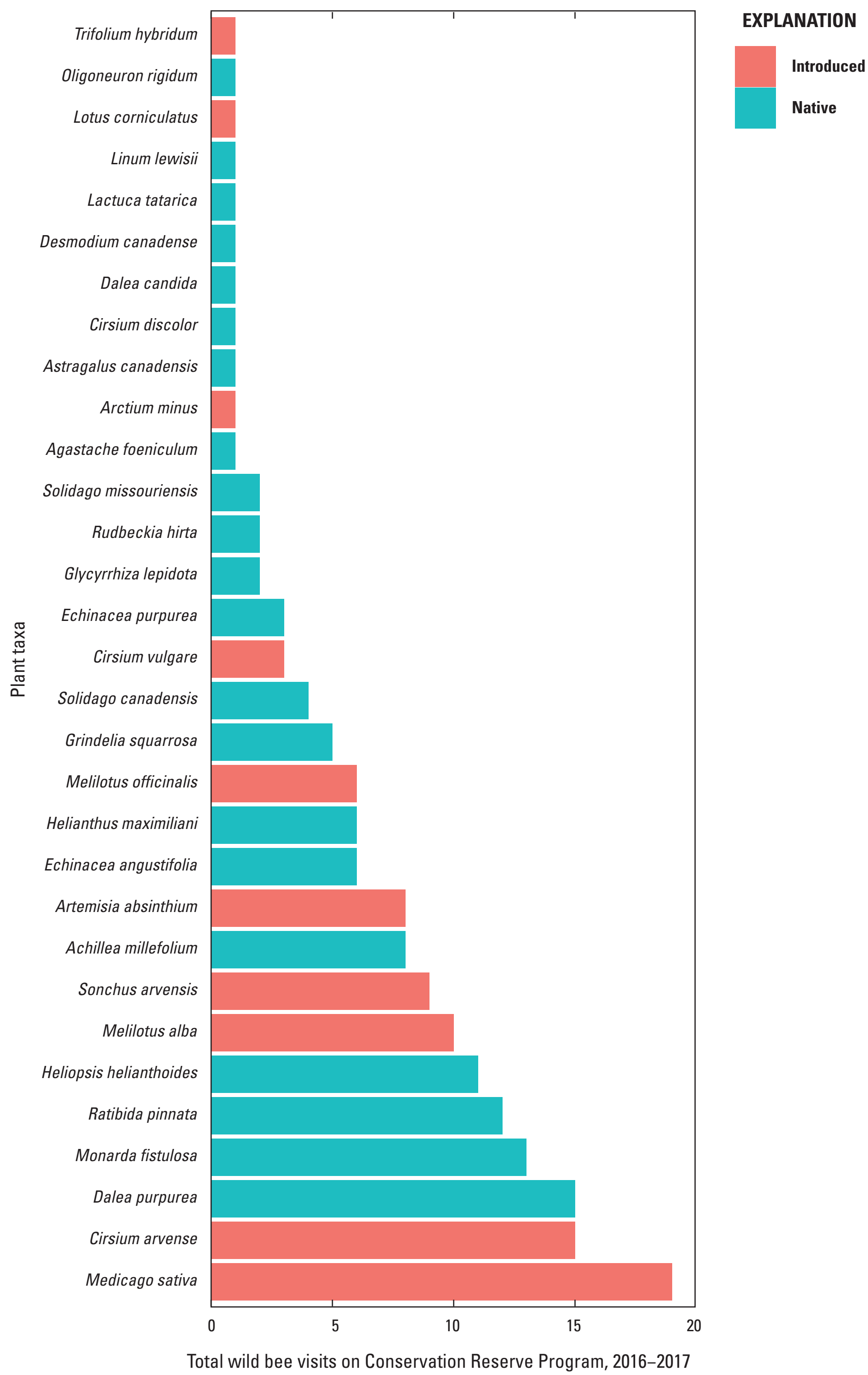


Figure 16. Wild bee flower visitations among all transects conducted on Conservation Reserve Program land, 2016–17.

Figure 17. Select wild bee species detected on private lands enrolled in the Conservation Reserve Program from 2016 to 2017. *A*, *Halictus confusus* (confusing metallic furrow bee); *B*, *Halictus ligatus* (ligated furrow bee); *C*, *Melissodes trinodis* (long-horned bee); *D*, *Perdita swenki* (mining bee); and *E*, *Ceratina* sp. (small carpenter bee). Photographs *A*, *C*, and *E* by Hadel Go; and photographs *B* and *D* by John Ascher. All photographs from https://www.discoverlife.org; used with permission.

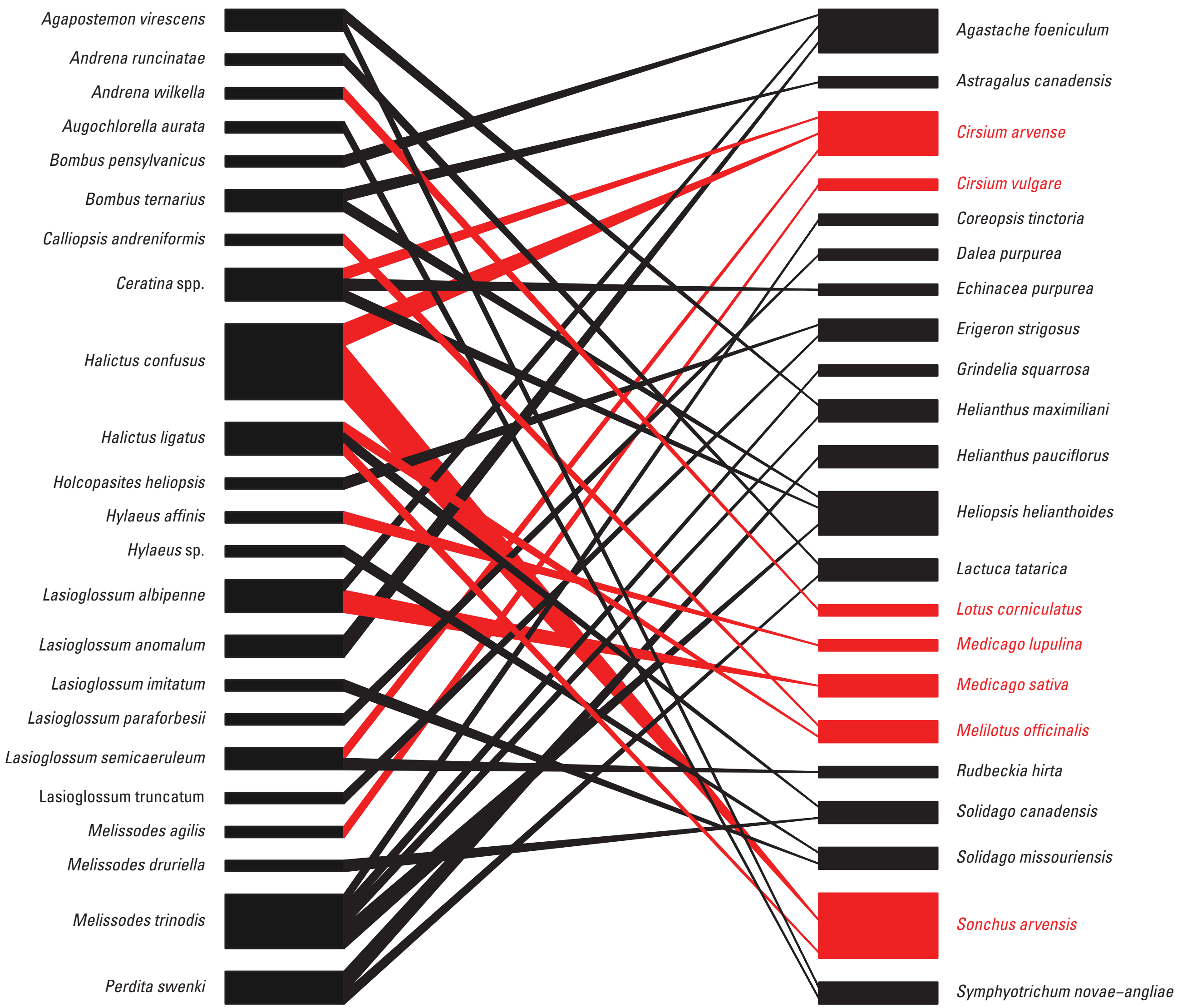
Environmental Quality Incentives Program

Overall, 164 unique plant taxa were observed blooming among EQIP fields over 3 years. Of all blooming taxa detected, 119 (73 percent) were native to the Northern Great Plains, and 45 plants (27 percent) were non-native, based on locality information found in the USDA PLANTS database (https://plants.sc.egov.usda.gov/index.html). Native and non-native flowers constituted 20 and 80 percent of total abundance of flowers detected on EQIP fields, respectively (fig. 19). These fields ranged in age from 1 to 3 years, where data were available from NRCS county offices.

We examined floral abundance among EQIP practice on a per transect basis because of the uneven distribution of transects among practices (73 transects on EQIP–327, 180 transects on EQIP–512, and 8 transects on EQIP–550). The number of flowers per transect varied over the season by EQIP practice type (fig. 20). Flower abundance (per transect) was highest in the early season, with EQIP–327 harboring more stems relative to EQIP–512 and EQIP–550. Flower abundance was relatively even among EQIP practices in the mid- and late season. Forb species richness was highest among EQIP–327 and EQIP–550 throughout the growing season (fig. 21). Non-native (introduced forbs) constituted a higher number of forb species on 550 range plantings, particularly during the mid- and late season.

A total of 1,019 honey bees were observed among all plant transects on EQIP fields (n=328 on EQIP–327, n=593 on EQIP–512, and n=98 on EQIP–550). The highest number of honey bees per transect were observed on EQIP–550 fields during all parts of the growing season (fig. 22). Figure 22 demonstrates the differences in honey bee use of different EQIP practices, thereby highlighting when specific practices may be underperforming in terms of honey bee use. For example, transects on EQIP–512, “Forage and Biomass Plantings,” had the lowest honey bee use during the mid- and late season. Interestingly, this practice also had the lowest forb species richness among the three EQIP practices.

Honey bees visited 38 (22 native, 16 introduced) different flowering plant species growing on EQIP fields (fig. 23). About 76 percent of all observed honey bee visits in EQIP fields were on non-native plants, compared with 24 percent on native plants. The top three plants visited by honey bees were *Melilotus officinalis* (yellow/white sweet clover), *Medicago sativa* (alfalfa), and *Helianthus maximiliani* (Maximilian sunflower). Collectively, these three species were responsible for 66 percent of all observed honey bee visits on EQIP fields.



NOTE: This network motif represents wild bees that were netted and identified in the lab and therefore are a different representation of wild bees depicted in figure 6. Red and black denote introduced and native plant species, respectively.

Figure 18. Wild bee and host-plant interaction networks for private lands enrolled in the Conservation Reserve Program in North Dakota, South Dakota, and Minnesota, 2016–17.

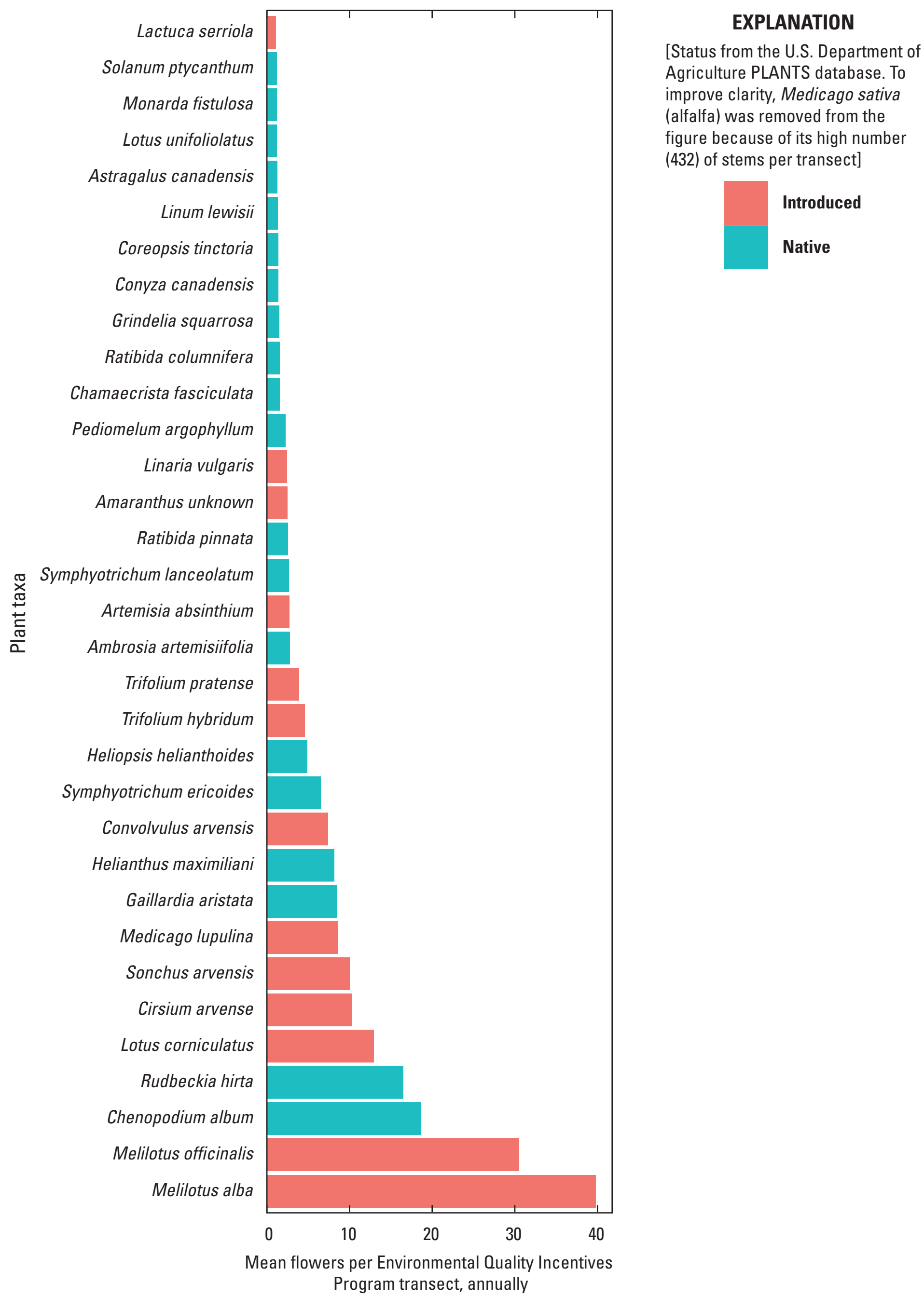


Figure 19. Top flowering plants observed blooming among all transects conducted on Environmental Quality Incentives Program fields, from June through September, 2015–17.

