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HNF-62689
Revision 0

Hanford Site Pollinator Study

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-09RL14728

P.O. Box 650
Richland, Washington 99352

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Date Published
September 2018

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

P.O. Box 550
Richland, Washington 99352

APPROVED
By Mary P. Curry at 11:11 am, Oct 22, 2018

Release Approval Date

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1.0 Introduction

1.1 Purpose and Need

Pollinators (animals that facilitate plant reproduction by moving pollen from flower to flower) are vital to the health of the world's ecosystems (Potts et al. 2010). Insects are the most common type of pollinator throughout the majority of the world. The mutualistic relationship of plants and pollinating insects has evolved on every continent from Antarctica to Australia (Kevan 1972, Potts et al. 2010). By enabling successful plant reproduction, pollinating insects support the health of nearly all other organisms in the environment that rely on healthy plant populations for food and shelter. Of the insect pollinators, bees are the most important group of pollinators worldwide (Kearns et al. 1998, Michener 2007). Within the last century, rapid declines in both wild and managed bee populations have been recorded throughout the world (Kearns et al. 1998, Goulson et al. 2005, Biesmeijer et al. 2006).

Bee declines are believed to be caused by a combination of stressors including habitat loss, pesticide use, and disease (Cane and Tepedino 2001, Furst et al. 2014). Habitat loss and fragmentation are major causes of bee population declines, especially for wild bees as they rely on flowering plants for forage and nesting (Potts et al. 2010, Winfree et al. 2009). Wild bees can have maximum foraging ranges as small as 150 m, making local habitat structure especially important (Gathmann and Tscharntke 2002). When humans remove native vegetation from the environment they are removing valuable bee food and nesting resources and are contributing to habitat loss and fragmentation, which negatively affects bee populations (Biesmeijer et al. 2006).

The greatest abundance of wild bees is suspected to be in semi-desert, arid environments, especially within western North America (Linsley 1958, Koh et al. 2016). This habitat classification matches the environment of the Hanford Site and surrounding Columbia River Basin, suggesting the Hanford Site may have abundant wild bee populations. Native bees are the primary insect pollinators of the Columbia River Basin (Tepedino and Griswold 1995). Although butterflies and moths play a role in pollination in the Columbia River Basin, they are much less efficient at transferring pollen and tend to visit flowering species only for nectar (Tepedino and Griswold 1995). Many species of native bees, honey bees, bumble bees, and butterflies have been documented on the Hanford Site (see Zack 1997); however, pollination-specific studies focusing on Hanford Site insects are uncommon. Over 600 species of bee are known to occur in this region, with the actual number believed to be much higher due to under sampling (Tepedino and Griswold 1995; Niwa et al. 2001). Arid lands of western North America have high proportions of specialized bees that are typically restricted to small geographic areas, making the Hanford Site and the surrounding region especially vulnerable to species loss when habitats are removed (Tepedino 1979).

The Hanford Site consists of 1,505 km^2 of land and is one of the last remaining stretches of shrub-steppe in eastern Washington that has not been converted to agriculture or developed. The major ecological systems within the Hanford Site are Inter-Mountain Basins Active and Stabilized Dune, Inter-Mountain Basins Big Sagebrush Steppe, and Inter-Mountain Basins Semi-Desert Shrub-Steppe (Easterly et al. 2017). These three ecological systems provide unique floral and habitat resources to bees and other pollinators. The presence of natural habitat among a sea of agriculture and suburban areas may provide a valuable refuge to wild bees; however, due to a lack of studies investigating the abundance and diversity of bees at the Hanford Site, these bees and their habitat cannot be properly managed or protected.

Currently, habitat preservation is the best known way to slow the rate of bee population declines (Grixti et al. 2009, Kearns et al. 1998, Tepedino 1979). When habitat is lost on the Hanford Site, bees and other pollinators lose valuable habitat and population declines are accelerated. In areas where habitat has already been lost, revegetation efforts need to focus on reestablishing the native plant communities that best support bees.

Bee habitat on the Hanford Site must be identified before it can be protected. Areas containing relatively high numbers of bees or other insect pollinators must also be identified. Little research currently exists investigating which habitat types within the shrub-steppe best support pollinator populations. When habitat protection is not an option, bee populations can be supported by mitigating for habitat loss through revegetation. In order to mitigate for pollinator habitat that has been removed, revegetation projects should include flowering plants that provide nutrition and habitat for bees. The flowering plant communities that support local bee species must be identified in order to properly mitigate for bee habitat loss.

The purpose of this study is to collect data on Hanford Site pollinators and to identify which plant communities attract a high abundance and diversity of bees. The plant species within these communities will be considered for use in revegetation projects aimed at creating bee habitat. This study will also be used to collect data on Hanford Site-specific bloom times for flowering plants. Plant communities with a variety of plants that bloom in different seasons are essential to supporting bee health throughout the spring, summer, and fall when bees are active. The bloom times will be used to develop a recommended mix of plants that bloom throughout multiple seasons.

After these data are collected, the plants that best support pollinator populations will be recommended for use in revegetation projects and added to the *Hanford Site Revegetation Manual* (HSRM, DOE/RL-2011-116). A long-term goal of this effort is to increase pollinator habitats on the Hanford Site. These data can also be used to identify habitats that support relatively large populations of bees and pollinating insects, and to better protect these areas from habitat loss.

1.2 Regulatory Drivers

The U.S. Department of Energy, Richland Operations Office (DOE-RL) conducts ecological monitoring on the Hanford Site to collect and track data needed to ensure DOE-RL compliance with an array of laws and policies. Ecological monitoring data provide baseline information about the plants, animals, and habitats under DOE-RL stewardship required for decision making under the *National Environmental Policy Act* and *Comprehensive Environmental Response, Compensation, and Liability Act*.

DOE-RL's *Environmental Assessment for Proposed Conveyance of Land at the Hanford Site, Richland, Washington* (DOE/EA-1915) resulted in a Finding of No Significant Impact (FONSI). Mitigation measures associated with this conveyance of land include conducting a pollinator habitat study for the Hanford Site: "focusing on identifying pollinator species and the plants and habitats they require for their life cycle. The study shall provide data and recommendations needed to carry out habitat enhancement, proper management, and collaboration with other agencies and institutions to ensure this valuable resource is protected" (DOE/EA-1915). This study meets those guidelines by identifying the main pollinators on the Hanford Site and identifying the plant communities that pollinators rely on throughout their life cycles. This study provides the data required to recommend pollinator-supporting plants to be used in habitat enhancement and identifies areas with high abundances and diversity of bees for future management. Other agencies collaborated with include Washington State Department of Fish and Wildlife and multiple branches of the Washington State University Department of Entomology.

1.2.1 Federal Laws and Regulations

1.2.1.1 Presidential Guidance and Memoranda. The 2014 presidential memorandum "Creating a Federal Strategy to Promote the Health of Honey Bees and Other Pollinators" calls for immediate action to be taken by land-owning federal departments to prevent further pollinator population decline (79 FR 35903-35907). This memorandum called for the establishment of a Pollinator Health Task Force that includes representatives from over 15 federal agencies including the U.S. Department of Energy. This task force developed the *Pollinator Research Action Plan* (Pollinator Health Task Force 2015a) that outlines key priorities and goals to improve pollinator health. One of the goals of this plan is to restore or enhance 2.8 million ha (7 million ac) of pollinator habitat on federally-owned land (Pollinator Health Task Force 2015b).

Two sections of the *Pollinator Research Action Plan* (Pollinator Health Task Force 2015a), Section II and Section VII, are especially relevant to future revegetation work on the Hanford Site. *Section II: Habitat (Including Stressors)* addresses the need for increased and improved pollinator habitat. Current understanding of pollinator habitat requirements is limited. A key priority research theme of this section is "identifying viable approaches to restore and create pollinator habitat." Determining the native plant communities that best support pollinators works toward the goal of restoring and creating pollinator habitats. *Section VII: Native Plant Development and Deployment* describes the necessity of native plant use in habitat restoration projects. Identifying the native plant species that provide support for the most pollinators is key for developing regional native seed mixes that are adapted to the climate and will attract native pollinators. Another key priority research theme of this section is identifying local and regional native plant species mixtures that will provide nutrition to pollinators throughout all seasons when they are active.

1.2.2 U.S. Department of Energy Orders and Guidance Documents

The Department of Energy (DOE) Pollinator Protection Plan (Pollinator Health Task Force 2015b, Appendix E) directs the adoption of Best Management Practices (BMPs) for pollinator health. The U.S. Department of Energy is a land-owning agency and will assess each site to determine if implementing the BMPs is appropriate. As per the plan, the commitment to enhance, preserve, and protect pollinator habitat according to BMPs is consistent with Section 3, Subsection (a) of 79 FR 35903-35907, which calls for

> "the development of a plan to enhance pollinator habitat and the implementation of a plan to manage lands and facilities under the auspices of the Department to enhance pollinator health on those lands."

1.2.3 Hanford Site Management Guidance

The DOE/RL-96-32, *Hanford Site Biological Resources Management Plan*, (BRMP) is identified by the *Hanford Comprehensive Land-Use Plan* (DOE/EIS-0222-SA-01) as the primary implementation control for managing and protecting natural resources on the Hanford Site. According to the *Hanford Comprehensive Land-Use Plan* (DOE/EIS-0222-SA-01), the BRMP

> *provides a mechanism for ensuring compliance with laws protecting biological resources; provides a framework for ensuring that appropriate biological resource goals, objectives, and tools are in place to make DOE an effective steward of the Hanford biological resources; and implements an ecosystem management approach for biological resources on the Site. The BRMP provides a comprehensive direction that specifies DOE biological resource policies, goals, and objectives.*

DOE-RL places priority on monitoring those plant and animal species or habitats with specific regulatory protections or requirements; that are rare and/or declining (e.g., federal or state listed endangered, threatened, or sensitive species); or are of significant interest to federal, state, or Tribal governments or the public. The BRMP ranks wildlife species and habitats (Levels 0-5), providing a graded approach to monitoring biological resources based on the level of concern for each resource. The data collected as part of this study may be used as guidance in developing future resource levels.

1.3 Goals and Objectives

The specific objectives of this study are to:

- Investigate the abundance and diversity of bees in different plant communities
- Collect information on pollinator abundance and diversity through different seasons
- Collect information on Hanford Site-specific bloom times of flowering plants.

In addition to this report, another product of this effort will be a list of pollinator-friendly plants recommended for use in Hanford Site revegetation projects, which will be included in an update of the HSRM (DOE/RL-2011-116).

1.4 Scope of Report

The remaining sections of this report cover the following topics:

- **Section 2** provides background information about the biology and ecology of bees, and discusses the basic attributes of each family of bee found over the course of this study.

- **Section 3** summarizes the methods used in this study and provides descriptions of the eight study sites.

- **Section 4** presents the results of the pollinator study effort, including an overview of the results for the entire Hanford Site and a detailed breakdown of the results at each study site.

- **Section 5** discusses the results and their overall implications for pollinator-focused revegetation efforts and pollinator management.

- **Section 6** describes future monitoring to expand on the results of this study and to monitor the effectiveness of pollinator-focused revegetation efforts.