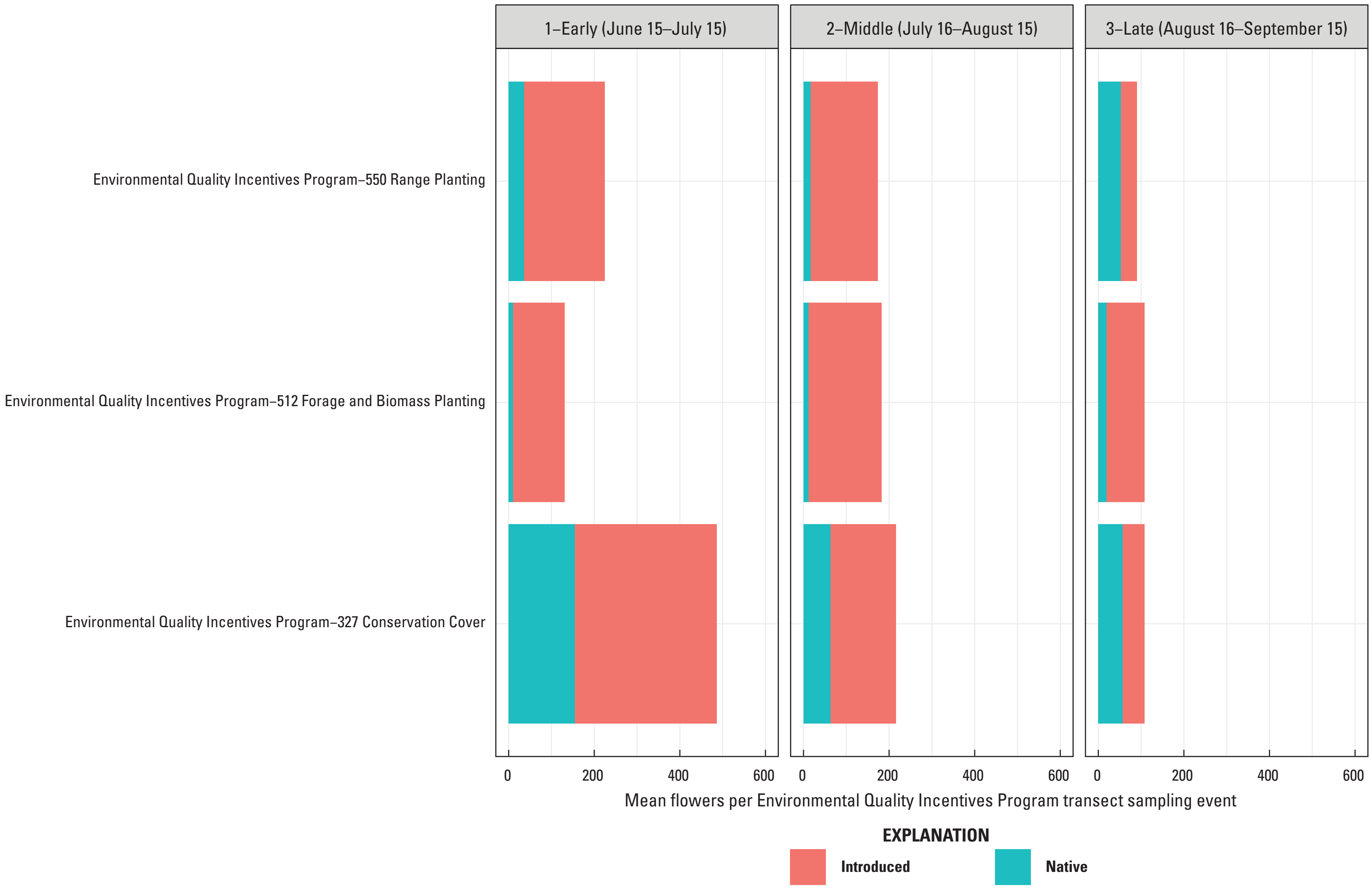


Figure 20. Mean flowering stems per transect sampling event among Environmental Quality Incentives Program practices across the growing season, 2015–17.

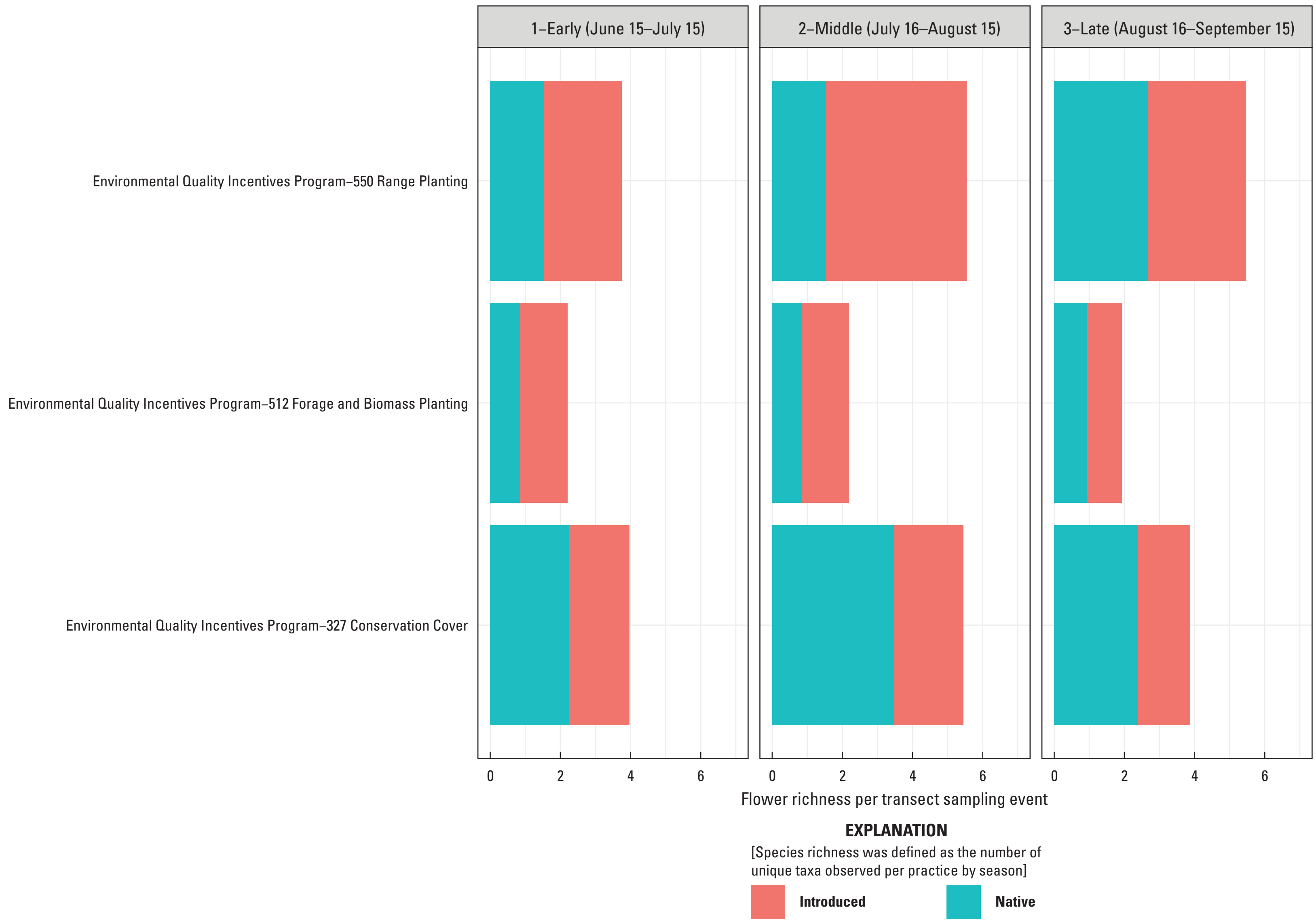


Figure 21. Flowering plant species richness per transect among Environmental Quality Incentives Program practices across the growing season, 2015–17.

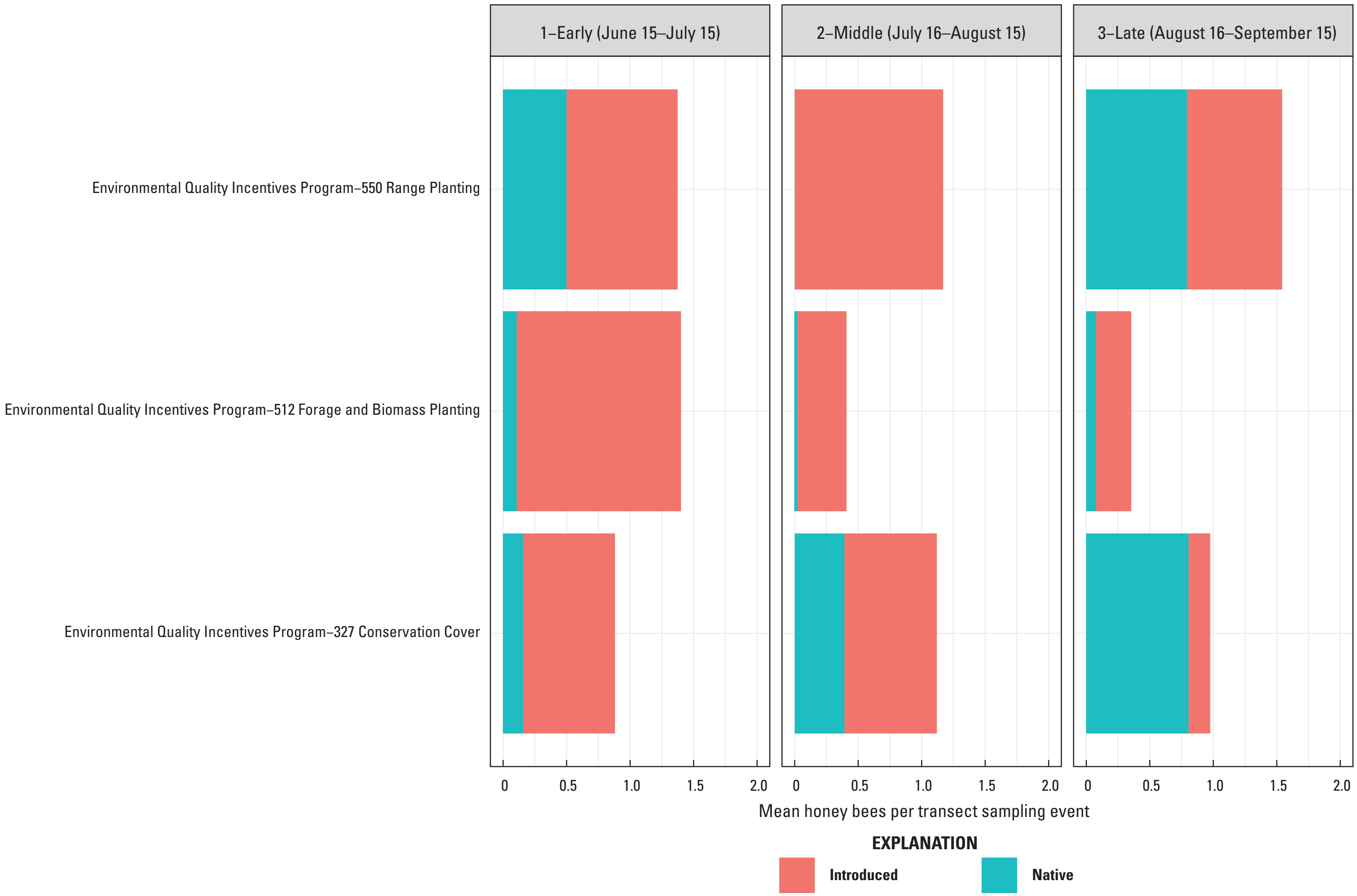


Figure 22. Number of honey bees observed per transect among Environmental Quality Incentives Program practices across the growing season, 2015–17.

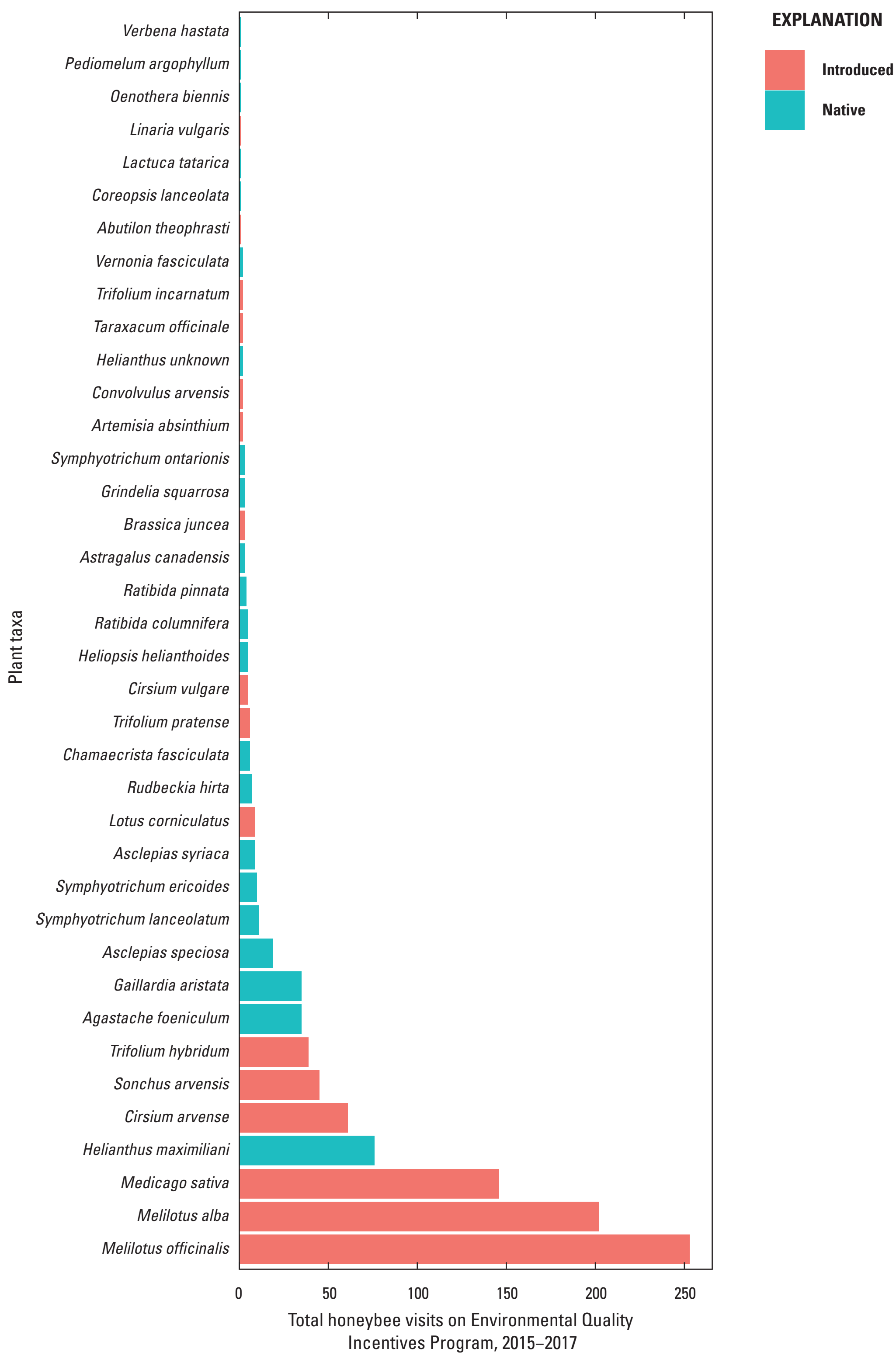


Figure 23. Flowering plants with observed honey bee visitation among all transects conducted on Environmental Quality Incentives Program lands, 2015–17.

Wild bees were observed on 27 (16 native, 11 introduced) different flowering plant species on EQIP fields (fig. 24). Wild bee visitation was not documented in 2015; thus, wild bee data presented below are with regards to the 2016 and 2017 field seasons only. In contrast to the observed visitation patterns of honey bees, just 35 percent of all observed wild bee visits were on introduced plants, compared with 65 percent on native plants. The top 3 plants visited by wild bees were *Helianthus maximiliani* (Maximilian sunflower), *Cirsium vulgare* (bull thistle), and *Gaillardia aristata* (blanket flower). Collectively, these three species were responsible for 56 percent of all observed wild bee visits.

A total of 251 wild bees were observed among all plant transects conducted on EQIP practice fields (*n*=113 on EQIP–327, *n*=19 on EQIP–512, and *n*=119 on EQIP–550). Of the netted individuals that were positively identified in the lab, the most abundant wild bee species detected on EQIP enrollments were *Melissodes trinodis* (long-horned bee) followed by *Melissodes agilis* (agile long-horned bee) and *Bombus griseocollis* (brown-belted bumble bee, fig. 25). Among the netted individuals, the most frequently visited flowers on EQIP enrollments were *Helianthus maximiliani* (Maximilian sunflower), *Gaillardia aristata* (blanket flower), and *Ratibida pinnata* (pinnate prairie coneflower). Figure 26 provides a complete network motif of all wild bee and host-plant interactions observed on EQIP from 2016 to 2017.

Relevance to the U.S. Department of Agriculture

Our analysis provides the USDA with baseline information on the performance of specific conservation programs and practices in a region targeted by the USDA for pollinator enhancement. To our knowledge, this is the first large-scale assessment of pollinator forage resources across multiple USDA programs, States, and years. The major findings from our plant-pollinator interaction field study include:

- A generalized decline of flower abundance and richness, and bee use of most CRP practices later in the growing season.
- Higher proportion of non-native flowers, compared to native flowers, on all CRP practices except for CP–42 and CP–25, “Rare and Declining Habitat.”
- Higher richness and abundance of flowers on CP–42 compared to all other CRP practices.
- The high abundance and honey bee use of *Melilotus officinalis* (yellow sweet clover) on both CRP and EQIP grasslands.
- High visitation of *Helianthus maximiliani* (Maximilian sunflower) by wild bees, and to a lesser extent honey bees, on EQIP enrollments.
- Non-native flowers were more abundant than native flowers on all EQIP practices; however, native flower richness was higher on EQIP–327 throughout the growing season.
- Flower abundance on EQIP fields was generally highest in the early and late parts of the growing season.
- Flower visitations were generally divergent between honey bees and wild bees, with honey bees using non-native flowers and wild bees using native flowers.
- Co-used, native species included *Helianthus maximiliani* (Maximilian sunflower), *Monarda fistulosa* (wild bergamot), and *Dalea purpurea* (purple prairie clover).

These data will be informative for designing seeding mix specification for future pollinator habitat plantings. Non-native plants such as *Melilotus officinalis* (yellow sweet clover) and *Medicago sativa* (alfalfa) were observed in high abundance in CRP and EQIP enrollments, and these plants were often visited by honey bees. Although there is concern among resource managers about the potential invasiveness of these plants, our research also demonstrates their importance for honey bees.

Emerging science has shown the potential for resource competition between wild bees and honey bees (Mallinger and others, 2017). Given the divergence we observed in wild bee and honey bee floral resource use, our data can be used to design seed mixes that can be specifically tailored for wild bees or honey bees. For example, native flowers such as *Ratibida pinnata* (prairie coneflower) and *Heliopsis helianthoides* (false sunflower), were often visited by wild bees but not honey bees. These species could be included in seed mixes in lower abundance if the goal is to exclusively promote wild bee use. Alternatively, our data suggest pollinator plantings that have an abundance of *Helianthus maximiliani* (Maximilian sunflower), *Monarda fistulosa* (wild bergamot), or *Dalea purpurea* (purple prairie clover) are likely to see high use by wild bees and honey bees.

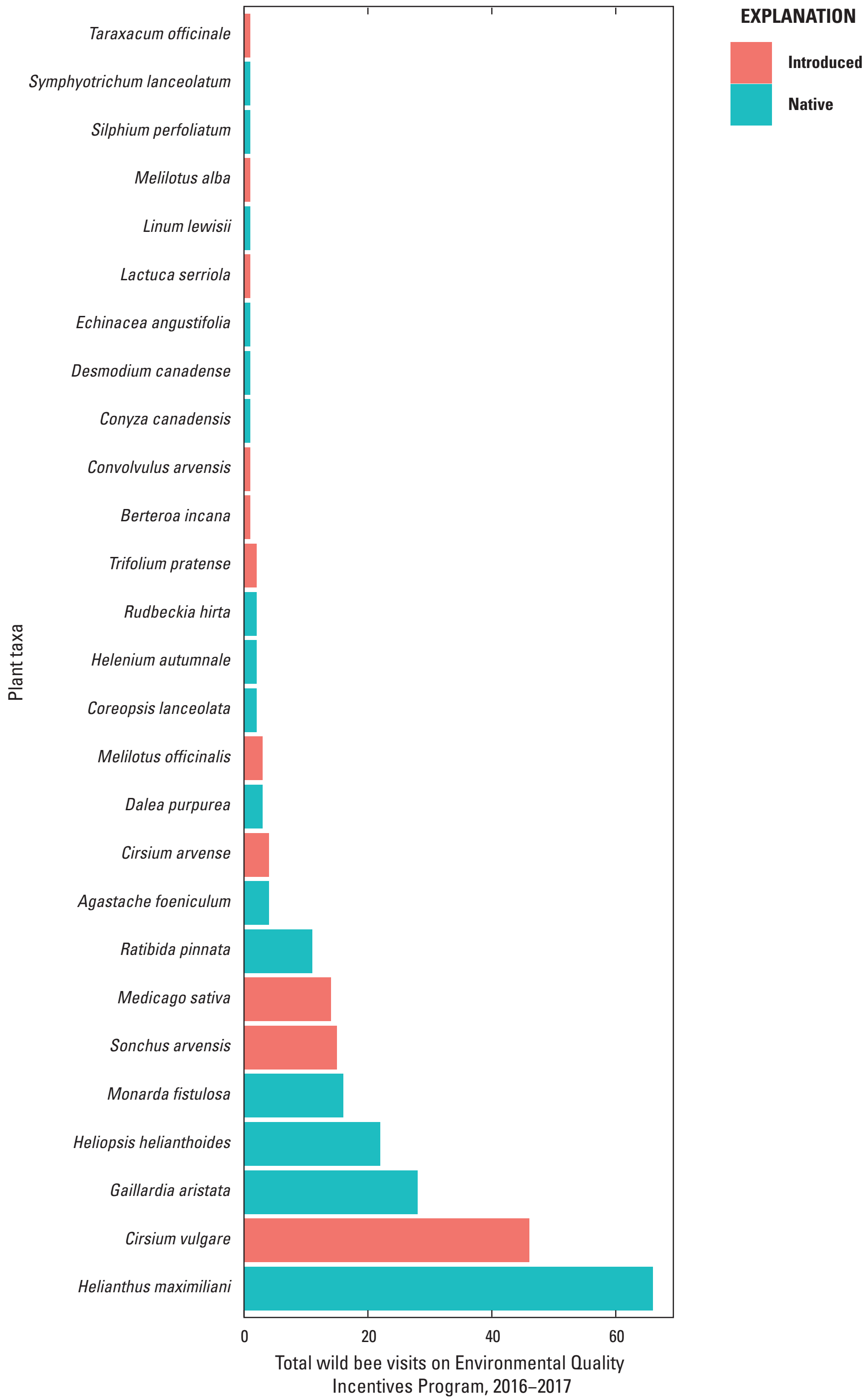


Figure 24. Flowering plants with observed wild bee visitation among all transects conducted on Environmental Quality Incentives Program lands, 2016–17.

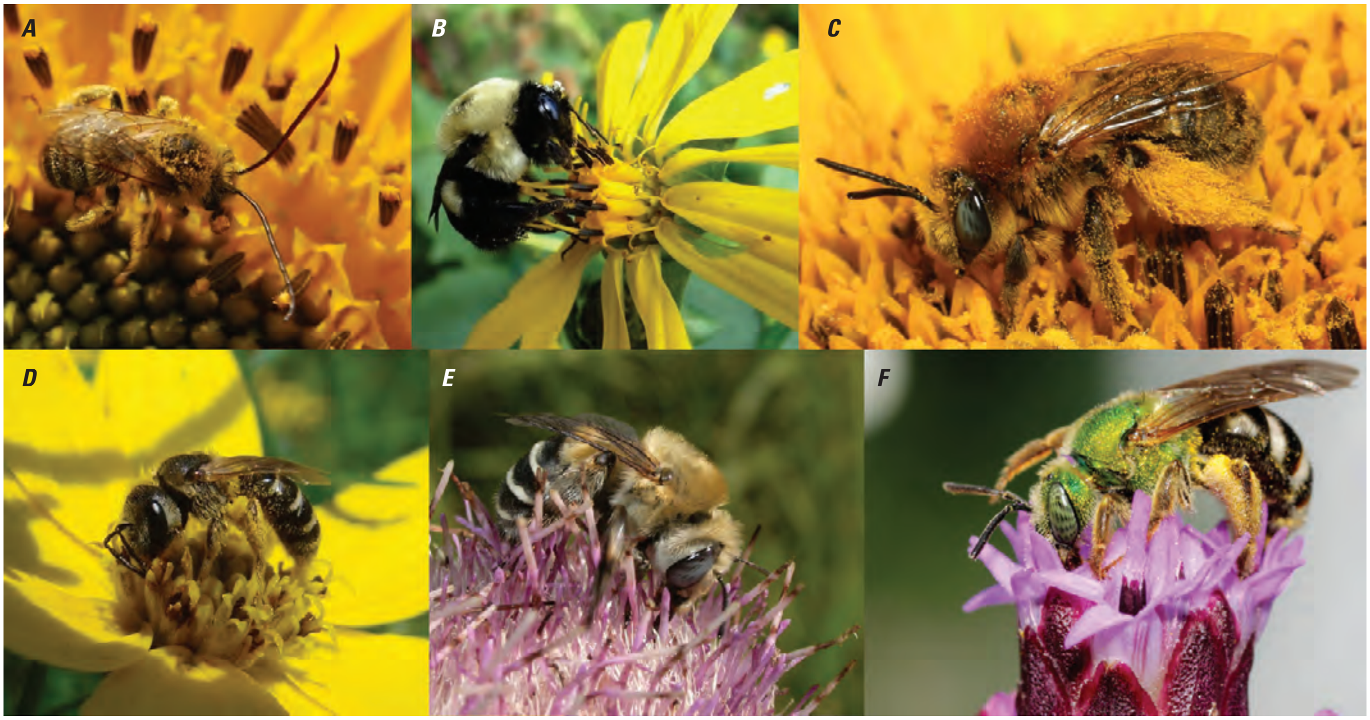
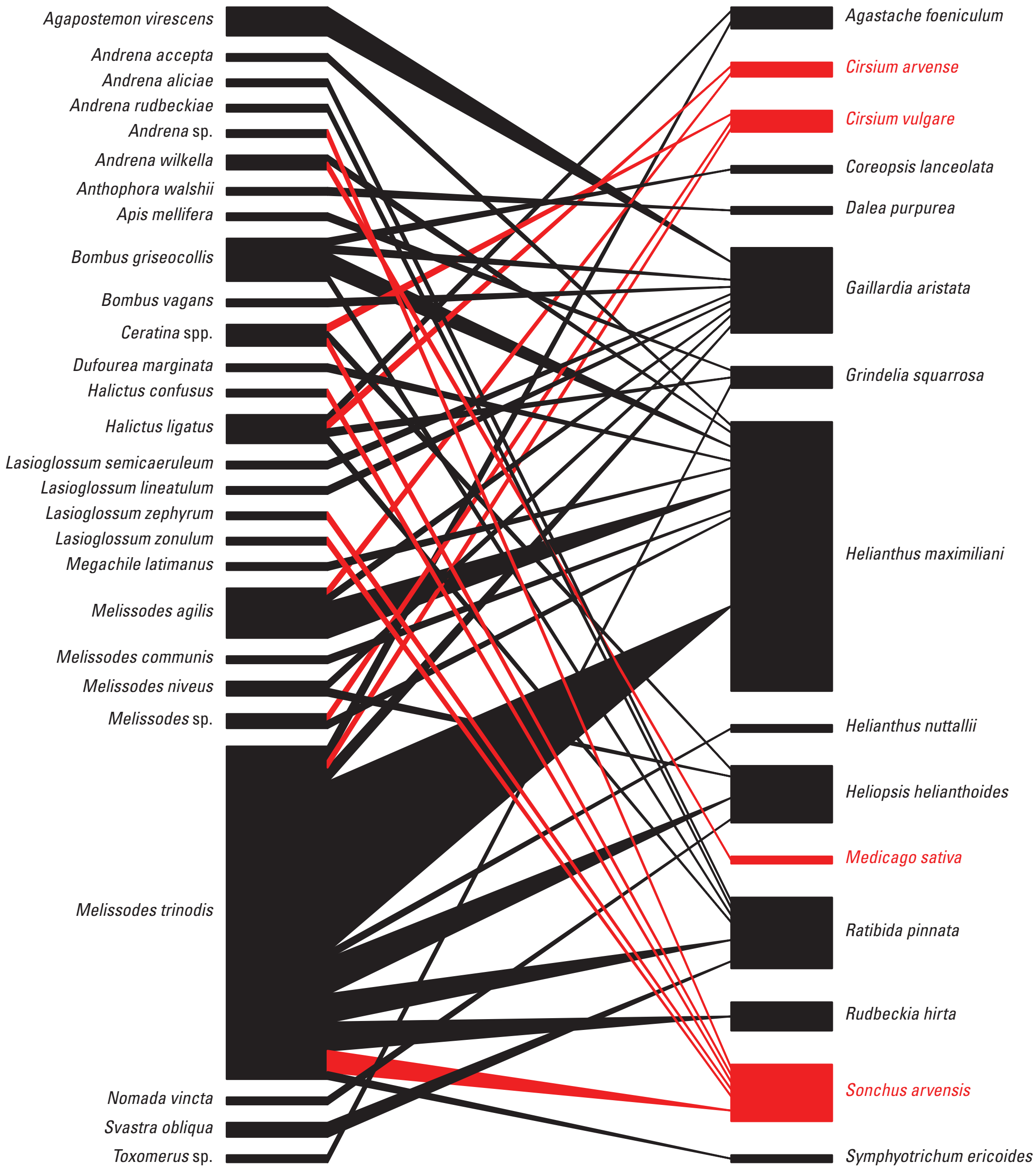


Figure 25. Select wild bee species detected on private lands enrolled in the Environmental Quality Incentives Program from 2016 to 2017. *A*, *Melissodes agilis* (male); photograph by the Pennsylvania Department of Agriculture. *B*, *Bombus griseocollis* (queen); photograph by John Asher. *C*, *Melissodes trinodis*; photograph by Hadel Go. *D*, *Halictus ligatus* (female); photograph by John Ascher. *E*, *Anthophora walshii*; photograph by J. Devalez. *F*, *Agapostemon virescens*; photograph by Hadel Go. All photographs from https://www.discoverlife.org; used with permission.

Our assessment of EQIP and CRP fields revealed a general pattern of high flower abundance and richness early in the growing season. Our data suggest CRP enrollments could benefit from the addition of late-blooming flowers, particularly those that bloom in mid-August to September. This finding is consistent with our landscape analysis in the “Floral Resource Limitations and Honey Bee Preference” section, showing reduced colony weight gain late in the growing season. Ideally, pollinator habitat should provide blooming flowers throughout the growing season. Flower abundance on EQIP enrollments was more uniform throughout the growing season, relative to the CRP, with non-native species representing most flowers observed. A greater emphasis on seeding and managing for native flowers would likely increase use of EQIP enrollments by wild bees, but targeting native flowers is unlikely to increase honey bee use unless those flowers are highly abundant. Interestingly, our data suggest flower richness on the EQIP was lowest from mid-July to mid-August. This is not necessarily problematic for honey bees because their flower use during this period in the northern Great Plains is primarily focused on nectar-rich legumes; however, low richness would likely negatively affect wild bee diversity.

Our fieldwork also identified multiple CRP practices with lower flower abundance during specific parts of the growing season. Although we did not do robust sampling on all CRP practices, our data do suggest flower abundance is low on practices such as CP–02, “Established Permanent Native Grasses,” CP–21, “Filter Strips,” and CP–22, “Riparian Buffer,” during some or all parts of the growing season (fig. 12). Even a modest increase in flower abundance and diversity on all USDA conservation program lands would bring a realized benefit to pollinators, given the substantial footprint these lands have in the agro-ecosystem of the northern Great Plains.



NOTE: This network motif represents wild bees that were netted and identified in the lab. Red and black denote introduced and native plant species, respectively.