- **Section 7** lists the literature cited throughout the report.

2.0 Biology and Ecology of Insect Pollinators

The main focus of this report is insect pollinators belonging to the order Hymenoptera, the insect order containing bees. Monitoring focused on this group of pollinators due to their perceived declines, abundance on site, and pollinating effectiveness. Insects of order Lepidoptera, butterflies and moths, were also collected and considered while making plant recommendations but were not the main focus of this study.

2.1 General Description of Biology and Ecology

Over 200,000 species of insects and other animals provide pollination services to plants (National Research Council 2007). Order Hymeroptera contains the majority of the insect pollinators as it encompasses wasps, ants, bees, and sawflies. Bees, or insects within clade Anthophila, are the main pollinators of most ecosystems. Bees have evolved with the surrounding plant communities and maintain both the diversity and function of ecosystems (Potts et al. 2003). In the United States alone it is estimated there are over 4,000 species of bees, many of them not yet known to science (Moisset and Buchmann 2011). Large, important groups of bees native to the United States include leaf-cutter bees (*Megachilidae* sp.), mason bees (*Osmia* sp.), bumble bees (*Bombus* sp.), sweat bees (*Halictidae* sp.), miner bees (*Andrena* sp.), and carpenter bees (*Xylocopa* sp.) (Linsley 1958). Honey bees (*Apis mellifera*), although heavily studied and utilized for agriculture, are an introduced species from Europe. Despite this, they are generalist pollinators and provide pollination services to a wide range of native plants.

2.1.1 Life History

The thousands of different bee species exhibit tremendous variation in sociality, foraging patterns, nesting, and habitat use (Linsley 1958). The majority of solitary bees spend the winter months in nests as pupae and emerge in the spring as adults. Bees are generally active from early spring to fall, the same seasons flowers are in bloom. The majority of solitary bees reach the end of their lifecycle by the winter months, when food sources are scarce to nonexistent. Bees that are colony nesters, like honey bees and bumble bees, are active at the same time as solitary bees.

Bees derive the majority of their nutrition and energy from the pollen and nectar of flowering plants (Michener 2007). Some bees are specialists that forage on only certain species or closely related groups of plants, while other bees are generalists and forage on a wide variety of plants. Different species of flowers produce pollen with varying levels of nutrients; variation in diet is important in maintaining the health of many bees.

2.1.2 Habitat Preferences

The majority of bees nest in the ground, with different bee species preferring to nest in various soil types. Some bees nest in plant stems, debris, and rocks. Many solitary bees live in arid, desert-like areas. If they are ground nesters, they require some amount of bare soil, which is common in healthy arid regions. Bees also require suitable forage and a water source within their flight range around the nest. Bees can collect water that has gathered on flowers or from puddles. The ranges of bees are highly variable and it is thought that range generally increases with body size (Gathmann and Tscharntke 2002). Generally, flight ranges for small, solitary species are within a few hundred meters of their nests (Gathmann and Tscharntke 2002). Larger species (e.g., bumble bees) can have flight ranges spanning well over a thousand meters (Zurbuchen et al. 2010).

2.2 Family Descriptions

There are currently seven families of bee that make up the clade Anthophila. Six of these families are found in the United States and five of these six families were found on the Hanford Site over the course of this study. These families have been formed by evolutionary biologists and entomologists based on shared physical and genetic traits, the classifications for these families will likely change as more genetic information is discovered. Brief descriptions of the five families found on the Hanford Site are in the following sections along with a description of the order Lepidoptera. All pictures are of bees collected or observed during this study.

2.2.1 Apidae

The family Apidae is arguably the most easily recognized family of bees in the clade Anthophila. It contains commonly seen bees such as honey bees, bumble bees (*Bombus,* Figure 1), and carpenter bees (*Xylocopa*). The trait that generally distinguishes Apidae bees from others is their larger body size and fluffy hair. The large amount of hair covering their body and pollen collecting hairs on their legs, called scopa, make Apidae bees adept at collecting and transferring pollen. Some species of Apidae bees have long, impressive antennae (*Eucerini*, Figure 2) while others are hulking, furry bees (such as *Anthophorini*). Though commonly known Apidae bees like honey and bumble bees are hive nesters, the majority of Apidae bees nest in the ground. Many parasitic bees, usually easy to distinguish from normal bees by their lack of hair, are also members of this family. Parasitic bees, similar to parasitic wasps, will lay their eggs in the nest of the host bee. Upon hatching the parasite will kill the host’s offspring (Wilson and Carril 2016).

Figure 1. A bumble bee (*Bombus*) in family Apidae.

Figure 2. A long-horned bee (*Eucerini*) in family Apidae.

2.2.2 Halictidae

Small, nearly hairless, and fast-flying bees in the family Halictidae are often confused with ants and other flying insects. Commonly called sweat bees, these small insects are abundant in the Columbia Basin (D. Walsh, personal communication, 19 December 2016). The sociality of halictids varies within and between species, with some species being completely solitary and others flexibly eusocial (Wilson and Carril 2016). Halictids are nearly all ground nesters that create mazes of interconnecting tunnels (Wilson and Carril 2016). This family contains the largest bee genus in the world, *Lasioglossum*, which has around 1800 species (Wilson and Carril 2016). Bees within this family range from large, metallic, bright green bees (*Agapostemon*) to dark, inconspicuous bees that can be as small as an ant (*Lasioglossum*). Though less hairy than most bees, their leg hairs are adapted to collect pollen. These small bees can collect pollen from plants with tiny flowers (e.g., *Cryptantha* and *Phacelia* species) (Figure 3).

Figure 3. A sweat bee (*Lasioglossum*) on threadleaf scorpionweed (*Phacelia linearus*).

2.2.3 Megachilidae

Megachilidae bees are commonly called leaf-cutter bees or mason bees. This family is well known to farmers as it contains alfalfa bees, blueberry bees, and blue orchard bees, all important pollinators of commercial crops. These bees are typically medium to large and have round, sometimes metallic bodies. A distinguishing characteristic of Megachilidae bees is their pollen collecting hairs, which are located below the abdomen rather than on the legs (Figure 4). Bees in the Megachilidae family also have large mandibles, or jaws, that can be serrated and sharp, allowing the bees to cut leaves and move the plant material back to their nests (Figure 5). The nesting habits of Megachilidae bees differs between species but many are cavity nesters who will use tunnel-like objects as nests. These bees will line their nests with plant material to create nest cells that will eventually contain their eggs (Wilson and Carril 2016).

Figure 4. A leaf-cutter bee (*Megachile*) with pollen-collecting hairs on the abdomen.

Figure 5. The serrated mandibles of a blue orchard bee (*Osmia*).

2.2.4 Andrenidae

The Andrenidae family, also known as miner bees, contains 4500 species making it the most diverse bee family. Two genera (*Andrena* and *Perdita*) make up 80% of all Andrenidae species. The genus *Perdita* contains some of the smallest species of bee in the world and are easy to identify due to their small size and distinct yellow markings (Figure 6). Many *Perdita* bees are specialists and rely on flowers such as primrose (*Oenothera* sp.), prickly pear cactus (*Opuntia* sp.), and globemallow (*Sphaeralcea*). *Andrena* bees are medium-sized bees that seem unaffected by cold weather and can be some of the first bees seen in the springtime. *Andrena* bees are harder to distinguish from other genera (Figure 7). The shared characteristic of all Andrenidae bees is two subantennal sutures, or faint lines on their face, that are difficult to see without a microscope. Andrenidae bees nest underground and line their nests with a waterproof secretion to protect the eggs from bacteria and moisture. The sociality of these bees varies among species (Wilson and Carril 2016).

Figure 6. A tiny *Perdita* bee, approximately 5 mm long.

Figure 7. An *Andrena* bee, showing distinctive facial foveae or dense patches of hair parallel to the eyes.

2.2.5 Colletidae

The Colletidae bee family contains a diverse array of bees ranging from the nearly hairless and small yellow-faced *Hylaeus* bees to large, furry *Caupolicana* bees. Bees in this family are referred to as cellophane bees because of a cellophane-like secretion the ground nesting bees use to line their nest cells. This family shares the unique trait of a bi-lobed tongue that is used to distribute the cellophane secretion along their nest cells (Figure 9). This family often has a heart-shaped face and furry bodies (Figure 8). Within the Columbia Basin, common genera from this family are *Colletes* and *Hylaeus*. All Colletidae bees are solitary and do not help other Colletidae bees care for their young; however, some nest in groups called aggregations. Colletidae bees can be pollination specialists and generalists depending on the species (Wilson and Carril 2016).

Figure 8. A cellophane bee (*Colletes*) with a heart-shaped face, another distinguishing characteristic of this genus.

Figure 9. The bi-lobed tongue of *Colletes*, a distinguishing trait used to identify this family.

2.2.6 Order Lepidoptera

Order Lepidoptera contains butterflies and moths, both important pollinators throughout the world. Butterflies and moths both visit flowers for the nectar, not for pollen, and unlike bees do not have pollen collecting hairs. Because of this, they are not as effective at transferring pollen between plants and provide less pollination services. Despite this, the amount of time butterflies and moths spend traveling between different flowers still results in some pollination. Butterflies can be distinguished from moths by their antennae; butterflies have straight antennae that typically end in a club shape, while moths have feathered or saw-edged antennae (Figure 10). Moths are typically active in the evening and at night and can specialize in collecting nectar from flowers that only open in the evening or early morning. Butterflies are typically active during the day, similar to bees, and may pollinate the same flowers (Figure 11).

Figure 10. A sagebrush sheep moth (*Hemileuca hera*) resting on rabbitbrush (*Chrysothamnus viscidiflorus*).

Figure 11. An Acmon blue butterfly (*Plebejus acmon*) foraging on turpentine spring-parsley (*Cymopterus terebinthinus*).

3.0 Methods

The following information is a brief description of the methods used in this study. For a detailed description of the methods, see Appendix A (*Ecological Monitoring Plan: Hanford Site Pollinator Study 2017*).

3.1 Study Sites

In order to meet the goals and objectives of this study, multiple plant communities were sampled across different seasons. The study sites are within four different habitats that are common throughout the Hanford Site in order to maximize the applicability of the data collected to future land management on the Hanford Site. These four habitats are distinguished by the shrub layer within each habitat (or lack thereof), as characterized by the BRMP. The four habitat types investigated are as follows:

- **Steppe/Grassland**. Habitat is dominated by native bunchgrasses with little to no shrubs in the overstory. Bunchgrasses may include needle-and-thread grass (*Hesperostipa comata*), Sandberg's bluegrass (*Poa secunda*), bluebunch wheatgrass (*Pseudoroegneria spicata*), or Indian ricegrass (*Achnatherum hymenoides*). (Abbreviated 'SG' in Figure 12.)

- **Early Colonizing Species**. Shrubs and sub-shrubs present in this habitat are early colonizing species, like green rabbitbrush (*Chrysothamnus viscidiflorus*), grey rabbitbrush (*Ericameria nauseosa*), or snow buckwheat (*Eriogonum niveum*). Other shrub species may be scattered but are not dominant in the area. (Abbreviated 'EC' in Figure 12.)