Figure 26. Wild bee and host-plant interaction networks for U.S. Department of Agriculture Environmental Quality Incentives Program in North Dakota, South Dakota, and Minnesota in 2016–17.

Floral Resource Limitations and Honey Bee Preference

A lack of flowers has been proposed as a leading driver of pollinator declines (Goulson and others, 2015) and is of primary concern in the northern Great Plains for managed honey bees (Hellerstein and others, 2017; Durant, 2019). In previous work highlighted in this report (see the "Landscape Suitability for Supporting Honey Bees," "Honey Bee and Land-Use Pilot Study," and "Land-Use Effects on Honey Bee Colony Health and Services" sections), we showed how land cover plays a role in shaping the health and vitality of honey bee colonies. In these analyses we assume the quality of floral resources provided by different land covers remains constant over time. However, our pollen identification work (see the "Genetic Analysis of Bee-Collected Pollen Across the Northern Great Plains" section) showed tremendous temporal variation in floral resources targeted by honey bees. Ideally, beekeepers will select apiary locations that provide their honey bee colonies with continuous access to flowers throughout the growing season; however, obtaining access to these highly coveted, and increasingly rare, sites is difficult (Durant, 2019). During periods when naturally occurring floral resources are limited, beekeepers are often forced to provide supplemental nutrition to their honey bee colonies in the form of pollen patties and sugar syrup. Identifying resource dearth periods, and flowers that bloom during these periods, provides the USDA with the information needed to develop seeding mixes that provide nutritious forage for honey bees during periods of resource scarcity.

We used patterns of colony weight gains and losses to identify periods during the growing season when honey bee colonies were losing weight. In an effort to assist the USDA with conservation delivery, we used flower abundance and honey bee visitation data from the 1,264 transects we collected across multiple land-cover types in the northern Great Plains from 2015 to 2017 to determine which flowers honey bees used and preferred during the identified dearth periods. The resulting observed patterns of resource availability, and honey bee flower preference data, may be used by the USDA to assist in designing seeding mixes that include honey bee preferred flowers that bloom during resource dearth periods.

Methods

In 2015–17, we fitted 72 honey bee colonies among our 36 research apiaries with digital scales (Solution Bee B-ware Smart Hive Monitors and custom scales) to monitor changes in colony mass through time (fig. 27). Apiaries used for this study are highlighted in Smart and others (2018) and in the "Land-Use Effects on Honey Bee Colony Health and Services" section. We set each scale to record a colony mass reading every 15 minutes from early June to late September. Changes in colony mass are primarily related to colony nectar collection and consumption. We treated abrupt changes in colony mass greater than 2.2 kilograms within 15 minutes as aberrations not related to colony growth or loss. For example, beekeepers routinely add or remove honey boxes from the colonies throughout the growing season. We disregarded these abrupt weight changes when calculating daily weight and weight change in honey bee colonies. Thus, the weight changes reported herein correspond to biological activity (primarily nectar collection and resource consumption) within the colony.

We used patterns of colony weight gains and losses to identify periods during the growing season when honey bee colonies were losing weight because of resource limitations. On each day, we determined whether the two scales deployed in each of the 36 apiaries had gained, lost, or remained the same weight relative to the previous day. For an apiary to be potentially considered to be experiencing a dearth, we required both scales in the apiary to have recorded a reduction in weight. Several consecutive days with an elevated proportion of apiaries losing weight is an indication of a true environmental dearth, as opposed to local weather patterns precluding colony foraging. We then plotted the daily proportion of apiaries experiencing weight loss over the season (fig. 28) and fit a locally estimated scatterplot smoothing line through the points to observe relations in the data. For each dearth period, we queried our plant-transect database containing flower bloom and bee-flower interaction data observed in 1,264 transects from June-September 2015–17. Specifically, we determined which plants we observed flowering during a particular dearth period. We then used bee-flower interaction data to calculate a preference index of specific honey bee-visited flowers within the two periods where we detected sustained weight loss in honey bee colonies. To calculate the preference index, we ranked use among the different honey bee observations made on flowers and then ranked availability of flowers (flower counts of the same plant species). We assigned ranks separately for each period (that is, early and late season) and used only the data collected within a particular period when calculating availability and use ranks. We then calculated the difference between rank use and rank availability. Typically, preference ranks ranged from least (positive value) to most (negative value) preferred (Johnson, 1980); however, to ease interpretation of the preference rankings, we converted all preference rankings to a positive value, where "1" represented the most preferred forb species. All preference and disfavor rankings should be interpreted relative to other plants, rather than absolute preference or disfavor. In addition to quantifying preference, we also contacted local seed vendors (Applewood Seed Company and Millborn Seeds) in the northern Great Plains to obtain the expected monetary cost of a pound (0.45 kilogram) of pure live seed (PLS) for plant species included in our analysis. Seed mix cost can vary throughout the year, so the prices we provide should not be interpreted as static. Nonetheless, it does allow for a comparison between honey bee-preferred plants and their expected cost

Figure 27. Bee researcher downloading data from a hive scale. Photograph by Katie Lee, University of Minnesota.

to landowners and the USDA. We used data from the USDA PLANTS database (https://plants.sc.egov.usda.gov/index.html) and Pheasants Forever seed mix calculators to determine the number of seeds per pound of PLS for each forb species. This allowed us to estimate the cost of 100,000 seeds for each species rather than cost of 1 pound of PLS. When there were discrepancies between PLANTS and the Pheasants Forever calculator in the number of seeds in a pound of PLS, we used the value reported by PLANTS. A data release for the plant preference data has been prepared by Otto and others (2020b).

Results

Colony Weight Change and Resource Dearth Periods

Colony scale data showed a consistent pattern of colony weight gain and loss throughout the growing season across years. In general, colonies arriving in the northern Great Plains lost weight from early June to late June (fig. 28). For example, >50 percent of colonies lost weight during the first week of June across our 3-year sampling window. By mid-July more than 80 percent of apiaries were gaining weight, suggesting an abundance in nectar resources during this period. During mid-July, the average honey bee colony gained 1.1 pounds daily. By mid-August, some honey bee colonies again began losing weight and continued to lose weight until our study was terminated in mid-September. Most of our honey bee colonies lost weight after the first week of September.

Plant Preference During Dearth Periods

Hive scale data defined periods where honey bees lost weight, particularly in June and September. These periods of resource dearth can be physiologically stressful for honey bees and can require more careful management by beekeepers through supplemental feeding. This provides a clear window of time that could be targeted by natural resource agencies to enhance pollinator forage to either (1) lessen the severity of colony weight loss, or (2) reduce the time span of the dearth period. Either of these could be accomplished by planting forbs that bloom during the target period that are preferred forage plants of honey bees. Below we provide summary data on flowering plant abundance, bee visitations, and bee preference during the identified dearth periods (tables 4 and 5).

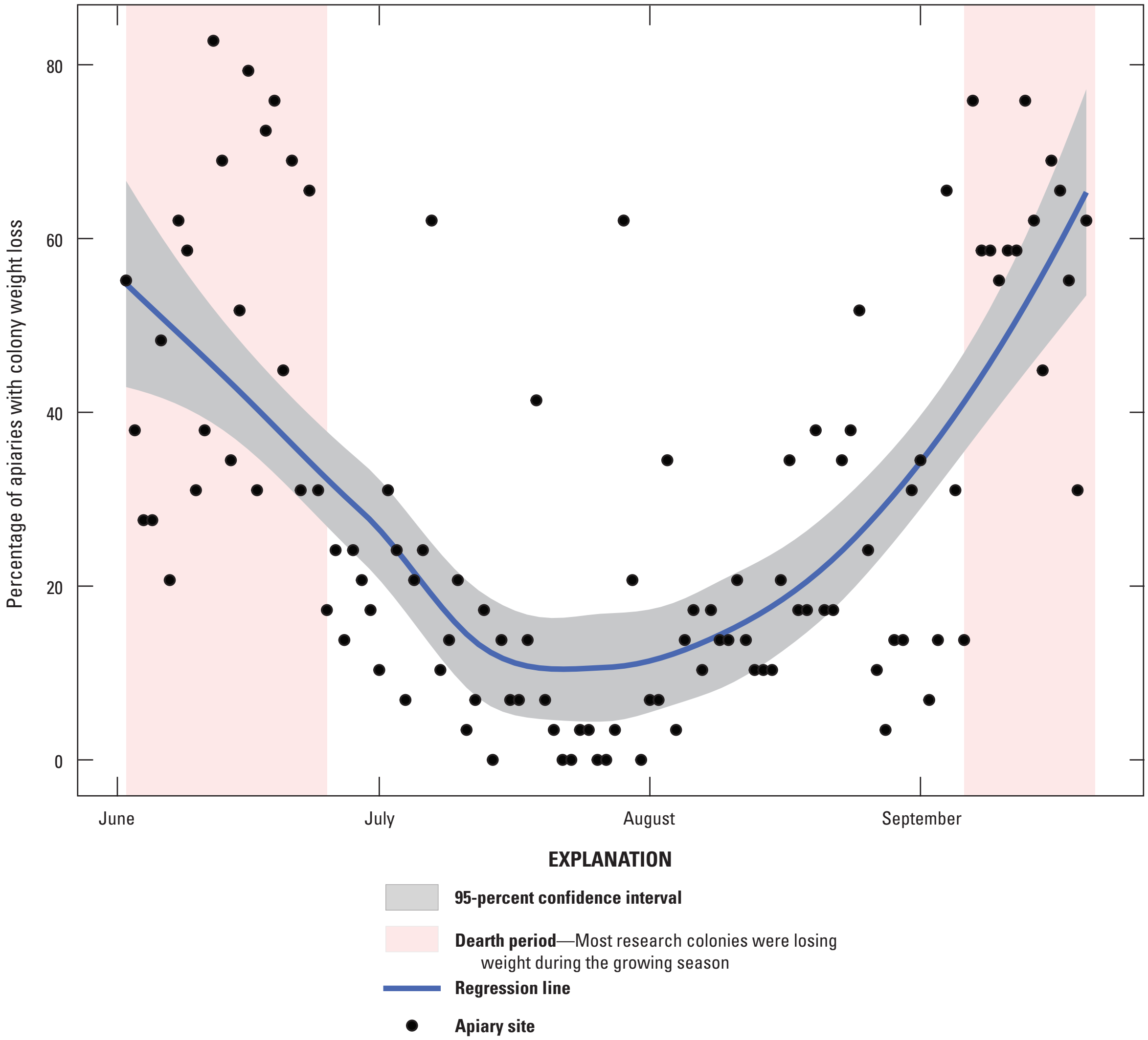


Figure 28. Percentage of research apiaries where honey bee colonies lost weight during a 24-hour period in North Dakota, South Dakota, and Minnesota in 2015–17.

We also provide the cost of PLS for each species, based on reported values from major seed vendors (Applewood Seed Company or Millborn Seeds) in the northern Great Plains. It is important to note we omitted flower abundance and honey bee observation data from July 1 to September 5, which represented most of our honey bee observation data. By omitting mid-season plant and honey bee data, we were able to isolate plants that were flowering, and preferred by honey bees, during dearth periods.

Tables 4 and 5 provide several insights into honey bee foraging during the early and late parts of the growing season. As expected, honey bee use of flowers was heavily weighted towards highly abundant flowers on the landscape. However, honey bee preference (where flower usage exceeds flower availability) included several flower species that were not highly abundant such as *Ratibida columnifera* (upright prairie coneflower), *Gaillardia aristata* (blanket flower), *Agastache foeniculum* (blue giant hyssop), *Helianthus maximiliani* (Maximilian sunflower), and *Carduus nutans* (musk thistle). In addition, the preference index showed honey bees preferred both native and introduced flower species during the early and late parts of the growing season. However, it should be noted that we had few honey bee observations for several of the flowers included in this preference ranking. For example, *Onobrychis viciifolia* (sainfoin), (*Symphyotrichum novae-angliae* (New England aster), and *Astragalus canadensis* (Canada milkvetch) were preferred based on our preference ranking, but we had only one honey bee observation for each of these species during particular periods. Thus, preference data for flower species should be interpreted with caution. Additional honey bee observations for these flower species may be required before these species could be considered highly preferred by honey bees.

Table 4. Flower counts, observed honey bee visits, preference ranking, and seed cost of plants detected on transects during the June nectar dearth period.

[$/lb PLS, U.S. dollar per pound of pure live seed; $, U.S. dollar; NA, not applicable]

Scientific name	Native status	Flowers	Honey bee visits[1]	Preference rank[2]	Seed cost ($/lb PLS)[3]	Seeds per pound[4]	Cost per 100,000 seeds
Ratibida columnifera	Native	32	4	1	$31	737,104	$4.21
Carduus nutans[5]	Introduced	333	14	2	NA	NA	NA
Rosa arkansana	Native	366	5	3	$325	40,341	$805.63
Gaillardia aristata	Native	505	8	4	$26	186,436	$13.95
Lotus corniculatus	Introduced	278	3	4	$10	369,840	$2.70
Trifolium hybridum	Introduced	1,751	69	4	$3.50	680,400	$0.51
Onobrychis viciifolia	Introduced	33	1	5	$2.65	30,240	$8.76
Trifolium repens	Introduced	3,054	15	6	$3.25	711,867	$0.46
Melilotus alba	Introduced	108	1	7	$4	258,560	$1.55
Medicago sativa	Introduced	23,151	145	8	$2.25	226,800	$0.99
Melilotus officinalis	Introduced	31,982	585	8	$2	258,560	$0.77
Cirsium arvense[5]	Introduced	114	1	9	NA	NA	NA
Achillea millefolium	Native	429	2	10	$36	2,852,012	$1.26
Leucanthemum vulgare	Introduced	133	1	11	NA	NA	NA
Euphorbia esula[5]	Introduced	1,090	2	12	NA	NA	NA
Anemone canadensis	Native	3,898	4	13	$500	128,000	$390.63
Trifolium pratense	Introduced	2,995	2	14	$2.50	272,160	$0.92
Galium boreale	Native	867	1	15	$1,000	725,760	$137.79
Medicago lupulina	Introduced	10,623	1	16	NA	NA	NA

[1]Minimum of one honey bee visitation observed during June 1–25, 2015–17.

[2]Preference ranking ranges from most (1) to least (16) preferred.

[3]Cost obtained from local seed vendors.

[4]Data obtained from the U.S. Department of Agriculture PLANTS database and Pheasants Forever seed mix calculator.

[5]Listed as noxious or troublesome weed in North Dakota, South Dakota, or Minnesota on U.S. Department of Agriculture PLANTS database, so no cost information.

Although *Ratibida columnifera* and *Gaillardia aristata* typically bloom during the later parts of the growing season, we did detect these species flowering on newly seeded pollinator plantings before July 1. Thus, we included them in our analysis of early season flowers but acknowledge these species are unlikely to bloom during the early growing season. It is important to note the preference index should not be interpreted as absolute preference. Rather, preference should be interpreted relative to the other plant species included in our study. For example, *Medicago sativa* (alfalfa) was more preferred than *Trifolium pratenese* (red clover) and less preferred than *Ratibida columnifera* (upright prairie coneflower) in the early summer.

Table 5. Flower counts, observed honey bee visits, preference ranking, and seed cost of plants on transects during the September nectar dearth period.