- **Late Successional, Mixed Shrub**. The habitat is characterized by a mix of shrub species that include a mix of big sagebrush (*Artemisia tridentata*), antelope bitterbrush (*Purshia tridentata*), spiny hopsage (*Grayia spinosa*), and/or scattered occurrences of rabbitbrush. The understory of this habitat is made up of native bunchgrasses and forbs. (Abbreviated 'MS' in Figure 12.)

- **Late Successional, Sagebrush**. The dominant shrub within the habitat is big sagebrush. Other shrub species are scarce or non-existent. The understory of this habitat is made up of native bunchgrasses and forbs. (Abbreviated 'SB' in Figure 12.)

There is a total of eight study sites, two within each of the four habitat types. This was set up to provide some means of duplication, though the paired sites each were unique from one another. The study sites are all within the boundary of the Hanford Site with four near river sites and four inland sites (Figure 12). Each study site is circular, with a 50-m radius spanning from the center point. The area of each study site totals approximately 7,854 m^2. Detailed descriptions of each study site can be found in Section 4.2.

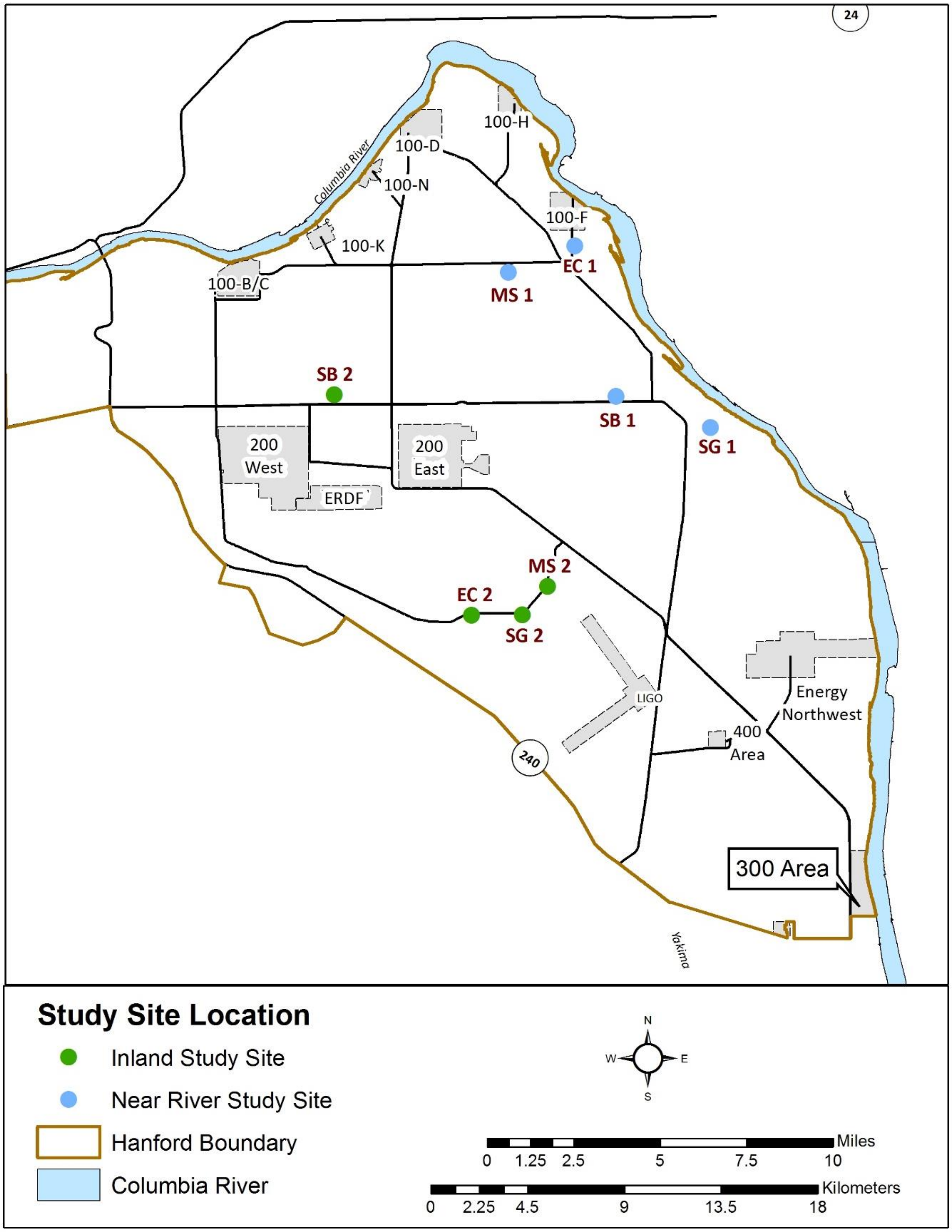

Figure 12. The eight pollinator study site locations on the Hanford Site.

3.2 Study Methods

Each study site had a piece of rebar hammered into the ground at its center, which was kept in place throughout the duration of the study (Figure 13). The rebar supported a pan trap was elevated to the approximate height of surrounding vegetation and used to capture bees and butterflies. Pan traps are slick plastic bowls filled with a diluted soap solution (Figure 14). The bowls are bright white, and pollinators are attracted to them as they would be to a flower (Tuell and Isaacs 2009). After landing in the soapy water, the insects typically drown. The traps allow staff to survey bee abundance without requiring staff to be present on the survey site most of the day as other techniques, like netting, require. Although pan traps may have some biases (Wilson et al. 2008), they can be standardized and compared across sites making them suitable for this study.

Site surveys took place once per week throughout the blooming season, from mid-March to mid-October[1]. This study spanned the vast majority of the season when insect pollinators were active. The surveys were generally performed on the same day every week, unless weather conditions were not ideal for sampling. Weather information, including temperature and cloud cover, was collected at each study site upon trap placement and when the trap was collected. Other daily weather information was provided by the Hanford Site Meteorological Station (HMS 2016).

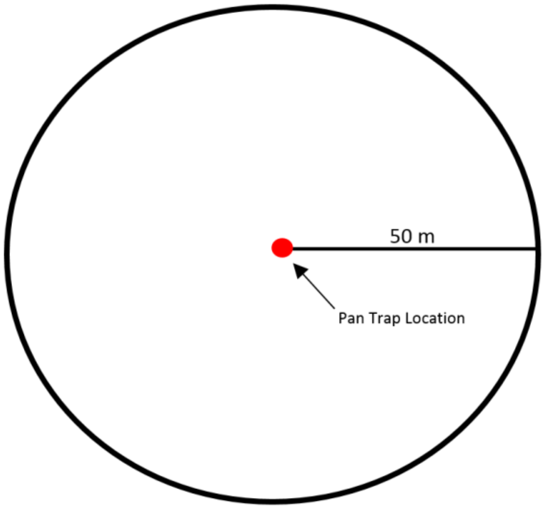

Figure 13: Study site set-up, with rebar and pan trap in center. All area within the circle is part of the study area. This figure is not to scale.

Figure 14: Pan trap at Steppe Grassland Site (SG-2).

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[1] Three pan traps were used per site from the weeks of 3/22/2017 until 4/19/2017. After these five weeks of monitoring it was determined that using three traps resulted in high quantities of bee mortality and that using one trap per site would be sufficient for collecting the data required. Starting the week of 4/25/2017, only one pan trap was used per site. Analysis of the data for this study requires the time periods of 3/22/2017-4/19/2017 and 4/25/2017-10/10/2017 to be analyzed separately in order to account for the change in methods.

Each study site was surveyed independently. Sites were no closer than 1,750 m to each other, in order to prevent overlap of the ranges of most native bee species. Near-river sites were between 1,100 m and 5,000 m from the Columbia River and between 3,500 m and 12,500 m from agricultural areas located across the river. Surveys began after sunrise, generally between 0700 and 0800 hours. Study sites were visited twice during the first survey day and once the following day.

Each week, during the first visit of each site, staff recorded weather information and secured pan traps onto the rebar filling the traps completely with a diluted soap solution. After pan traps had been set out at each site, staff returned to each site to conduct bloom surveys and pollinator observations. Bloom surveys consisted of recording all blooming plant species within the survey area. A 50-m rope was attached to the central rebar stake and stretched to its length so staff could easily identify the boundaries of the study area. Within the boundaries, staff identified all blooming species. For each blooming species, staff estimated the percentage of that species in bloom defined as having at least one flower blooming. This measure was used to estimate bloom times of Hanford Site plants. The month in which each plant species had the greatest proportion of plants in the study area blooming was considered “peak bloom.” In addition to this, staff estimated the coverage of the blooming plants of each species within the study area. This was done by visually estimating the proportion of the ground surface within the study area covered by the blooming individuals of each species. This visual estimation of absolute cover was used to calculate a weekly “bloom coverage” for each site. While recording the number of individuals in bloom, pollinators present on the reproductive structures of plants were recorded on an incidental basis.

The pan traps were set out for approximately 24 hours. On the next survey day, staff visited each site to collect the contents of the pan traps. Upon collection, the traps were emptied and the contents removed with a mesh strainer or spoon. Bees were sorted from the other insects and collected; butterflies were tallied then disposed of with the other insects. All bees were checked for radiological contamination with no contamination found. Bees were kept separated according to date and survey site and stored in a plastic bag in a freezer. After collection, bees were identified to the tribe or genus level.

The weather information, bloom survey data, bee observations, and bee collection data were all compiled weekly for each site. This information was analyzed for trends using a variety of statistical techniques, the results of which are presented in Section 4.0.

4.0 Results

The following section presents the results of the 2017 Hanford Site Pollinator Study. Section 4.1 details the results found across all study sites, including information on pollinator abundance and diversity throughout the study. Sections 4.2 breaks the results down by individual study site and other variables.

In all statistical reporting, a 95% confidence interval was used to determine significance. In the statistical analysis of this data, parametric tests, including correlation tests that assume a parametric distribution, were not used as the data are non-parametric. The Anderson Darling normality tests suggested the distribution of the data was not normal. Kendall's Tau Test of Independence was used to determine correlation. Mann-Whitney U tests and Kruskal-Wallis tests with subsequent Dunn testing and Bonferroni correction were used to compare variables across study sites. Chi-squared testing was not used in relationship testing between grouped sites and in the cumulative site analysis due to the expected value tests assumption that pollinator presence would be equal and uniform throughout all sites. This would be an inadequate assumption provided that all sites contained unique plant communities and features that either were or were not preferential to bees.

4.1 Sitewide Results

Between April 25, 2017,[2] and October 10, 2017, 1,902 bees and 139 butterflies and moths were collected from pan traps and identified to the tribe or genus level. In addition to this, 157 bees and 26 butterflies and moths were observed foraging on plants within the study sites.

Five of the six North American families of bee were represented in our study sample (Table 1). The bee family not represented is Melittidae, which was also not found in the 1997 entomological survey of Hanford (Zack 1997). Of the 1,902 bees collected, 1,374 were in family Halictidae, representing about 72% of all bees collected. Within the five families of bee, 25 unique morphological groups (both Tribes and Genera) were identified[3]. Table 2 lists these groups, combining some identified genera into their tribe when not all members of the tribe could be identified to the genus level. A single genus within the family Halictidae, *Lasioglossum*, accounted for 1,068 of the total sample, representing over 56% of the total bees collected.

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[2] Data collected from 3/23/2017 through 4/19/2017 are not included in Section 4.0 as three pan traps were used to collect insects and this data would need to be analyzed separately.

[3] One bee from the genus *Panurgini*, of family Andrenidae, was identified from the 4/4/2017 survey, bringing the total to 26 unique morphological groups. This genus is not included in analysis as it was found before the change in methods on 4/25/2017.

Table 1. Families of bee collected over the course of the study.

Family	**Total Bees Collected**
Andrenidae	96
Apidae	156
Colletidae	3
Halictidae	1374
Megachilidae	273
Total Bees	**1902**

Table 2. Groups of bees collected over the course of the study.

Family	**Tribe/Genus**	**Total Bees Collected**
Andrenidae	Andrena	9
	Perdita	87
Apidae	Triepeolus	1
	Melecta	1
	Nomada	2
	Apis	3
	Bombus	8
	Anthophorini[a]	18
	Diadasia	54
	Eucerini[b]	69
Colletidae	Colletes	3
Halictidae	Halictus	25
	Agapostemon	281
	Lasioglossum	1068
Megachilidae	Lithurgopsis	1
	Osmiini[c]	13
	Anthidiini[d]	65
	Megachile	194

[a] Hapropoda, Anthophora
[b] Melissodes, Eucera
[c] Osmia, Unknown Osmiini
[d] Dianthidium, Paranthidium, Anthidium, Unknown Anthidiini

4.1.1 Seasonality of Pollinators

Twenty-three weekly site surveys occurred between 4/25/2017 and 10/10/2017. The number of bees and butterflies collected varied tremendously throughout the study period (Table 3). The total number of pollinators collected in a single survey peaked on 6/13/2017, at 279 pollinators. The number of butterflies and moths collected peaked on 5/2/2017, at 46, well above the weekly mean of 6 Lepidopterans. The total number of bees collected peaked on 6/13/2017, at 272 bees, compared to the mean of 82 Hymenopterans collected per week. June had the highest number of bees collected, and May had the highest number of butterflies and moths collected (Figure 15). The last survey date (10/10/2017) was the date with the fewest pollinators collected.

Each of the five bee families experienced similar increases and decreases in abundance throughout the study period shown in Figure 16. All of the bee families reached maximum numbers in June with the exception of Colletidae, which had one bee collected in May, June, and October. Families Apidae and Megachilidae peaked on 6/13/2017 with 52 and 51 bees collected, respectively. Andrenidae peaked 6/20/2017 with 39 individuals collected. Halictidae peaked 6/27/2017, with 171 individuals collected. Occasional increases in family numbers occurred in September and October, notably for Megachilidae and Halictidae.

Table 3. Weekly totals of pollinators collected throughout the study.

Date	Hymenoptera	Lepidoptera	Total Pollinators Collected
4/25/2017	36	18	54
5/2/2017	40	46	86
5/11/2017	32	2	34
5/15/2017	38	5	43
5/30/2017	66	1	67
6/6/2017	168	5	173
6/13/2017	272	7	279
6/20/2017	238	2	240
6/27/2017	198	2	200
7/5/2017	145	5	150
7/11/2017	150	7	157
7/18/2017	117	2	119
7/25/2017	97	6	103
8/1/2017	79	4	83
8/8/2017	48	3	51
8/15/2017	50	0	50
8/21/2017	44	1	45
8/30/2017	33	4	37
9/11/2017	18	10	28
9/18/2017	4	4	8
9/26/2017	17	1	18
10/2/2017	11	4	15
10/10/2017	1	1	2

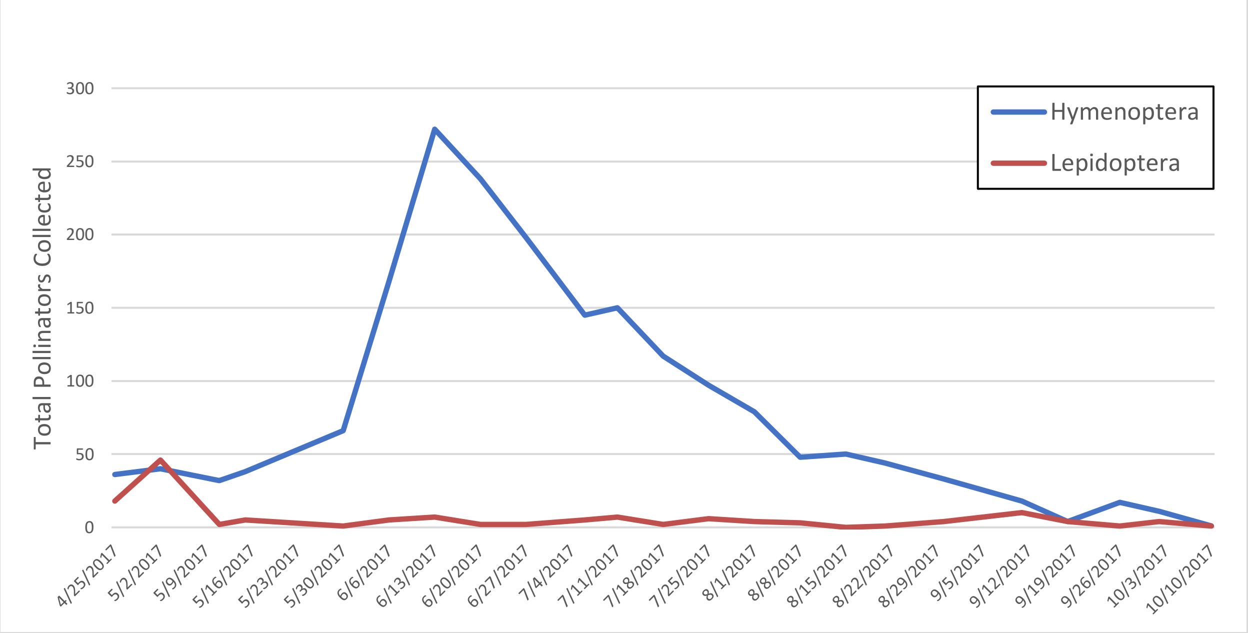

Figure 15. Total pollinators collected weekly, by order, 4/25/2017 - 10/10/2017.

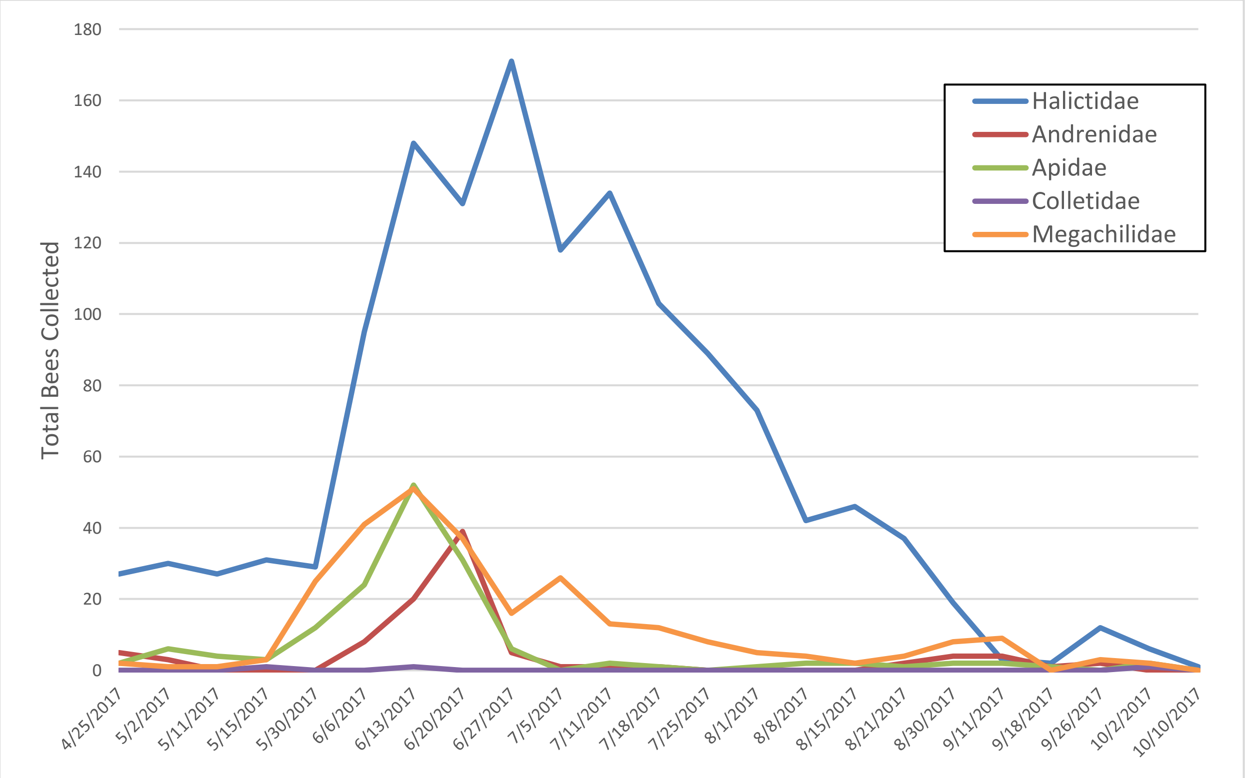

Figure 16. Total bees collected weekly, by family, 4/25/2017 - 10/10/2017.

Seasonal pulses were seen in most families of bee throughout the course of this study. Bees in the family Halictidae made up the majority of bees collected for most weeks (Figure 17). Halictidae bees were collected every week throughout the study. Megachilidae bees were the second most common and were found from April until October. There were only 2 weeks when Megachilidae bees were not collected, one in September and one in October. Apidae bees were mostly collected in May and June. From July to October, Apidae bees were not commonly collected with an average of one Apidae bee collected per week. Andrenidae bees were found in late April and early May, then after a decrease reached their highest numbers in June. Andrenidae bees were rare until late August, where the numbers increased slightly before dropping back to zero in October. Colletidae bees were the rarest collected in this study with one bee found in May, June, and October.

Lepidopterans had high abundance in late April and May, mainly due to the abundance of butterflies captured during this period (Figure 18). Numbers of butterflies captured varied through June and July, dropped in August, and rose once again in September before dropping to zero in October. Moth numbers remained respectively low throughout the study, with small increases in late April, July, September, and October. Moth and butterfly numbers seem to follow a similar pattern through the late summer and fall.