[$/lb PLS, U.S. dollar per pound of pure live seed; $, U.S. dollar; NA, not applicable]

Scientific name	Plant status	Flowers	Honey bee visits[1]	Preference rank[2]	Seed cost ($/lb PLS)[3]	Seeds per pound[4]	Cost per 100,000 seeds
Agastache foeniculum	Native	91	4	1	$114	1,440,000	$7.92
Gaillardia aristata	Native	985	17	2	$26	186,436	$13.95
Helianthus maximiliani	Native	1,701	72	2	$43	196,360	$21.90
Chamaecrista fasciculata	Native	862	15	3	$17	65,000	$26.15
Symphyotrichum ontarionis	Native	184	3	4	$950	4,000,000	$23.75
Trifolium repens	Introduced	7	1	4	$3.25	711,867	$0.46
Astragalus canadensis	Native	21	1	5	$79	270,500	$29.21
Symphyotrichum novae-angliae	Native	31	1	6	$650	1,100,000	$59.09
Solidago rigidum	Native	1,028	8	7	$243	1,009,000	$24.08
Taraxacum officinale	Introduced	39	1	8	NA	NA	NA
Melilotus alba	Introduced	2,709	35	9	$4	258,560	$1.55
Sonchus arvensis[5]	Introduced	1,734	16	9	NA	NA	NA
Cirsium vulgare[5]	Introduced	54	1	10	NA	NA	NA
Trifolium pratense	Introduced	767	3	10	$2.50	272,160	$0.92
Symphyotrichum lanceolatum	Native	1,522	5	11	$950	700,000	$135.71
Medicago sativa	Introduced	25,380	61	12	$2.25	226,800	$0.99
Melilotus officinalis	Introduced	6,230	22	12	$2	258,560	$0.77
Coreopsis lanceolata	Native	115	1	13	$29	221000	$13.12
Rudbeckia hirta	Native	1,658	4	14	$26	1,575,760	$1.65
Cirsium arvense[5]	Introduced	275	1	15	NA	NA	NA
Linaria vulgaris[5]	Introduced	316	1	16	NA	NA	NA
Symphyotrichum ericoides	Native	9,173	11	17	$750	3,200,000	$23.44
Solidago missouriensis	Native	321	1	18	$1,800	1,998,238	$90.08
Solidago canadensis	Native	1,762	2	19	$800	4,600,000	$17.39
Heliopsis helianthoides	Native	1,768	2	20	$34	100,800	$33.73

[1]Minimum of one honey bee visitation observed during September 6–29, 2015–17.

[2]Preference ranking ranges from most (1) to least (20) preferred.

[3]Cost obtained from local seed vendors.

[4]Data obtained from the U.S. Department of Agriculture PLANTS database and Pheasants Forever seed mix calculator.

[5]Listed as noxious or troublesome weed in North Dakota, South Dakota, or Minnesota on U.S. Department of Agriculture PLANTS database, so no cost information.

Relevance to the U.S. Department of Agriculture

Our analysis provides the USDA with specific periods when floral resources for honey bees are scarce on the landscapes and cause honey bee colonies to lose weight. Although we did not include wild bees in this analysis, it is likely that dearth periods that limit honey bee colony growth similarly affect wild bees, particularly social bees such as bumble bees. To keep colonies strong during periods of few resources, beekeepers need to supplement honey bees with feed. These feedings cost beekeepers financial resources in purchasing the feed, fuel costs for driving to apiaries, and staff time. Enhancing bee forage during resource dearth is likely to reduce beekeeper input costs, thereby having a positive financial effect on beekeepers and improving the health of honey bees. Providing forage for bees in the early summer will help honey bee colonies produce more brood and adult bees. It is these bees that will be the colony workforce during the peak summer months for honey production. Providing forage for bees in the late summer and early fall will support the health of the adult bees that will survive the overwintering period. Research has shown that diverse pollen diets of fall bees supports overwintering immune system function and is directly tied to colony overwintering survival (Smart and others, 2016).

Our analysis identifies those periods when honey bee colonies are losing weight and highlights specific forb species that flower during those periods. Furthermore, we show which forb species are most preferred by honey bees and provide the 2019 market value from seed vendors in the northern Great Plains. The USDA can use our data to evaluate seeding mixes for a variety of conservation programs to bolster pollinator forage on the landscape. This work, coupled with the landscape-scale analyses of Otto and others (2016, 2018), provide the USDA with a hierarchical pathway to establishing cost-effective pollinator habitat in the northern Great Plains. For example, Otto and others (2016, 2018) show areas in North Dakota and South Dakota that have experienced the greatest loss in pollinator forage from 2006 to 2016 and areas that support the highest density of apiaries. These could be considered “priority areas” for pollinator forage enhancement on new and existing lands enrolled in USDA programs. The concept of prioritizing areas within a landscape for conservation delivery has been used for decades by the USDA to reduce soil erosion on environmentally sensitive lands and establish critical habitat for imperiled wildlife. A similar prioritization concept could be applied to USDA programs and practices to target priority areas for honey bee forage. Results from our field research can then be applied to develop cost-effective seed mixes that include plants preferred by honey bees during periods of resource scarcity. By taking this hierarchal approach to address forage deficiencies for honey bees, the USDA will maximize conservation delivery and reduce program costs.

It is important to note the seed cost data we provide (tables 4 and 5) are based on price per pound of PLS. Although informative, price per pound of PLS does not take into account the size of individual seeds and therefore provides a misleading representation of what it would actually cost to include that particular species in a seed mix. For example, *Galium boreale* (northern bedstraw) is $1,000 per pound of PLS; however, a pound contains more than 700,000 seeds. The standard seeding rate for grassland conservation practices is 40 seeds per square foot (430 seeds per square meter; The Xerces Society, 2011). If we develop a seeding mix that includes 0.28 *Galium boreale* seeds per square foot, then the retail cost of including this species in a mix would be roughly $10 per acre. Designing seeding mixes based on a seeding rate (seeds per square foot) can help reduce the cost of high-diversity planting, as opposed to designing mixes based on the cost of a pound of PLS. In Otto and others (2017) we assumed a seeding rate of 40 seeds per square foot and constructed a 26-species forb mix for $184 per acre.

Future Work

The multi-year, regional dataset we have collected on plants and bees will improve our understanding of how bees interact with their local environment and of the role that USDA conservation covers play in supporting pollinators. During this research project, we identified new science topics we would like to pursue in the future. Many of these would require no additional data collection. First, our research has identified what flowering plants are growing on private lands enrolled in USDA conservation programs and what flowers the bees use and prefer. We would like to extend this work by determining what flowering plants were seeded on these fields and how that compares to what species eventually flowered and were used by the bees. This would allow the USDA to relate the seeding mix specifications to specific pollinator outcome metrics. Second, most large-scale analyses of bee habitat and forage assume the value of land covers is static and homogeneous for pollinators. However, we detected substantial variation in flower diversity and abundance across land-cover types and growing season, and within growing seasons. Even within particular USDA program lands, we detected substantial variation in flower diversity and abundance (see the “Plant-Pollinator Interactions on Private Lands Enrolled in the Conservation Reserve Program or Environmental Quality Incentives Program” section). We would like to investigate the role of different land covers (including USDA enrollments) in shaping bee habitat across the northern Great Plains and how the value of these land covers changes through time. To our knowledge, no large-scale assessment of temporal variance in pollinator forage across multiple private and public land holdings has ever been done.

The Pollinator Library—A Decision-Support Tool for Enhancing Pollinator Habitat

The following section highlights the utility of the Pollinator Library for accessing data on flowering plants that are important to bees and designing pollinator seed mixes. Increased societal concern over declining pollinators has led to national efforts to engineer habitat for honey bees and wild bees. One of three national goals for improving pollinator health called for the creation or enhancement of 7 million acres of pollinator habitat by 2020 (Pollinator Health Task Force, 2015). The USDA developed multiple programs, practices, and initiatives to incentivize landowners to establish pollinator habitat on their farms. Designing seed mixes that provide forage for bees can be logistically challenging, and little knowledge on what flowers are used by bees can reduce the effect of habitat plantings on pollinators. Although the peer-reviewed literature contains information on what flowers are good for bees, this information is often inaccessible to natural resource managers tasked with designing seed mixes and can often be site or region specific.

In 2014, we partnered with the FSA and NRCS to develop the Pollinator Library. The goal of the Pollinator Library is to provide natural resource managers with easily accessible information on flower use by wild and managed bees. The Pollinator Library (https://www.npwrc.usgs.gov/pollinator/) website supports management and research of plant-pollinator systems by documenting, synthesizing, and disseminating information on flowers that are used by pollinators and other insects (fig. 29). We hope that by providing free access to essential forage information, the Pollinator Library will lead to an improved understanding of the forage needs of flower-visiting insects. Our intended audience of the Pollinator Library is natural resource managers who are tasked with designing seed mixes for pollinators but may not have detailed knowledge of what flowers are important for bees. Currently, the Pollinator Library hosts about 27,000 records of plant-pollinator interactions and covers 13 States. By serving as an easily accessible conservation delivery tool, the Pollinator Library helps to fill critical information gaps identified by the Pollinator Health Task Force. In 2015 and 2016, the Pollinator Library had more than 7,000 national and international users.

In 2017, the NPWRC science team published a paper on how natural resource managers can use the information available in the Pollinator Library to evaluate pollinator seeding mixes and to assess pollinator resource use on U.S. Fish and Wildlife Service national wildlife refuges and waterfowl production areas and on USDA CRP and EQIP lands (Otto and others 2017). This paper was intended to serve as a “cookbook” for natural resource managers of how to use plant-pollinator interaction data to design seeding mixes for conservation plantings. In addition, this paper also highlights how seed cost can be considered when designing seed mixes. Briefly, we summarized records of 314 native bee and 849 honey bee interactions detected on 63 different plant species. Because our field assessment of wild bees on the EQIP began in 2016, we do not present data on wild bees on EQIP enrollments in this paper. Our long-term goal is to publish a follow-up paper that provides a complete assessment of native bee and honey bee observations on the EQIP, and other land-use types, from 2015 to 2019.

Based on data queried from the Pollinator Library, the forbs most frequently visited by wild bees were *Monarda fistulosa* (wild bergamot), *Sonchus arvensis* (sow thistle), and *Zizia aurea* (golden alexander), while honey bees most frequently visited *Cirsium arvense* (Canada thistle), *Melilotus officinalis* (yellow sweet clover), and *Medicago sativa* (alfalfa). More than 77 percent of all wild bee observations were made on native forbs. In this paper, we point out that pollinator use of forbs does not necessarily mean these forbs are preferred because bees may simply be using forbs consistent with their abundance on the landscape (Williams and others 2011). The Pollinator Library does not offer bee-forb preference data; however, we do investigate honey bee forb preference in the “Floral Resource Limitations and Honey Bee Preference” section.

Otto and others (2017) showed that designing seed mixes with high forb diversity is important for supporting native pollinator communities—a finding supported by other research outside of the northern Great Plains (Harmon-Threatt and Hendrix, 2015; Williams and others, 2015). Our research showed the seeding mix with the highest forb richness (26 species) included the highest number of native bee species, genera, families, and individual bee counts, based on data from the Pollinator Library. Seed cost for the 26-species forb mix cost slightly less than the 9-species mix, thereby demonstrating that high diversity does not necessarily cost more. We also showed that land-use types with higher forb diversity, such as national wildlife refuges, supported more complex native bee networks. Thus, seeding mixes that result in the successful establishment of diverse forb communities are likely to support diverse native pollinator communities in the northern Great Plains. However, we also determined that high-diversity mixes may not maximize benefits to honey bees. The 3-species forb mix outperformed the 9- and 26-species mixes in terms of honey bee visitations. This led to the conclusion that seeding mixes need to be tailored to meet the unique needs of native bees and honey bees in the agricultural areas of the northern Great Plains. Indeed, seed mixes that include highly abundant forb species are more likely to attract large numbers of honey bees, whereas plantings that are diverse, and not dominated by a single forb species, are likely to attract different wild bees.

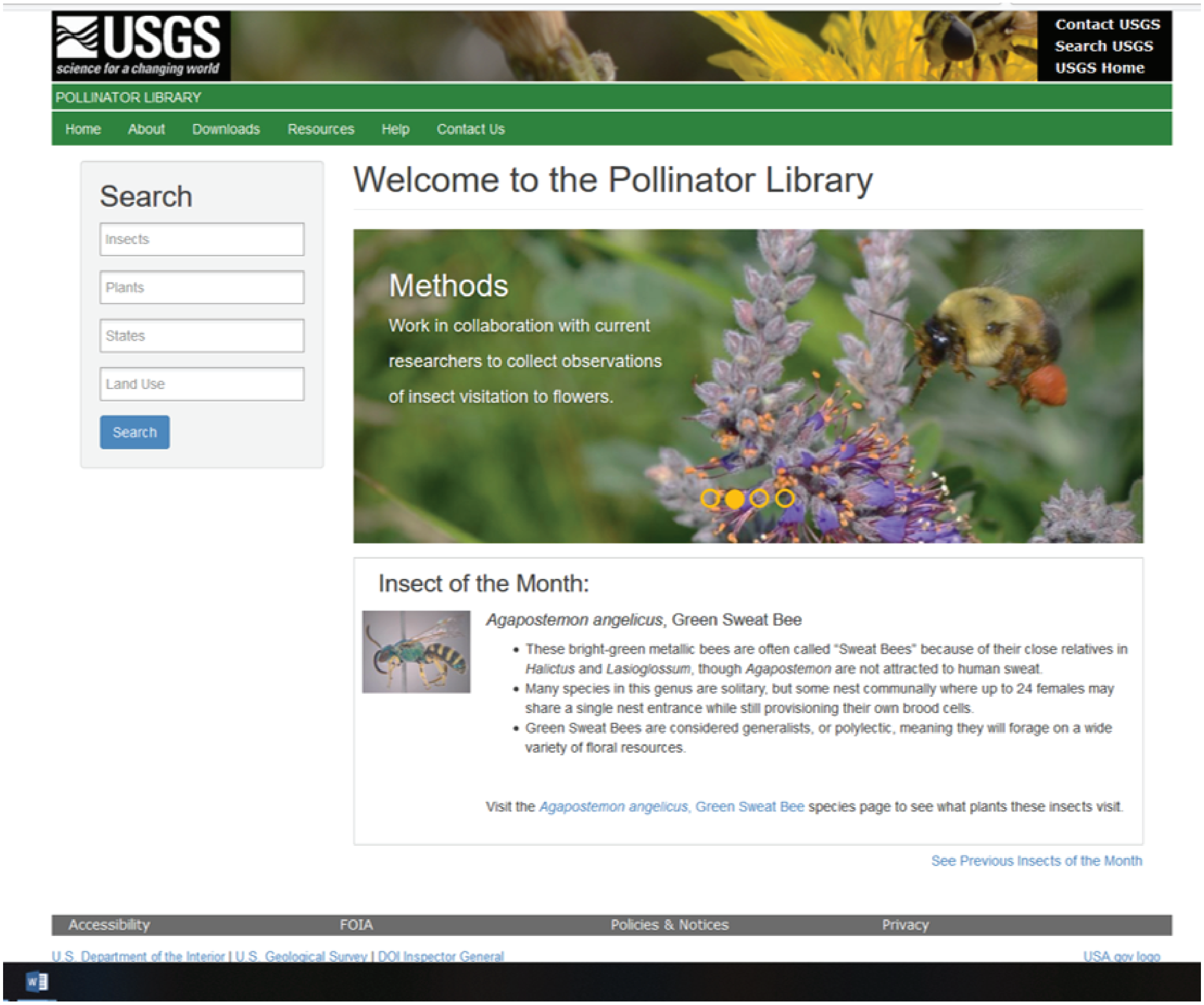


Figure 29. The U.S. Geological Survey Pollinator Library website.