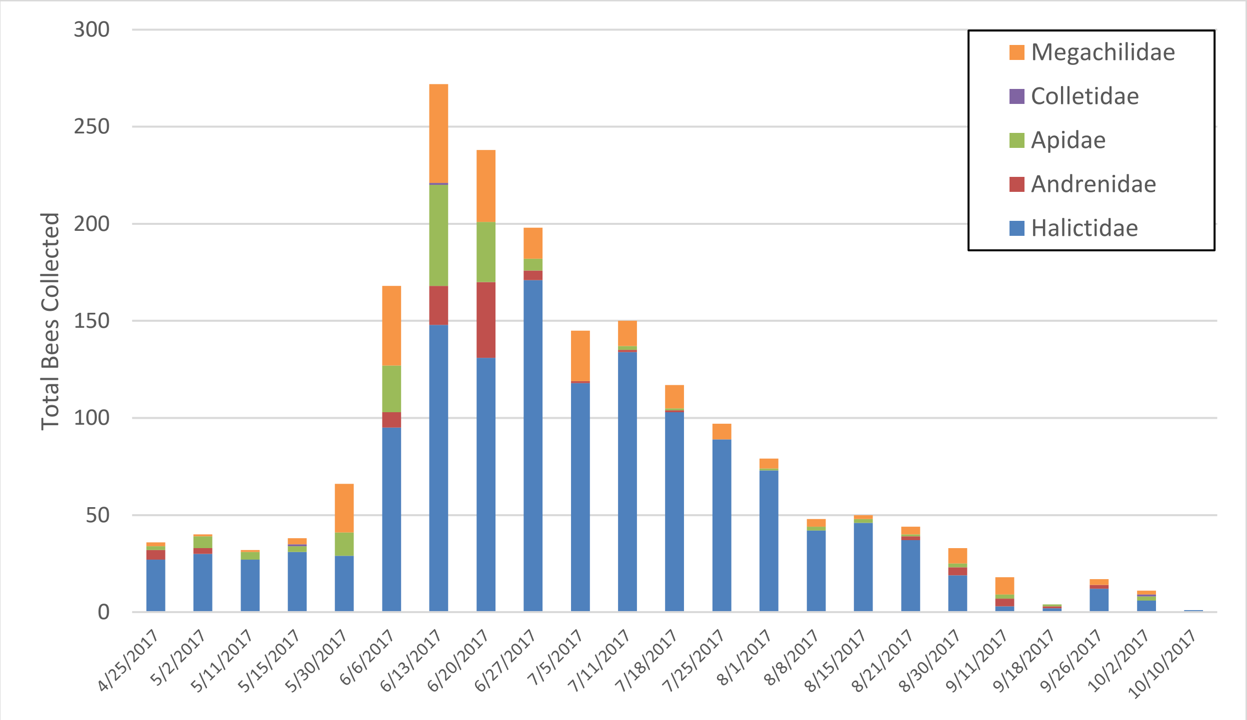

Figure 17. Total bees collected weekly, broken down by family, 4/25/2017 - 10/10/2017.

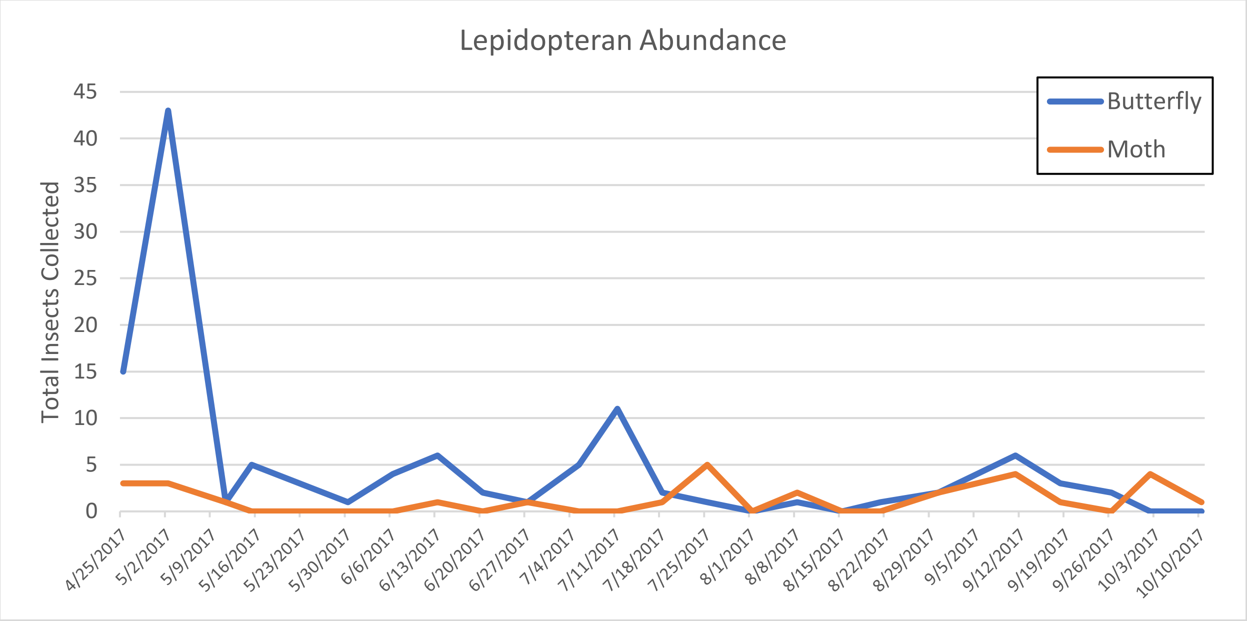

Figure 18. Total butterflies and moths captured 4/25/2017 - 10/10/2017.

4.1.2 Pulses in Bee Genera

Seasonal pulses[4] in genera and tribes were seen along with seasonal pulses in families. These pulses were most defined in the Andrenidae and Megachilidae families. Andrenidae had two distinct seasonal pulses, each attributed to a specific genera of bee (Figure 19). The first pulse of *Andrena* bees occurred in April, and the second pulse of *Perdita* bees occurred in late June. Megachilidae bees saw similar seasonal pulses in tribes and genera (Figure 20). In early spring, *Osmiini* bees were prevalent. By May, *Osmiini* numbers had decreased and *Megachile* numbers began rapidly increasing. *Megachile* was fairly common throughout the remainder of the study with another increase in late August. *Anthidiini* bees were first seen in early June and reached peak numbers by the end of June. This spike in *Anthidiini* correlates with a rapid drop in *Megachile* numbers. *Anthidiini* was then present until September.

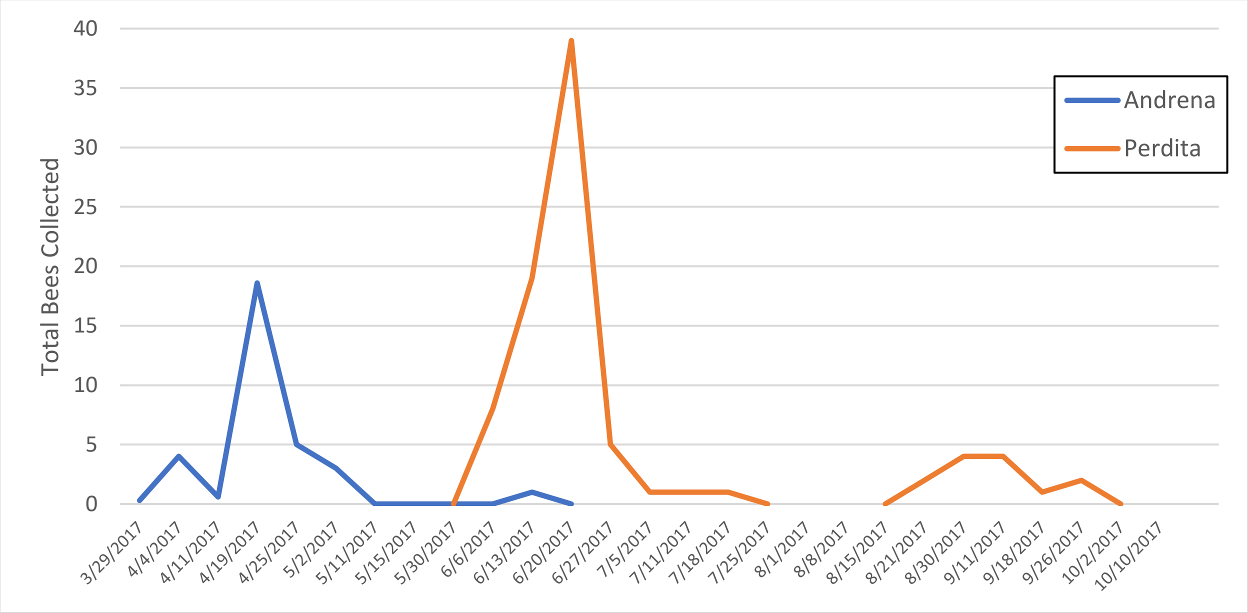

Figure 19. Pulses in genera of Andrenidae bees collected from 3/29/2017 - 10/10/2017.

Pulses in the family Halictidae did not follow the pattern of Andrenidae and Megachilidae (Figure 21). *Lasioglossum* is the dominant genus within this family and was present week after week, generally dominating bowl counts through June and July. The next most common genus in this family, *Agapostemon*, experienced two pulses in abundance, one in June and one in early August. As numbers of *Lasioglossum* bees decline in July, *Agapostemon* bees increase in number. This trend continues until early August when *Agapostemon* numbers begin to decline and *Lasioglossum* numbers increase. A few *Halictus* bees were present in April and early June.

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[4] Data collected prior to the 4/25/2017 methods change are included when describing seasonal pulses. The total bees collected displayed on the graphs before 4/25/2017 has been divided by 3 to roughly account for the 3 pan traps that were capturing bees in the early spring.

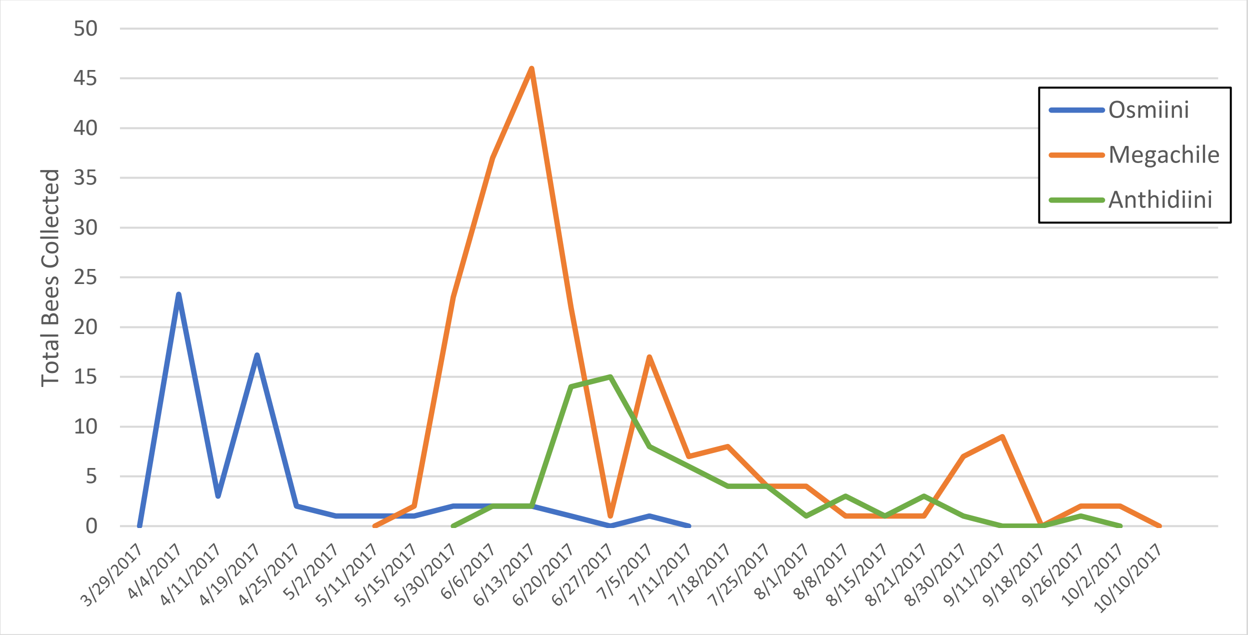

Figure 20. Pulses in genera of Megachilidae bees collected from 3/29/2017 - 10/10/2017.