Future Work

The USGS Pollinator Library is a decision-support tool that USDA staff can use to better understand what flowering plants are good for wild bees and honey bees. We are currently improving the website to have quicker load and search times. In addition, we are creating a new analysis package that will display the results of queried searches in a way that will be meaningful to users interested in designing pollinator seed mixes (fig. 30). Our long-term goal is to incorporate a seed mix calculator in the Pollinator Library so that users can use the website to optimize their seeding mixes to maximize the effect on pollinators with reduced cost to the landowner. Our goal is to have the updated version of the Pollinator Library available online by December 2020 (fig. 30)

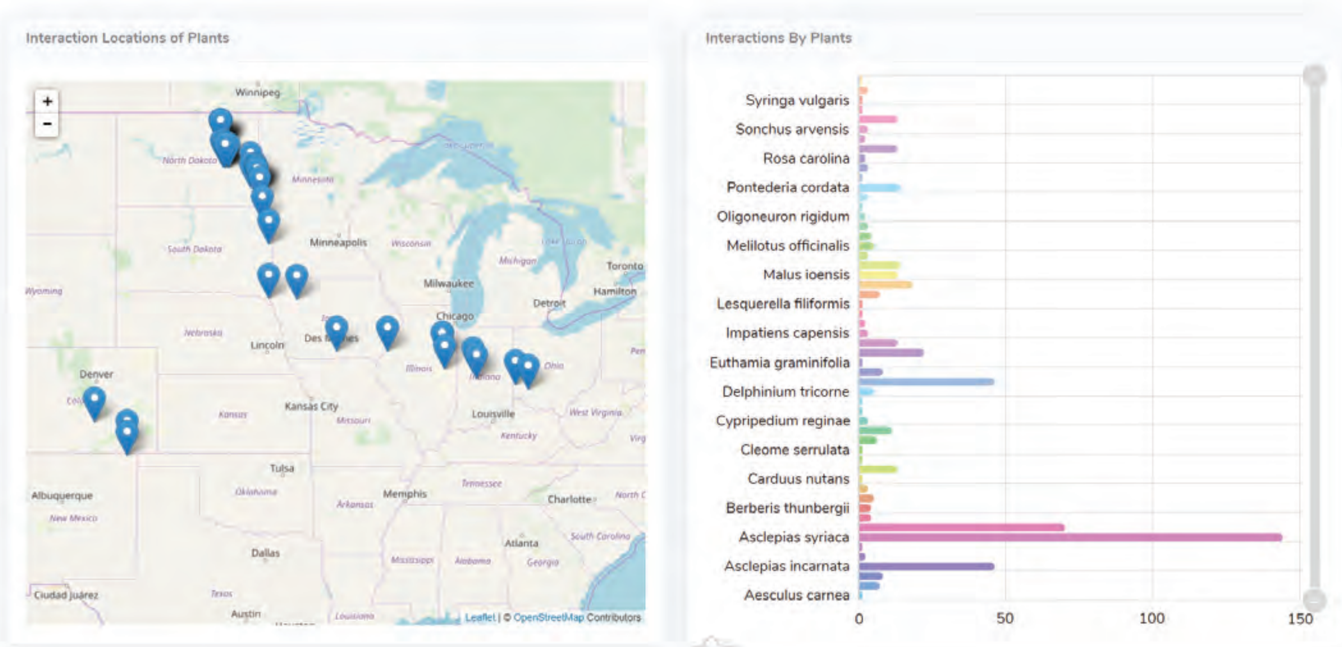


Figure 30. Summary graphics provided by the updated version of the U.S. Geological Survey Pollinator Library. The graphics were generated by performing a search on *Bombus griseocollis*, the brown-belted bumble bee.

Summary

Our research emphasizes a pressing need for pollinator habitat and forage in the northern Great Plains and highlights the role of U.S. Department of Agriculture (USDA) conservation lands in supporting wild bees and honey bees. The spatial and temporal scales of our research are unique in that we cover a three-State region in a part of the United States that supports about 40 percent of all honey bee colonies and an estimated 250 wild bee species from 2015 to 2017. To our knowledge, no other pollinator study has taken place at this scale, across multiple growing seasons, and with specific relevance to USDA conservation programs. In this report, we highlight the following key research elements: (1) the influence of large-scale land covers on bee health and landscape suitability for supporting commercial apiaries in the future, (2) a multiscale analysis of honey bee forage use, and (3) flower availability, and honey bee and wild bee visitations on private lands enrolled in the Conservation Reserve Program and Environmental Quality Incentives Program. Within each core research area in this report, we highlight the relevance of our research to USDA Farm Service Agency and Natural Resources Conservation Service program delivery and discussed future research needs. Through this series of studies, we identify specific areas within the northern Great Plains that could be targeted for floral resource enhancement to support the greatest number of honey bee colonies and provide holistic evaluation of forage plants that are important to supporting bee nutrition. We also identify the early summer and early fall as periods when floral resources are limited for bees and provide a list of honey bee-preferred forage plants that flower during these periods. Notably, our assessment of USDA conservation lands also revealed the early fall as being a period when floral resources were most limited for bees. In our bee preference analysis, we identified *Agastache foeniculum*, *Gaillardia aristata*, *Helianthus maximiliani*, and several other forbs as species preferred by honey bees and that bloom during the early fall. This provides natural resource managers with clear guidance on (1) when floral resources for bees are most scarce on the landscape and on USDA program lands, and (2) specific plants that could be included in seeding mixes to help alleviate the resource limitation. We recognize that high cost of seed made preclude natural resource managers from including some highly preferred species within a seed mix. To that end, we provide seed cost information in our tables of preferred plants. Additionally, we provide a published example of how natural resource managers can use plant-pollinator interaction data from the USGS Pollinator Library to design cost-effective seeding mixes for both honey bees and wild bees. This analysis considers biological impact and cost when designing seed mixes.

Pollen genetic analyses and floral resource assessments on USDA conservation lands provided comparable results but also identified method-specific conclusions that could not have been reached without the use of multiple sampling methods. For example, the genetic analysis of bee collected pollen and our honey bee visitation records indicated *Melilotus* spp. is a widely used resource by honey bees. However, our genetic analysis indicated less than 0.01 percent of all honey bee-collected pollen was from *Medicago sativa*, and yet this species was among the most visited plant species on CRP and EQIP, based on our honey bee visitation data. Thus, honey bees seem to be reluctant collectors of *Medicago sativa* pollen but often visit it as a nectar resource. This apparent discrepancy reveals why it is advantageous to use multiple methods to quantify pollinator resource use. Natural resource managers may consider including *Medicago sativa* in a seed mix, if the goal is to improve honey production, but it is unlikely that this species will contribute to the long-term health of a colony if the bees do not collect pollen from it.

In 2020 and beyond, our team will use our existing dataset to address several research objectives including (1) quantifying dietary niche overlap in honey bees and wild bees to assist with designing seed mixes that minimize competitive interactions, (2) investigating how the diversity of land covers surrounding our research apiaries is related to the diversity and quality of pollens collected by the bees, (3) developing a one-page fact sheet of honey bee and wild bee flower preference, and (4) evaluating the cost-effectiveness of high-diversity pollinator plantings. In addition, future research is needed to quantify the multiple ecosystem services provided by USDA conservation programs, so the environmental effects of conservation lands can be accurately weighed against their monetary cost to taxpayers.

The northern Great Plains is perhaps the most important part of the United States for supporting honey bees during the summer. Our research has established a direct link between USDA conservation programs and the suitability of the landscape for supporting large numbers of commercial honey bee colonies. Thus, our research highlights the far-reaching effects of USDA conservation programs on other sectors of agriculture that require pollinators for crop pollination across the United States. In concert with benefiting pollinators directly, USDA conservation programs can also benefit landowners and producers by preventing listing of declining pollinators under the Endangered Species Act, which would likely create additional government oversight of how private lands in the NGP are managed.

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Appendix 1. Bee Pollen Detection Data and Plant Taxa Information

Table 1.1. Complete list of taxa detected in samples of bee-collected pollen in 2015 and 2016.

[Operational taxonomic unit (OTU) counts provide an index of taxon abundance]

Taxa	Level	OTU counts	Percentage of total
Melilotus	Genus	35,259,793	42.594
Asteraceae	Family	4,166,069	5.033
Trifolium	Genus	3,131,198	3.782
Fabaceae	Family	3,095,758	3.740
Sonchus arvensis	Species	3,024,336	3.653
Symphyotrichum cordifolium	Species	2,413,921	2.916
Solidago	Genus	2,025,703	2.447
Artemisia absinthium	Species	1,527,973	1.846
Grindelia	Genus	1,502,559	1.815
Anemone canadensis	Species	1,435,727	1.734
Symphyotrichum	Genus	1,142,716	1.380
Ambrosia trifida	Species	1,058,929	1.279
Brassica	Genus	945,728	1.142
Arctium lappa	Species	894,012	1.080
Tephroseris	Genus	876,074	1.058
Sonchus	Genus	850,457	1.027
Brassica nigra	Species	842,060	1.017
Lotus	Genus	694,258	0.839
Cirsium arvense	Species	659,909	0.797
Sparganium eurycarpum	Species	634,809	0.767
Salix	Genus	611,912	0.739
Trifolium hybridum	Species	590,938	0.714
Hesperis sibirica	Species	542,014	0.655
Alopecurus	Genus	516,047	0.623
Lonicera	Genus	495,620	0.599
Helianthus annuus	Species	477,215	0.576
Alisma	Genus	464,472	0.561
Helianthus	Genus	431,724	0.522
Grindelia hirsutula	Species	421,058	0.509
Taraxacum	Genus	359,571	0.434
Brassicaceae	Family	348,126	0.421
Lythrum salicaria	Species	333,931	0.403
Raphanus sativus	Species	324,916	0.392
Rhamnus	Genus	321,898	0.389
Glycine	Genus	301,608	0.364
Securigera varia	Species	301,431	0.364
Impatiens capensis	Species	297,347	0.359
Hydrophyllum tenuipes	Species	294,396	0.356
Solidago canadensis	Species	285,058	0.344
Carduus acanthoides	Species	265,565	0.321

Table 1.1. Complete list of taxa detected in samples of bee-collected pollen in 2015 and 2016.—Continued

[Operational taxonomic unit (OTU) counts provide an index of taxon abundance]

Taxa	Level	OTU counts	Percentage of total
Ageratina adenophora	Species	261,991	0.316
Alopecurus aequalis	Species	259,533	0.314
Glycine max	Species	253,298	0.306
Poaceae	Family	252,363	0.305
Elaeagnus	Genus	250,529	0.303
Chamaecrista nictitans	Species	249,474	0.301
Dalea purpurea	Species	227,778	0.275
Caprifoliaceae	Family	226,890	0.274
Cyclachaena xanthiifolia	Species	224,721	0.271
Lithospermum	Genus	224,512	0.271
Hesperis	Genus	212,080	0.256
Plantago lanceolata	Species	188,237	0.227
Boltonia	Genus	178,375	0.215
Ranunculaceae	Family	177,795	0.215
Amorpha	Genus	167,520	0.202
Sium suave	Species	156,018	0.188
Symphyotrichum subulatum	Species	155,099	0.187
Apiaceae	Family	141,448	0.171
Rosa	Genus	137,227	0.166
Sinapis alba	Species	128,653	0.155
Centaurea stoebe	Species	123,024	0.149
Sambucus	Genus	116,112	0.140
Ambrosia artemisiifolia	Species	110,956	0.134
Amaranthus tuberculatus	Species	109,544	0.132
Bacopa	Genus	106,448	0.129
Sagittaria	Genus	106,014	0.128
Clematis	Genus	104,790	0.127
Salicaceae	Family	102,670	0.124
Xanthium	Genus	98,413	0.119
Phalaris arundinacea	Species	97,686	0.118
Fagopyrum esculentum	Species	90,268	0.109
Solanum	Genus	86,703	0.105
Allium tricoccum	Species	84,743	0.102
Brassica napus	Species	83,064	0.100
Amorpha apiculata	Species	76,398	0.092
Oleaceae	Family	75,243	0.091
Astragalus	Genus	72,101	0.087
Linaria	Genus	70,081	0.085
Eutrochium	Genus	65,477	0.079
Linaria vulgaris	Species	61,981	0.075
Glycyrrhiza lepidota	Species	61,215	0.074
Brassica oleracea	Species	60,536	0.073
Bolboschoenus caldwellii	Species	60,034	0.073

Table 1.1. Complete list of taxa detected in samples of bee-collected pollen in 2015 and 2016.—Continued

[Operational taxonomic unit (OTU) counts provide an index of taxon abundance]

Taxa	Level	OTU counts	Percentage of total
Syringa	Genus	58,724	0.071
Typhaceae	Family	58,021	0.070
Syringa josikaea	Species	54,259	0.066
Dupontia fisheri	Species	53,739	0.065
Rhamnaceae	Family	52,012	0.063
Thalictrum	Genus	51,974	0.063
Zizia aurea	Species	51,431	0.062
Cicuta	Genus	51,210	0.062
Juglans	Genus	50,122	0.061
Hydrangea paniculata	Species	48,874	0.059
Hydrophyllaceae	Family	47,539	0.057
Rhamnus davurica	Species	47,075	0.057
Ammannia	Genus	45,731	0.055
Phacelia tanacetifolia	Species	44,969	0.054
Carduus	Genus	44,305	0.054
Eupatorium	Genus	43,412	0.052
Alismataceae	Family	42,425	0.051
Heliopsis helianthoides	Species	41,868	0.051
Acer tataricum	Species	40,920	0.049
Ranunculus hispidus var. *nitidus*	Species	40,576	0.049
Ambrosia	Genus	39,347	0.048
Cirsium	Genus	38,277	0.046
Ranunculus	Genus	37,636	0.045
Chamaecrista	Genus	36,308	0.044
Lythrum	Genus	35,631	0.043
Capsella bursa-pastoris	Species	34,260	0.041
Plantago	Genus	33,958	0.041
Elaeagnaceae	Family	33,492	0.040
Zea mays	Species	33,186	0.040
Cirsium vulgare	Species	31,351	0.038
Astragalus scaberrimus	Species	29,722	0.036
Chenopodium album	Species	29,187	0.035
Verbascum	Genus	28,870	0.035
Bassia scoparia	Species	28,619	0.035
Berteroa incana	Species	28,234	0.034
Rumex	Genus	26,514	0.032
Cephalanthus	Genus	25,881	0.031
Euphorbia	Genus	24,564	0.030
Pisum sativum	Species	23,944	0.029
Bidens	Genus	23,887	0.029
Plantaginaceae	Family	23,520	0.028
Amaranthaceae	Family	23,262	0.028
Phalaris	Genus	23,251	0.028

Table 1.1. Complete list of taxa detected in samples of bee-collected pollen in 2015 and 2016.—Continued

[Operational taxonomic unit (OTU) counts provide an index of taxon abundance]

Taxa	Level	OTU counts	Percentage of total
Lythraceae	Family	21,787	0.026
Artemisia	Genus	21,466	0.026
Hydrophyllum	Genus	21,329	0.026
Conium maculatum	Species	20,166	0.024
Erucastrum gallicum	Species	20,054	0.024
Rhaponticum uniflorum	Species	19,703	0.024
Rhus	Genus	19,426	0.023
Ageratina	Genus	19,103	0.023
Rosaceae	Family	18,952	0.023
Lotus corniculatus	Species	18,434	0.022
Rudbeckia hirta	Species	18,320	0.022
Hypochaeris radicata	Species	17,956	0.022
Melilotus officinalis	Species	17,715	0.021
Acer	Genus	17,589	0.021
Sambucus nigra ssp. *canadensis*	Species	17,391	0.021
Sagittaria montevidensis	Species	17,021	0.021
Sapindaceae	Family	16,772	0.020
Persicaria viscosa	Species	16,659	0.020
Rudbeckia laciniata	Species	16,655	0.020
Ranunculus fuegianus	Species	15,779	0.019
Ulmus	Genus	15,130	0.018
Rudbeckia	Genus	14,962	0.018
Nymphaea odorata	Species	14,648	0.018
Medicago sativa	Species	13,332	0.016
Poa	Genus	13,198	0.016
Arctium	Genus	13,147	0.016
Tephroseris integrifolia	Species	12,717	0.015
Boraginaceae	Family	12,619	0.015
Raphanus	Genus	12,594	0.015
Rhamnus cathartica	Species	11,671	0.014
Centaurea	Genus	11,445	0.014
Symphyotrichum novae-angliae	Species	11,216	0.014
Phytolacca	Genus	11,030	0.013
Persicaria	Genus	10,615	0.013
Fagopyrum	Genus	10,526	0.013
Viburnum prunifolium	Species	10,494	0.013
Balsaminaceae	Family	9,923	0.012
Cyperaceae	Family	8,756	0.011
Amaranthaceae	Family	8,108	0.010
Parthenocissus quinquefolia	Species	7,872	0.010
Heliotropiaceae	Family	7,269	0.009
Potentilla	Genus	7,251	0.009
Decodon verticillatus	Species	7,154	0.009