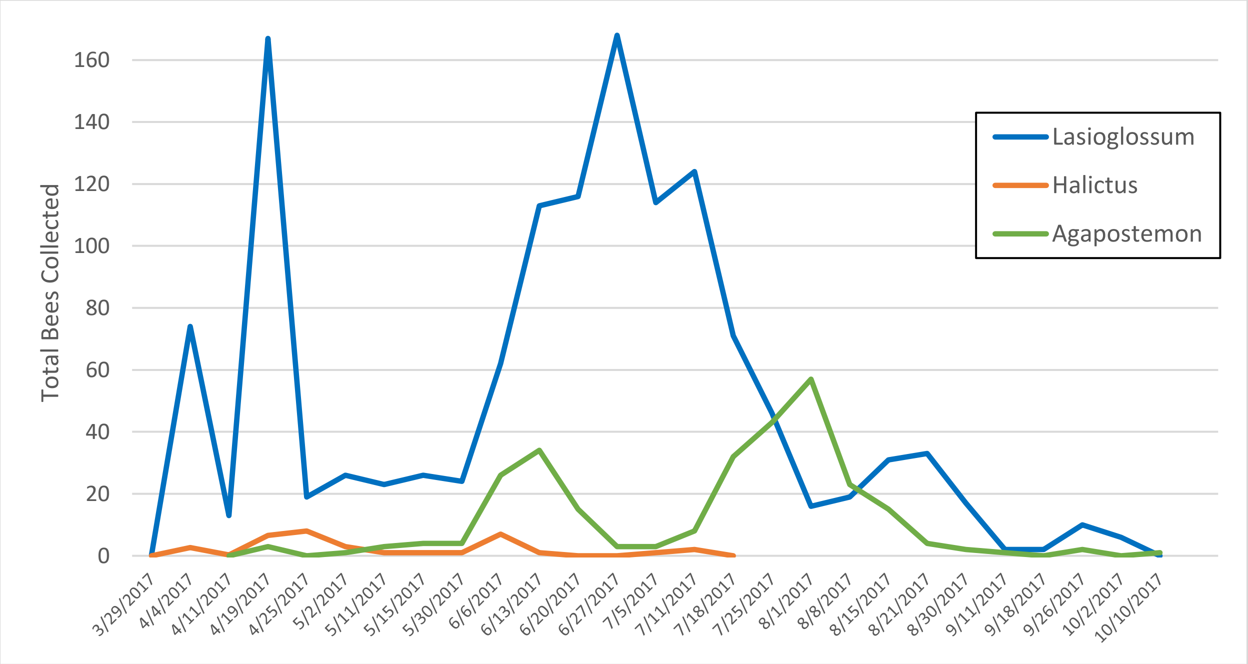

Figure 21. Pulses in genera of Halictidae bees collected from 3/29/2017 - 10/10/2017.

The majority of Apidae bee tribes and genera pulsed in June. A notable genus within Apidae is *Diadasia*, a specialist bee with a tight and brief pulse in abundance (Figure 22). Other significant genera within Apidae include *Bombus*, which was only collected in June and July; *Apis*, which was collected sporadically throughout the study; and *Eucerini*, the most commonly collected group of Apidae bees, which was common through June then sporadically found in the late summer and fall months. The remaining bee family, Colletidae, only had three individuals collected over the course of the study. One occurred in May, June, and October.

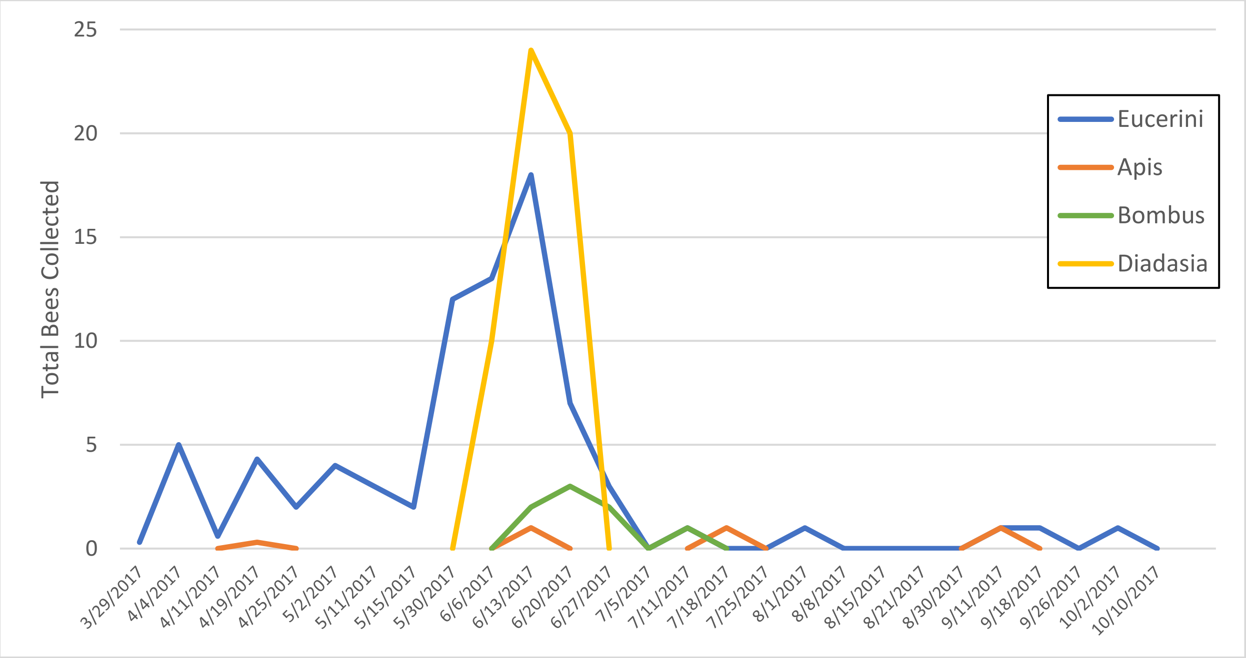

Figure 22. Pulses in some tribes and genera of Apidae bees, collected 3/29/2017 - 10/10/2017. This table does not include Anthophorini, Nomada, Melecta, or Triepeolus.

4.1.3 Relationships Between Forbs and Bees

The relationship between blooming plants and bees were compared using correlation analysis. Relationships between bloom coverage and bee abundance, bloom diversity and bee abundance, bloom coverage and bee diversity, and bloom diversity and bee diversity were all analyzed for each site and for all the study sites as a whole. Bloom coverage, as described in Section 3.2, is measured as the percent coverage of blooming plants at each site. When evaluating all sites together, average bloom coverage was used.

4.1.3.1 Bloom Coverage and Bee Abundance. Bee abundance was measured as the average number of bees collected per week. Bloom coverage was measured as the average bloom coverage over all sites per week. Bloom coverage had an unexpected correlation with bee abundance. Based on the results of this study, average bloom coverage and the average number of bees collected have a significant negative relationship (r_t = - 0.59, $p < 0.0001$). There are a number of factors that may have contributed to this (Section 5.4). This test was repeated for each site, and the correlation ranged from positive to negative. Four of the eight sites had a significant negative correlation between bloom coverage and bee abundance (SG-2, EC-1, EC-2).

4.1.3.2 Bloom Diversity and Bee Abundance. Bloom diversity was also compared to bee abundance. Bloom diversity was measured as the average number of species of plants in bloom at all sites per week. Bloom diversity had no significant correlation with bee abundance when evaluating all sites together. This test was repeated for each site, and the only significant correlation found was at the SG-1 site, which had a significant positive correlation between bloom diversity and bee abundance (r_t = 0.37, p = 0.02).

4.1.3.3 Bloom Coverage and Bee Diversity. Bloom coverage and bee diversity had a similar relationship to that between bloom coverage and bee abundance. Based on the results of this study, average bloom coverage and the average unique groups of bees collected over all sites have a significant negative relationship (r_t = - 0.49, $p < 0.01$). Given that bee abundance and bee diversity had a strong positive correlation (Section 4.1.4), the factors that may have contributed to the relationship between bloom coverage and bee diversity are likely the same as those that contributed to the relationship between bloom coverage and bee abundance, discussed in Section 5.4. This test was repeated for each site. Two of the eight sites had significant negative correlations between bloom coverage and bee diversity (EC-1, EC-2).

4.1.3.4 Bloom Diversity and Bee Diversity. There was no significant correlation found between bloom diversity and bee diversity among and within all sites.

4.1.4 Diversity of Pollinators

The diversity of bees collected measured by the number of unique tribes and genera identified each week generally increased with increasing bee abundance (Figure 23). Bee diversity and abundance had a strong positive correlation ($r_t = 0.55$, $p = 0.001$). It is important to consider that this measure of diversity is somewhat arbitrary, as there were multiple species within each genera and tribe that were not taken into account. The greatest diversity, as well as highest abundance, of bees collected in a single week was 16 groups, found on June 13, 2017. Diversity gradually rose from April through June, then began to drop in late June until the end of the study in October. When compared to the number of bees collected, May, September, and October had higher diversity per amount of bees collected than the other months.

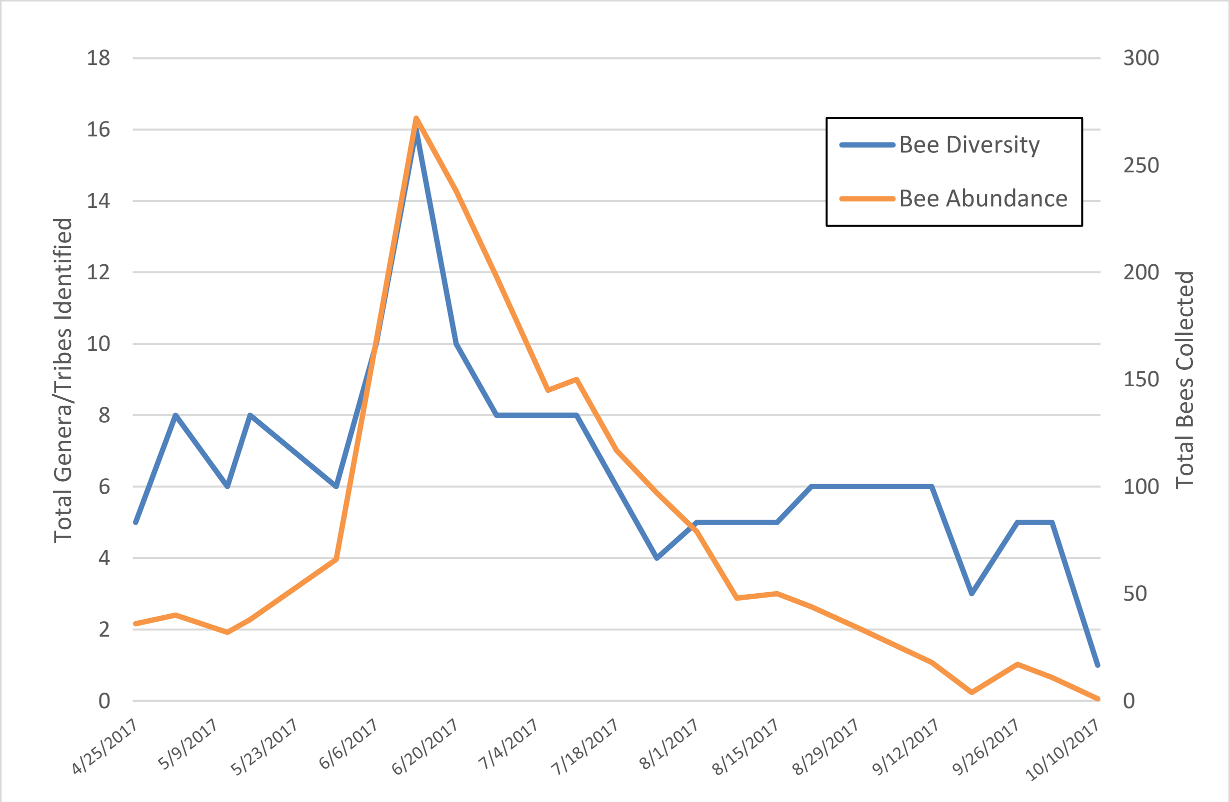

Figure 23. Total number of unique tribes and genera collected weekly, and weekly bee abundance, 4/25/2017 - 10/10/2017.

4.1.5 Pollinator Observations

Observations of pollinators foraging on flowers, though incidental, were important initial steps in identifying the amount and type of pollinators certain forbs supported. The highest number of bees were observed in June, corresponding with when the most bees were collected in pan traps. Fifty-six bees were observed foraging on flowers in June (Figure 26). The June peak bloom of prairie clover (*Dalea ornata*) contributed heavily to this increase in observations, with 36 bees and 6 butterflies observed foraging on prairie clover in sites EC-1 and MS-1 (Figure 24, Figure 25). Prairie clover had the highest number of bees observed foraging on it (Table 4). Butterfly numbers peaked in August, and the majority of butterflies observed in August were observed on snow buckwheat (*Eriogonum niveum*). Snow buckwheat was host to the highest number of butterfly observations and the second most number of bees. Bird vetch (*Vicia cracca*), a non-native plant found at SG-1, hosted the third highest number of bees. Other non-natives with pollinators observed foraging on them include rush skeletonweed (*Chondrilla juncea*) and yellow starthistle (*Centaurea solstitialis*). A notable observation occurred June 20 and June 27, 2017, at EC2, when a total of 10 small *Lasioglossum* bees were observed foraging on wingnut cryptantha (*Cryptantha pterocarya*).

Figure 24. *Agapostemon* sp. foraging on prairie clover (*Dalea ornata*).

Figure 25. *Bombus* sp. foraging on prairie clover (*Dalea ornata*).

Table 4. Plants with more than 1 pollinator observed foraging.

Common Name	Scientific Name	Total Pollinators	Hymenoptera	Lepidoptera
Prairie clover	*Dalea ornata*	42	36	6
Snow buckwheat	*Eriogonum niveum*	28	18	10
Bird vetch	*Vicia cracca*[a]	13	12	1
Wingnut cryptantha	*Cryptantha pterocarya*	10	10	-
Pale-evening primrose	*Oenothera pallida*	8	8	-
Douglas' dustymaiden	*Chaenactis douglasii*	8	6	2
Carey's balsamroot	*Balsamorhiza careyana*	7	7	-
Tarweed fiddleneck	*Amsinckia lycopsoides*	7	6	1
Stalked-pod milkvetch	*Astragalus sclerocarpus*	6	6	-
Turpentine springparsley	*Cymenopterus terebinthinus*	6	2	4
Threadleaf phacelia	*Phacelia linearis*	5	5	-
Rush skeletonweed	*Chondrilla juncea*[a]	5	5	-
Yellow starthistle	*Centaurea solstitialis*[a]	4	4	-
Sharpleaf penstemon	*Penstemon acuminatis*	4	4	-
Yellowbells	*Fritillaria pudica*	4	4	-
Upland larkspur	*Delphinium nuttallianum*	4	3	1
Diffuse knapweed	*Centaurea diffusa*[a]	3	3	-
Long-leafed phlox	*Phlox longifolia*	2	2	-
Hoary tansyaster	*Machaeranthera canescens*	2	2	-
Grey rabbitbrush	*Ericameria nauseosa*	2	2	-
Showy Townsend daisy	*Townsendia florifer*	2	2	-
	Sisymbrium altissimum[a]	2	1	-

[a] non-native

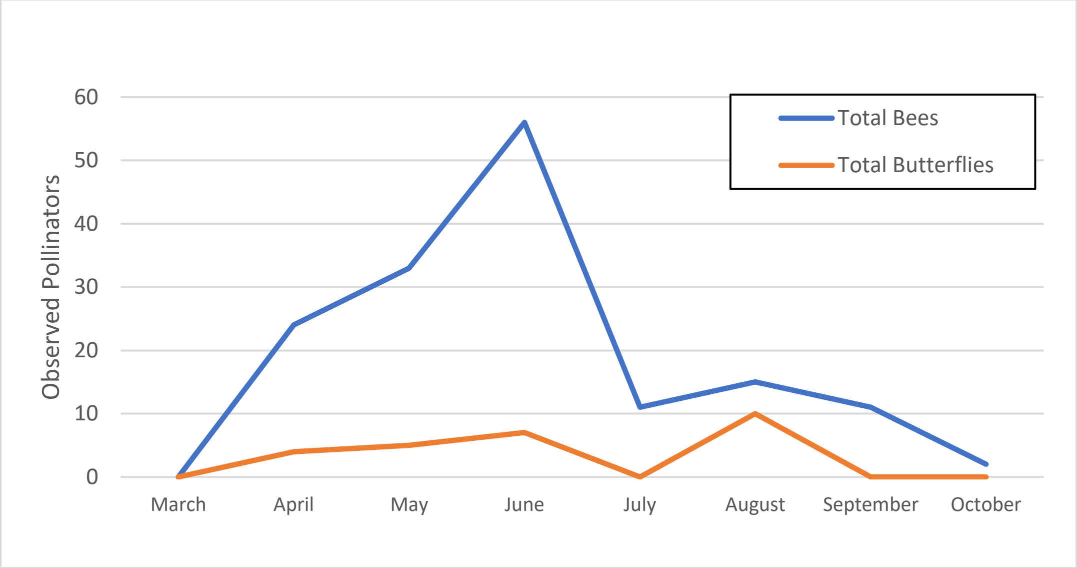

Figure 26. Pollinator observations over the course of the study.

4.1.6 Results by Shared Ecological Features

Sites varied in diversity, abundance, and seasonality of pollinators collected. Section 4.2 summarizes differences between individual sites. Along with comparing individual sites, sites were grouped by shared ecological features and compared.

Sites were categorized by ecological system following the Upland Vegetation of the Central Hanford Site report (Easterly et al. 2017). When sorting the sites into ecological systems, five of the sites fell within the Inter-Mountain Basins Active and Stabilized Dune System (EC-1, EC-2, MS-1, MS-2, and SG-2). Two sites were part of the Inter-Mountain Basins Semi-Desert Shrub-Steppe System (SB-1, SB-2), and the remaining site fell within the Columbia Plateau Steppe and Grassland System (SG-1). When comparing abundance across ecological systems, the grassland system had significantly higher bee abundance than both the dune and shrub-steppe systems ($p < 0.0001$; $p = 0.001$). Though the dune systems had a higher average count of bees collected per week than shrub-steppe systems, the two systems did not significantly differ from each other in bee abundance. As only one site was categorized as a grassland ecological system, more information is needed in comparing ecological systems before making definite conclusions about differences in bee abundances between these areas.

A Mann-Whitney U test was conducted to compare bee abundance between inland and near-river sites and between sandy soil and loamy soil sites. There was no significant difference between bee abundance or diversity between inland and near-river sites. Site soil type was defined as the most common soil within 200 m of the study site. All sites were classified as either Burbank Loamy Sand (SB1, SB2, MS1) or Quincy Sand (SG1, SG2, EC1, EC2, MS2). Quincy Sand sites did not have significantly more bees captured than the Burbank Loamy Sand Sites when testing at a 95% confidence interval ($U = 4528$, $p = 0.054$), though the average amount of bees collected per week in Quincy Sand Sites was nearly double that of Burbank Loamy Sand sites (12.5 and 6.8, respectively). The average floral availability, measured by adding the peak bloom percentages[5] at each site and averaging between sites, was 34.1% at Quincy Sand Sites and 19% at Burbank Loamy Sand Sites.

Certain habitat types seem to disproportionately support certain types of bees. Within the Late Successional Sagebrush Sites, 65% of all *Anthidiini* and 76% of all *Diadasia* bees were collected. Within the Early Colonizing Sites, 72% of all *Anthophorini* and 37% of all *Megachile* bees were collected.

4.2 Individual Site Results

Site-specific results, including bloom and bee visitation data, are presented in this section. Percent coverage listed for each species in Tables 5 through 12 is approximate to total site coverage at the height of that species' bloom, so coverage may add up to over 100%. Bloom coverage was visually estimated throughout the study and is reported as absolute coverage. The species listed for each study site are not all inclusive but include blooming species with absolute coverage of at least 0.5% in the study area. The measure of bloom coverage appearing in the graphs in this section represents the total percentage of area within each study site covered by blooming species.

Soil information is from the 1966 Soil Survey of the Hanford Project and performed by B.F. Hajek (Hajek 1966), which is the primary source of soil types used in BRMP. Relationships between bloom coverage, bloom diversity, bee abundance, and bee diversity were tested at all sites. Significant results are reported in the sections below. Bee abundance and bee diversity were measured with the bees collected from pan traps.

Over the course of the study the highest numbers of bees were collected at the Steppe Grassland 1 site (450 individuals) and at the Early Colonizing 2 site (447 individuals). The least amount of bees were collected at the Early Colonizing 1 site (96 individuals) and the Mixed Shrub 1 site (117 individuals). Kruskal-Wallis testing of bee abundance at each study site shows that sites significantly differ in bee abundance (p =0.001). Post-hoc analysis was performed for each site to identify where the significant differences lay. Differences among study sites are summarized in their respective sections below.

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[5] Average floral availability does not include forb species, which reached peak bloom in March, before the beginning of the study period.