Table 1.1. Complete list of taxa detected in samples of bee-collected pollen in 2015 and 2016.—Continued

[Operational taxonomic unit (OTU) counts provide an index of taxon abundance]

Taxa	Level	OTU counts	Percentage of total
Verbascum macrocarpum	Species	7,120	0.009
Capsella	Genus	7,013	0.008
Vitaceae	Family	6,826	0.008
Ranunculus repens	Species	6,595	0.008
Heterotheca villosa	Species	6,527	0.008
Iva	Genus	6,514	0.008
Sonchus megalocarpus	Species	5,952	0.007
Cichorium intybus	Species	5,853	0.007
Euthamia	Genus	5,362	0.006
Linum	Genus	5,300	0.006
Sorghum	Genus	5,042	0.006
Pisum	Genus	4,613	0.006
Tilia	Genus	4,462	0.005
Asclepias syriaca	Species	4,370	0.005
Silphium perfoliatum	Species	4,249	0.005
Juglandaceae	Family	4,230	0.005
Melampsora	Genus	4,157	0.005
Gleditsia	Genus	4,062	0.005
Polygonaceae	Family	4,010	0.005
Populus deltoides	Species	3,972	0.005
Viburnum	Genus	3,842	0.005
Solanaceae	Family	3,838	0.005
Dasiphora	Genus	3,835	0.005
Cornaceae	Family	3,497	0.004
Salvia	Genus	3,460	0.004
Bolboschoenus	Genus	3,374	0.004
Monarda fistulosa	Species	3,106	0.004
Sisymbrium linifolium	Species	2,998	0.004
Glycyrrhiza	Genus	2,707	0.003
Daucus	Genus	2,519	0.003
Tanacetum vulgare	Species	2,442	0.003
Hydrangea	Genus	2,384	0.003
Clematis virginiana	Species	2,282	0.003
Rhaponticum	Genus	2,268	0.003
Cucumis	Genus	2,260	0.003
Imbribryum blandum	Species	2,185	0.003
Echinacea angustifolia	Species	2,147	0.003
Adoxaceae	Family	2,141	0.003
Securigera	Genus	2,023	0.002
Silphium	Genus	1,956	0.002
Euphorbia esula	Species	1,893	0.002
Linaceae	Family	1,889	0.002
Erigeron philadelphicus	Species	1,886	0.002

Table 1.1. Complete list of taxa detected in samples of bee-collected pollen in 2015 and 2016.—Continued

[Operational taxonomic unit (OTU) counts provide an index of taxon abundance]

Taxa	Level	OTU counts	Percentage of total
Amaranthus	Genus	1,746	0.002
Allium	Genus	1,587	0.002
Cucumis sativus	Species	1,556	0.002
Trifolium repens	Species	1,547	0.002
Oxalis	Genus	1,541	0.002
Dalea candida	Species	1,538	0.002
Oenothera	Genus	1,535	0.002
Ratibida columnifera	Species	1,485	0.002
Musa acuminata	Species	1,467	0.002
Solidago houghtonii	Species	1,465	0.002
Verbena	Genus	1,368	0.002
Sparganium	Genus	1,227	0.001
Doellingeria umbellata	Species	1,227	0.001
Trifolium nigrescens	Species	1,209	0.001
Lotus tenuis	Species	1,172	0.001
Hydrangeaceae	Family	1,135	0.001
Medicago	Genus	1,134	0.001
Convolvulus arvensis	Species	1,123	0.001
Dasiphora fruticosa	Species	1,102	0.001
Erysimum	Genus	1,075	0.001
Musa	Genus	1,033	0.001
Brassica juncea	Species	994	0.001
Crepis	Genus	991	0.001
Ratibida	Genus	955	0.001
Scrophulariaceae	Family	892	0.001
Parthenocissus	Genus	844	0.001
Zinnia violacea	Species	839	0.001
Triticum	Genus	797	0.001
Sorbus aucuparia	Species	794	0.001
Lactuca	Genus	790	0.001
Persicaria amphibia	Species	777	0.001
Tragopogon	Genus	741	0.001
Berteroa	Genus	726	0.001
Viburnum opulus	Species	608	0.001
Andropogon	Genus	600	0.001
Sisymbrium altissimum	Species	594	0.001
Quercus	Genus	579	0.001
Dactylis glomerata	Species	524	0.001
Carex	Genus	521	0.001
Nepeta cataria	Species	511	0.001
Salsola	Genus	505	0.001
Schoenoplectus tabernaemontani	Species	487	0.001
Rhus copallinum	Species	468	0.001

Table 1.1. Complete list of taxa detected in samples of bee-collected pollen in 2015 and 2016.—Continued

[Operational taxonomic unit (OTU) counts provide an index of taxon abundance]

Taxa	Level	OTU counts	Percentage of total
Rosa acicularis	Species	462	0.001
Sisymbrium	Genus	455	0.001
Elaeagnus commutata	Species	448	0.001
Hypericum prolificum	Species	416	0.001
Asparagus oligoclonos	Species	414	0.001
Buddleja officinalis	Species	409	0.000
Phleum alpinum	Species	409	0.000
Imbribryum	Genus	389	0.000
Erucastrum	Genus	377	0.000
Triticum	Genus	373	0.000
Sicyos	Genus	369	0.000
Heterotheca	Genus	356	0.000
Urtica	Genus	337	0.000
Silene	Genus	313	0.000
Phleum pratense	Species	313	0.000
Astragalus laxmannii	Species	311	0.000
Aquilegia	Genus	303	0.000
Vicia	Genus	298	0.000
Amaryllidaceae	Family	297	0.000
Malvaceae	Family	278	0.000
Chenopodium	Genus	277	0.000
Anacardiaceae	Family	271	0.000
Sinapis	Genus	264	0.000
Cucurbitaceae	Family	262	0.000
Cerastium arvense	Species	262	0.000
Bryaceae	Family	261	0.000
Melilotus albus	Species	256	0.000
Senecio	Genus	249	0.000
Mentha	Genus	245	0.000
Onobrychis viciifolia	Species	234	0.000
Potentilla anserina	Species	225	0.000
Dulichium	Genus	222	0.000
Brickellia	Genus	214	0.000
Spathidiidae	Family	212	0.000
Celastrus scandens	Species	201	0.000
Parthenocissus vitacea	Species	200	0.000
Carduus crispus	Species	199	0.000
Papaver orientale	Species	188	0.000
Symphoricarpos occidentalis	Species	170	0.000
Sporobolus	Genus	166	0.000
Secale	Genus	160	0.000
Euphorbiaceae	Family	159	0.000
Alternaria	Genus	152	0.000

Table 1.1. Complete list of taxa detected in samples of bee-collected pollen in 2015 and 2016.—Continued

[Operational taxonomic unit (OTU) counts provide an index of taxon abundance]

Taxa	Level	OTU counts	Percentage of total
Nuphar variegata	Species	147	0.000
Caryophyllaceae	Family	140	0.000
Onobrychis	Genus	140	0.000
Trifolium incarnatum	Species	138	0.000
Packera	Genus	136	0.000
Ptelea	Genus	135	0.000
Trifolium pallescens	Species	133	0.000
Cornus	Genus	130	0.000
Boltonia asteroides	Species	130	0.000
Anemone	Genus	126	0.000
Monarda	Genus	126	0.000
Ceratodon	Genus	123	0.000
Verbenaceae	Family	119	0.000
Dipsacus	Genus	117	0.000
Nymphaea	Genus	111	0.000
Apocynaceae	Family	110	0.000
Rubiaceae	Family	110	0.000
Zizania	Genus	110	0.000
Rubus	Genus	108	0.000
Schoenoplectus	Genus	102	0.000
Lonicera dioica	Species	101	0.000
Papaveraceae	Family	94	0.000
Typha	Genus	90	0.000
Verbesina	Genus	90	0.000
Nymphaeaceae	Family	89	0.000
Fraxinus	Genus	85	0.000
Descurainia sophia	Species	85	0.000
Ceratodon purpureus	Species	83	0.000
Sium	Genus	80	0.000
Gastrostyla steinii	Species	75	0.000
Erigeron	Genus	73	0.000
Eupatorium perfoliatum	Species	71	0.000
Lotus japonicus	Species	70	0.000
Potamogeton amplifolius	Species	70	0.000
Erigeron annuus	Species	69	0.000
Musaceae	Family	67	0.000
Osmorhiza	Genus	66	0.000
Thlaspi	Genus	57	0.000
Potentilla anserinoides	Species	56	0.000
Sisymbrium loeselii	Species	55	0.000
Ligularia	Genus	53	0.000
Moniliella	Genus	51	0.000
Tilia americana var. *caroliniana*	Species	51	0.000

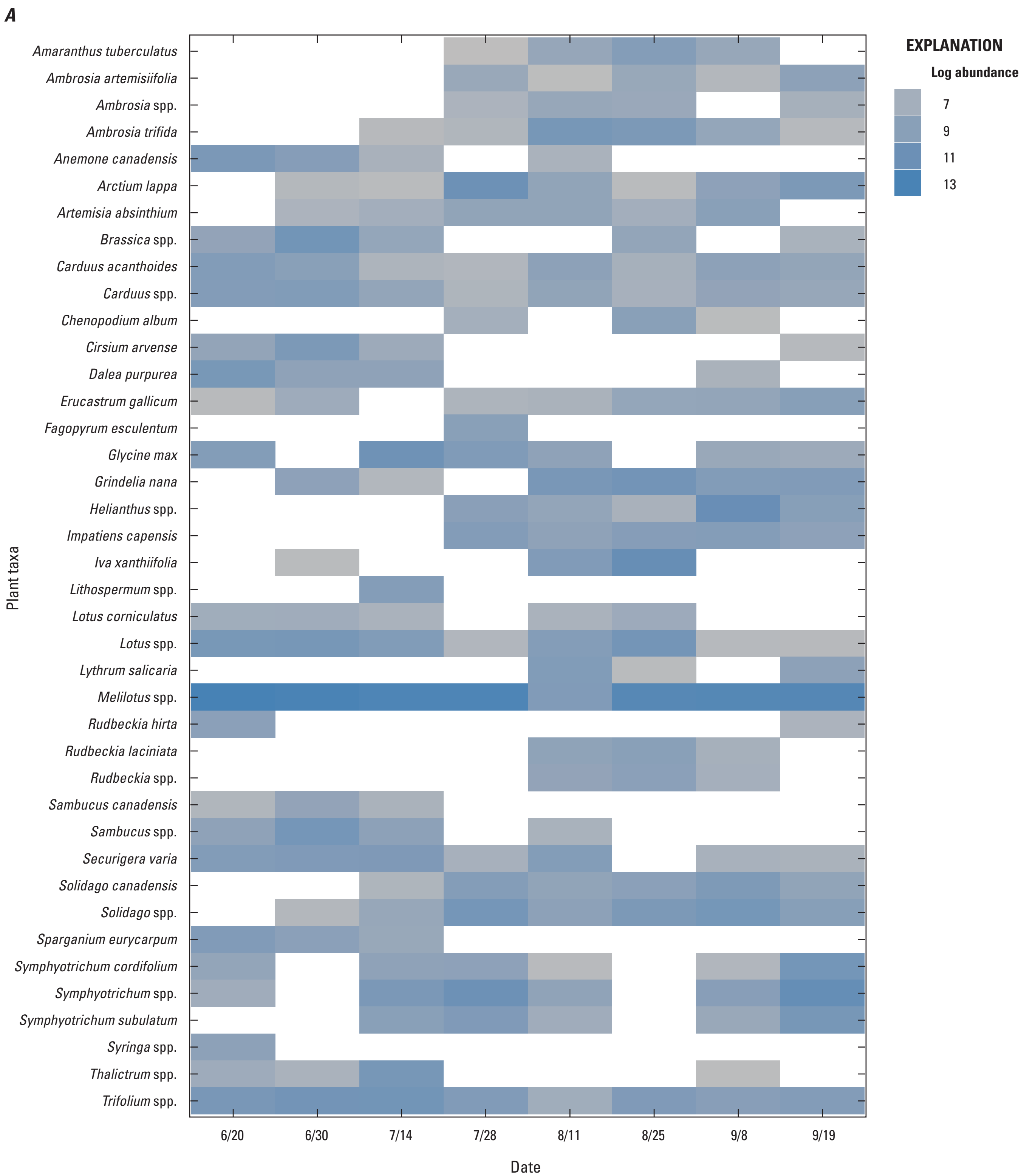

Figure 1.1. Top 40 most commonly detected plant genera and species (logarithmic summation of operational taxonomic units) across all dates for pollen samples collected in 2016. *A*, South Dakota. *B*, Minnesota.

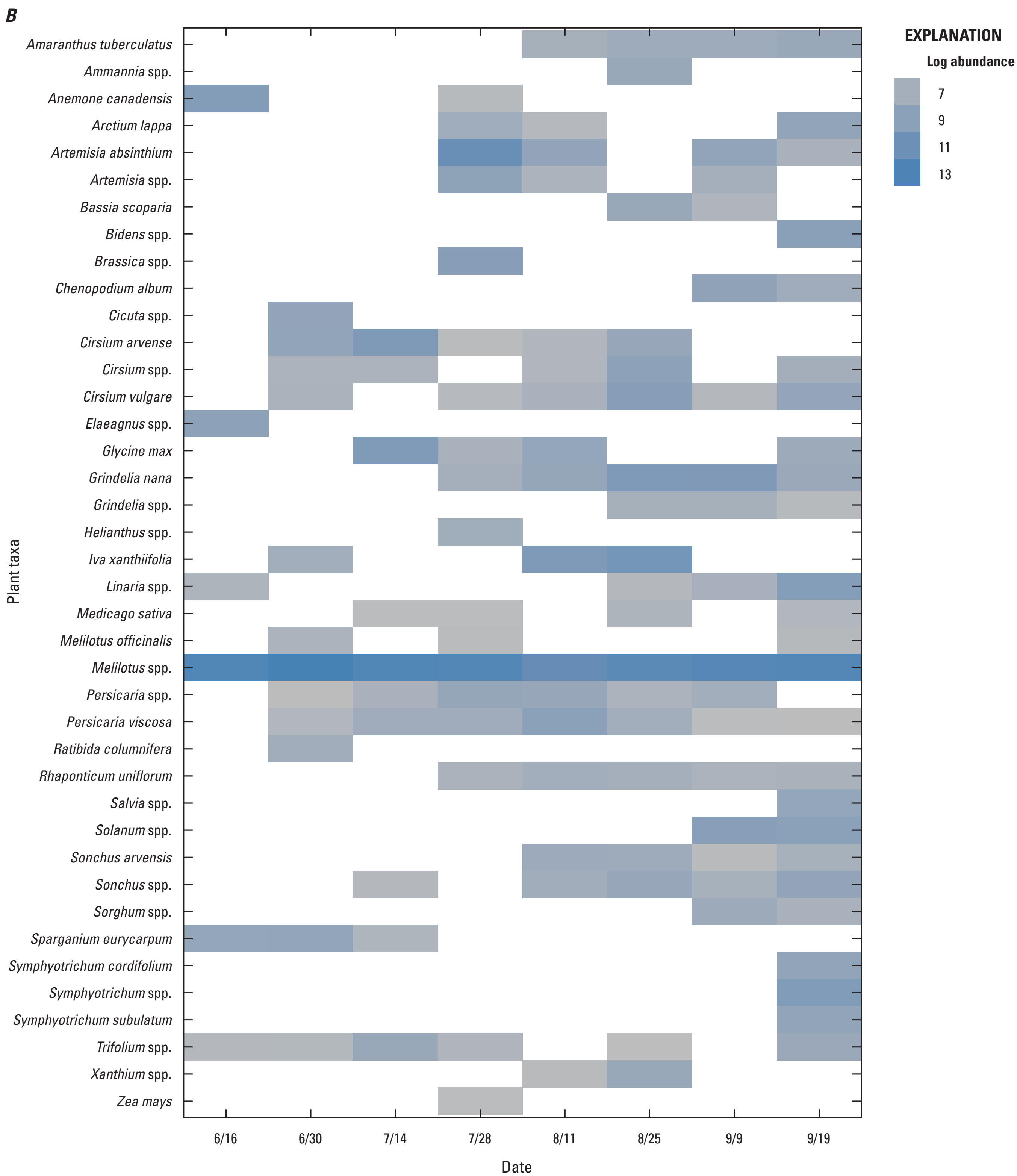

Figure 1.1. Top 40 most commonly detected plant genera and species (logarithmic summation of operational taxonomic units) across all dates for pollen samples collected in 2016. *A*, South Dakota. *B*, Minnesota.—Continued

Table 1.2. Scientific and common names of plant taxa.

Scientific name	Common name
Abutilon theophrasti	Velvet leaf
Achillea millefolium	Common yarrow
Agastache foeniculum	Blue giant hyssop
Agastache scrophulariifolia	Purple giant hyssop
Ageratina altissima	White snakeroot
Agoseris glauca	Pale agoseris
Agrimonia spp.	American water plantain
Alisma subcordatum	Small water plantain
Allium spp.	Onion
Allium stellatum	Prairie onion
Amaranthus retroflexus	Redroot pigweed
Amaranthus spp.	Amaranth
Ambrosia artemisiifolia	Common ragweed
Ambrosia psilostachya	Ragweed
Ambrosia spp.	Ragweed
Amorpha canescens	Leadplant
Amorpha fruticosa	Indigobush
Anemone canadensis	Canada anemone
Anemone cylindrica	Thimbleweed
Anemone virginiana	Tall thimbleweed
Apocynum cannabinum	Indian hemp
Apocynum spp.	Dogbane
Arabis hirsuta	Creamflower rockcress
Arabidopsis lyrata ssp. *lyrata*	Lyrate rockcress
Arctium minus	Common burdock
Arctium spp.	Burdock
Potentilla anserina ssp. *anserine*	Silverweed cinquefoil
Artemisia absinthium	Absinthe wormwood
Artemisia biennis	Biennial wormwood
Artemisia campestris	Field sagewort
Artemisia dracunculus	Tarragon
Artemisia frigida	Prairie sagewort
Artemisia ludoviciana	Cudweed sagewort
Asclepias incarnata	Swamp milkweed
Asclepias ovalifolia	Oval-leaf milkweed
Asclepias speciosa	Showy milkweed
Asclepias spp.	Milkweed
Asclepias syriaca	Common milkweed
Asclepias tuberosa	Butterflyweed
Asclepias verticillata	Whorled milkweed
Astragalus agrestis	Purple milkvetch
Astragalus canadensis	Canada milkvetch
Astragalus cicer	Chickpea milkvetch
Astragalus crassicarpus	Groundplum milkvetch

Table 1.2. Scientific and common names of plant taxa.—Continued

Scientific name	Common name
Astragalus flexuosus	Slender milkvetch
Astragalus spp.	Vetch
Atriplex patula	Spear saltbush
Kochia scoparia ssp. scoparia	Kochia
Berteroa incana	Hoary alyssum
Brassica juncea	Indian mustard
Brassica rapa	Field mustard
Brassica spp.	Mustard
Brickellia eupatorioides	False boneset
Oenothera serrulata	Yellow evening primrose
Calystegia sepium	Hedge bindweed
Calystegia spithamaea	Low false bindweed
Campanula rotundifolia	Harebell
Campanula americana	American bellflower
Cannabis sativa	Marijuana
Capsella bursa-pastoris	Shepherd's purse
Carduus nutans	Nodding thistle
Cerastium arvense	Field chickweed
Chamaecrista fasciculata	Partridge pea
Chenopodium album	Lamb's quarters
Chenopodium spp.	Goosefoot
Cicuta maculata	Water hemlock
Cirsium altissimum	Canada thistle
Cirsium arvense	Canada thistle
Cirsium discolor	Pasture thistle
Cirsium flodmanii	Flodman's thistle
Cirsium spp.	Thistle
Cirsium undulatum	Wavyleaf thistle
Cirsium vulgare	Bull thistle
Peritoma serrulata	Rocky mountain bee plant
Comandra umbellata	Bastard toadflax
Convolvulus arvensis	Field bindweed
Convolvulus spp.	Bindweed
Conyza canadensis	Canada fleabane
Coreopsis grandiflora	Large flowered coreopsis
Coreopsis lanceolata	Lanceleaved coreopsis
Coreopsis tinctoria	Plains coreopsis
Cornus amomum	Silky dogwood
Cornus racemosa	Northern swamp dogwood
Cornus sericea	Red-osier dogwood
Dalea candida	White prairie clover
Dalea purpurea	Purple prairie clover
Delphinium carolinianum	Carolina larkspur
Descurainia sophia	Flixweed

Table 1.2. Scientific and common names of plant taxa.—Continued

Scientific name	Common name
Descurainia spp.	Mustard
Desmanthus illinoensis	Illinois bundleflower
Desmodium canadense	Canada tickclover
Desmodium spp.	Tick-trefoil
Diodella teres	Buttonweed
Rudbeckia amplexicaulis	Clasping coneflower
Echinacea angustifolia	Narrow-leaved purple coneflower
Echinacea purpurea	Narrow-leaved purple coneflower
Echinacea spp.	Coneflower
Echinocystis lobata	Wild cucumber
Epilobium leptophyllum	Bog willowherb
Epilobium spp.	Willow herb
Erigeron annuus	Daisy fleabane
Erigeron philadelphicus	Common fleabane
Erigeron spp.	Fleabane
Erigeron strigosus	White milkwort
Erucastrum gallicum	Dog mustard
Erysimum cheiranthoides	Wormseed wallflower
Erysimum inconspicuum	Small-flowered wallflower
Eupatorium spp.	Boneset
Euphorbia esula	Leafy spurge
Euphorbia glyptosperma	Ridge-seed spurge
Euphorbia maculata	Spotted spurge
Euthamia graminifolia	Grass-leaved goldenrod
Fagopyrum esculentum	Buckwheat
Fragaria virginiana	Wild strawberry
Fumaria vaillantii	Earth smoke
Gaillardia aristata	Blanket flower
Gaillardia pulchella	Indian blanket
Galium boreale	Northern bedstraw
Gentiana puberulenta	Downy gentian
Geum aleppicum	Yellow avens
Geum canadense	White avens
Geum triflorum	Prairie smoke
Glycyrrhiza lepidota	Licorice
Grindelia squarrosa	Curlycup gumweed
Gutierrezia sarothrae	Broom snakeweed
Hackelia spp.	Stickseed
Hackelia virginiana	Virginia stickseed
Hedeoma hispida	Rough false pennyroyal
Helenium autumnale	Sneezeweed
Helenium spp.	Sneezeweed
Helianthemum spp.	Frostweed
Helianthus annuus	Common sunflower

Table 1.2. Scientific and common names of plant taxa.—Continued

Scientific name	Common name
Helianthus grosseserratus	Stiff sunflower
Helianthus maximiliani	Maximilian sunflower
Helianthus nuttallii	Nuttall's sunflower
Helianthus pauciflorus	Stiff sunflower
Helianthus petiolaris	Prairie sunflower
Helianthus spp.	Common sunflower
Heliopsis helianthoides	Oxeye
Heracleum sphondylium ssp. *montanum*	Common cow parsnip
Hesperis matronalis	Dame's rocket
Heterotheca spp.	False goldenaster
Heterotheca villosa	Hairy goldenaster
Hibiscus trionum	Flower of an hour
Hieracium spp.	Hawkweed
Hypochaeris radicata	False dandelion
Hypoxis hirsuta	Yellow stargrass
Ipomoea pandurata	Wild potato vine
Lactuca canadensis	Canada lettuce
Lactuca serriola	Prickly lettuce
Lactuca spp.	Lettuce
Mulgedium oblongifolium	Blue lettuce
Lappula squarrosa	European stickseed
Lathyrus spp.	Wild pea
Lathyrus venosus	Veiny pea
Lathyrus vernus	Spring vetch
Leonurus cardiaca	Motherwort
Lepidium densiflorum	Common peppergrass
Leucanthemum vulgare	Oxeye daisy
Liatris aspera	Rough blazingstar
Liatris punctata	Gayfeather
Liatris pycnostachya	Prairie blazingstar
Liatris spp.	Blazing star
Lilium philadelphicum	Wood lily
Linaria vulgaris	Butter and eggs
Linum lewisii	Blue flax
Linum rigidum	Stiffstem flax
Linum sulcatum	Grooved flax
Lithospermum canescens	Hoary puccoon
Lobelia siphilitica	Great blue lobelia
Lobelia spicata	Pale-spike lobelia
Lotus corniculatus	Bird's-foot trefoil
Acmispon americanus var. *americanus*	American birdsfoot trefoil
Lycopus americanus	American bugleweed
Lycopus asper	Rough bugleweed
Lygodesmia juncea	Rush skeletonplant

Table 1.2. Scientific and common names of plant taxa.—Continued

Scientific name	Common name
Malva neglecta	Common mallow
Matricaria discoidea	Pineappleweed
Medicago lupulina	Black medick
Medicago sativa	Alfalfa
Melilotus albus	White sweet clover
Melilotus officinalis	Yellow sweet clover
Mentha arvensis	Field mint
Mirabilis nyctaginea	Wild four o'clock
Monarda fistulosa	Bee balm
Myosoton aquaticum	Giant chickweed
Nepeta cataria	Catnip
None	None
Oenothera biennis	Evening primrose
Oenothera suffrutescens	Scarlet gaura
Solidago ptarmicoides	Prairie goldenrod
Solidago rigida	Stiff goldenrod
Onobrychis viciifolia	Common sainfoin
Onosmodium bejariense	False gromwell
Oxalis corniculata	Creeping woodsorrel
Oxalis spp.	Sorrel
Oxalis stricta	Yellow wood sorrel
Oxytropis lambertii	Purple locoweed
Packera plattensis	Prairie ragwort
Pediomelum argophyllum	Silverleaf scurfpea
Pediomelum esculentum	Breadroot scurfpea
Penstemon gracilis	Slender beardtongue
Persicaria spp.	Knotweed
Phacelia tanacetifolia	Lacy phacelia
Phlox pilosa	Downy phlox
Phlox spp.	Phlox
Physalis heterophylla	Clammy ground cherry
Physalis spp.	Ground cherry
Physalis longifolia var. *subglabrata*	Longleaf ground cherry
Physalis virginiana	Virginia groundcherry
Plantago major	Common plantain
Polygala alba	White milkwort
Polygala spp.	Milkwort
Polygala verticillata	Whorled milkwort
Persicaria amphibia	Water smartweed
Polygonum aviculare ssp. *depressum*	Common knotweed
Fallopia convolvulus	Wild buckwheat
Persicaria hydropiperoides	Water smartweed
Persicaria pensylvanica	Pennsylvania smartweed
Fallopia scandens	Climbing false buckwheat

Table 1.2. Scientific and common names of plant taxa.—Continued

Scientific name	Common name
Polygonum spp.	Knotweed
Portulaca oleracea	Common purslane
Potentilla anserina	Silverweed cinquefoil
Drymocallis arguta	Rough cinquefoil
Potentilla norvegica	Rough cinquefoil
Potentilla supina ssp. *paradoxa*	Bushy cinquefoil
Potentilla pensylvanica	Pennsylvania cinquefoil
Potentilla spp.	Rough cinquefoil
Pulicaria dysenterica	Common fleabane
Ranunculus cymbalaria	Seaside crowfoot
Ranunculus hispidus	Bristly buttercup
Ranunculus spp.	Buttercup
Raphanus sativus	White radish
Ratibida columnifera	Mexican hat
Ratibida pinnata	Grayheaded coneflower
Rorippa palustris	Bog yellowcress
Rosa arkansana	Prairie rose
Rudbeckia hirta	Blackeyed susan
Rumex crispus	Curly dock
Securigera varia	Crown vetch
Senecio integerrimus	Lambstongue ragwort
Senecio spp.	Ragwort
Silene antirrhina	Sleepy catchfly
Silene csereii	Balkan catchfly
Silene vulgaris	White campion
Silene spp.	Unknown silene
Silphium integrifolium	Cup plant
Silphium perfoliatum	Cup plant
Sinapis arvensis	Charlock
Sisymbrium altissimum	Tumble mustard
Sisyrinchium montanum	Blue-eyed grass
Sium suave	Water parsnip
Solanum nigrum	Black nightshade
Solanum ptychanthum	Eastern black nightshade
Solanum rostratum	Buffalo bur
Solanum spp.	White vine
Solidago canadensis	Canada goldenrod
Solidago missouriensis	Missouri goldenrod
Solidago mollis	Velvety goldenrod
Solidago nemoralis	Gray goldenrod
Solidago rigida	Stiff goldenrod
Solidago spp.	Goldenrod
Sonchus arvensis	Field sow thistle
Sonchus asper	Spiny sow thistle

Table 1.2. Scientific and common names of plant taxa.—Continued

Scientific name	Common name
Sonchus oleraceus	Common sowthistle
Sphaeralcea coccinea	Scarlet globemallow
Stachys palustris	Marsh hedgenettle
Stachys pilosa	Hairy hedgenettle
Stachys spp.	Hedgenettle
Symphoricarpos occidentalis	Western snowberry
Symphyotrichum ericoides	Heath aster
Symphyotrichum falcatum	White prairie aster
Symphyotrichum laeve	Smooth blue aster
Symphyotrichum lanceolatum	Panicled aster
Symphyotrichum novae-angliae	New england aster
Symphyotrichum ontarionis	Ontario aster
Symphyotrichum pilosum	Awl's aster
Symphyotrichum puniceum	Purple-stemmed aster
Symphyotrichum sericeum	Silky aster
Symphyotrichum spp.	Aster
Taraxacum officinale	Common dandelion
Taraxacum spp.	Dandelion
Teucrium canadense	American germander
Thalictrum dioicum	Early meadow-rue
Thalictrum spp.	Thalictrum
Thaspium trifoliatum	Meadow parsnip
Thlaspi arvense	Field pennycress
Toxicodendron radicans	Poison ivy
Tradescantia bracteata	Bracted spiderwort
Tragopogon dubius	Goat's beard
Trifolium campestre	Dutch white clover
Trifolium dubium	Suckling clover
Trifolium hybridum	Alsike clover
Trifolium incarnatum	Crimson clover
Trifolium pratense	Red clover
Trifolium repens	Dutch white clover
Trifolium spp.	Clover
Turritis glabra	Tower mustard
Urtica dioica	Stinging nettle
Verbascum thapsus	Common mullein
Verbena bracteata	Bracted vervain
Verbena hastata	Blue vervain
Verbena stricta	Hoary vervain
Verbena urticifolia	White vervain
Vernonia fasciculata	Prairie ironweed
Vicia americana	Purple vetch
Vicia cracca	Cow vetch
Vicia sativa	Common vetch

Table 1.2. Scientific and common names of plant taxa.—Continued

Scientific name	Common name
Vicia spp.	Vetch
Vicia tetrasperma	Slender vetch
Vigna unguiculata	Cow pea
Viola nuttallii	Nuttall's violet
Viola pubescens	Wood violet
Viola spp.	Unknown viola
Xanthisma spinulosum	Lacy phacelia
Anticlea elegans var. *elegans*	Mountain death camas
Toxicoscordion venenosum var. *venenosum*	Meadow death camas
Zizia aptera	Heart-leaved alexanders
Zizia aurea	Golden alexanders

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