4.2.1 Steppe Grassland Sites

4.2.1.1 Steppe Grassland Site 1 (SG-1). The SG-1 study site is near the Hanford Townsite and is the closest study site to both the Columbia River (1,100 m away) and the agricultural fields across the river (3,500 m away). The soil at this site is Quincy Sand. The SG-1 site is dominated by bunchgrasses and lacks native forb coverage compared to the other study sites, but has non-native flowering annuals that bloom throughout most seasons (Table 5). This site is characterized by an expansive stand of needle-and-thread grass (*Hesperostipa comata*) that can reach above 1 m at its peak in late summer and had coverage estimated up to 40% (Figure 27). Other bunchgrasses at this site include Sandberg's bluegrass (3% coverage, *Poa secunda*) and bulbous bluegrass (7% coverage, *Poa bulbosa*). Interspersed between the bunchgrass is cheatgrass (*Bromus tectorum*), the other dominant species at this site, which in the spring had an estimated coverage over 60%. Habitats surrounding this site consist of rabbitbrush/bunchgrass mosaic and Sandberg's bluegrass-cheatgrass areas (Easterly et al. 2017).

Table 5. Blooming Plants at SG-1 with coverage of 0.5% or greater.

Common Name	Scientific Name	Peak Bloom	Bloom Period	% Coverage	Classification
Forbs					
Spring draba	*Draba verna*	March	Mar - April	2	Non-native
Stalked-pod milkvetch	*Astragalus sclerocarpus*	May	April - May	0.5	Native
Jim Hill's tumblemustard	*Sisymbrium altissimum*	May	April - Aug	2	Non-native
Tarweed fiddleneck	*Amsinckia lycopsoides*	May	May	0.5	Native
Bird vetch	*Vicia cracca*	May	May - Aug	1	Non-native
Yellow star-thistle	*Centaurea solstitialis*	July	June - Oct	1	Non-native
Yellow salsify	*Tragopogon dubius*	July	July - Aug	0.5	Non-native
Diffuse knapweed	*Centaurea diffusa*	July	July - Aug	0.5	Non-native
Prickly lettuce	*Lactuca serriola*	August	July - Sept	0.5	Non-native
Sweet clover	*Melilotus officinalis*	August	August	0.5	Non-native
Horseweed	*Conyza canadensis*	August	Aug - Sept	1	Native
Hoary tansyaster	*Machaeranthera canescens*	September	Aug - Oct	0.5	Native

Figure 27. The Steppe Grassland 1 Site in July.

The SG-1 site had many attributes that set it apart from other sites. This site is the closest to the Columbia River, putting both the river and study site within the ranges of large-bodied bees like bumblebees and honeybees. This site is also the closest to agricultural activities across the river; however, this distance is likely too far for the vast majority of bees to travel. SG-1 only has 12 blooming plants with coverage above 0.5%. Sixty-six percent of these blooming plants are non-native, the highest proportion of non-native plants of all the study sites. The maximum bloom coverage was 3.75%, reached August 30, 2017, relatively late in the season compared to the other study sites. This was the lowest bloom coverage out of all the study sites. Twenty-five bees were observed foraging on flowers at SG-1 throughout the course of the study. Thirteen of the bees were observed on bird vetch and five on stalked-pod milkvetch (*Astragalus sclerocarpus*). Twenty of the 25 bees were observed foraging on non-native species.

Four hundred and fifty bees, 28 butterflies, and 3 moths were collected from this site over the course of the study. This was the greatest number of bees collected at any site throughout the study. When comparing abundances across sites, the SG-1 site had statistically significant higher bee abundances than three of the seven other sites, RB-1, MS-1, and MS-2. Bee abundance at this site peaked on July 18, 2017, about 1 month later than the majority of the other sites. When the changes in bloom coverage and bee abundance are compared, it appears they follow a slightly similar pattern (Figure 28). The two variables have a slight positive correlation but this is not statistically significant ($r = 0.25$, $p = 0.1$). There was a significant, positive correlation between the diversity of blooming plants at this site and the abundance of bees ($r = 0.37$, $p = 0.02$).

Fifteen groups of bee were found at SG-1, making it the site with the most diverse bee populations (Figure 29). A large amount of both *Lasioglossum* and *Agapostemon* individuals were found at this site while other groups had fairly low numbers. This is the only site where *Triepeolus* was collected.

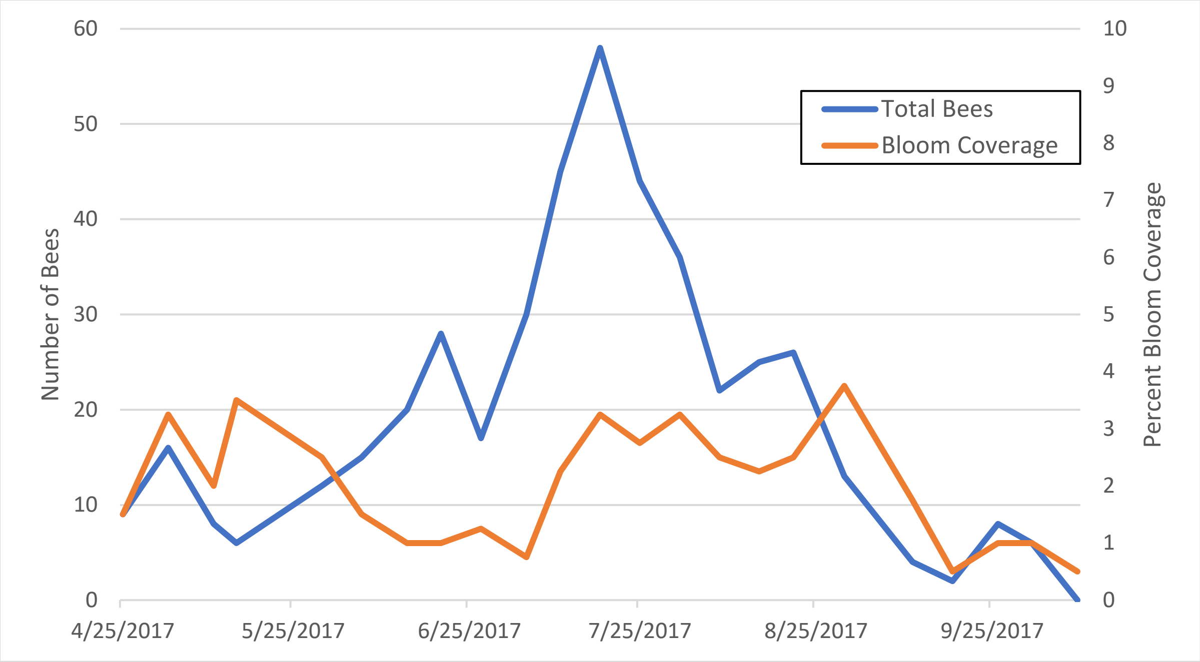

Figure 28. Bloom coverage and bee abundance at the SG-1 Site.

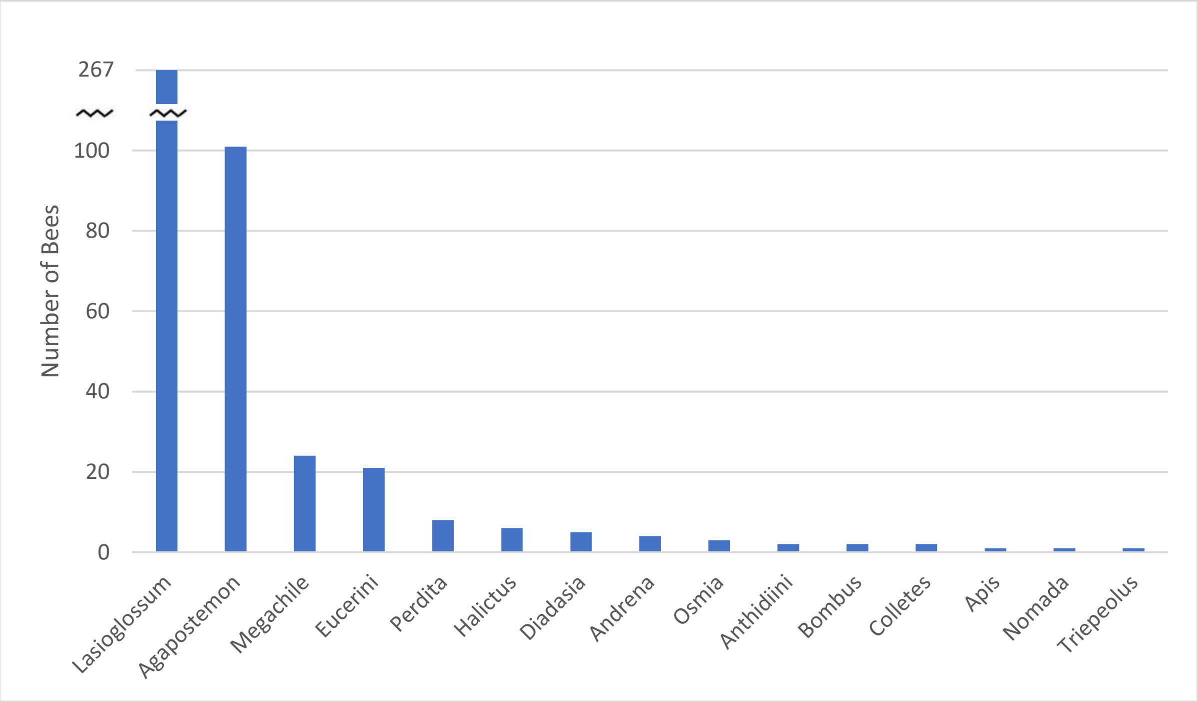

Figure 29. Groups of bees collected at SG-1, 4/25/2017 - 10/10/2017.

4.2.1.2 Steppe Grassland Site 2 (SG-2). The SG-2 study site is located along Army Loop Road near the center of the Hanford Site. It is located in a sandy, stabilized dune area and the soil type is Quincy Sand. This site is dominated by needle-and-thread grass (15% coverage) and cheatgrass (60% coverage), similar to SG-1 (Figure 30). Indian ricegrass (1% coverage, *Achnatherum hymenoides*) and Sandberg's bluegrass (3% coverage) were also present. Grey rabbitbrush (1% coverage, *Ericameria nauseosa*) and green rabbitbrush (3% coverage, *Chrysothamnus viscidiflorus*) are present in the southwest portion of the site. The SG-2 site has greater native forb coverage and diversity than the SG-1 site (Table 6). Carey's balsamroot (1% coverage, *Balsamorhiza careyana*), long-leafed phlox (1% coverage, *Phlox longifolia*), and tarweed fiddleneck (2% coverage, *Amsinckia lycopsoides*) were some of the spring blooming forbs in this area. Pale evening primrose (0.5% coverage, *Oenothera pallida*) bloomed at this site throughout nearly all seasons; hoary tansyaster (3% coverage, *Machaeranthera canescens*) was the dominant blooming species in the late summer and fall. This site is surrounded by a Bitterbrush/Bunchgrass mosaic (Easterly et al. 2017).

Table 6. Blooming plants at SG-2 with coverage 0.5% or greater.

Common Name	Scientific Name	Peak Bloom	Bloom Period	% Coverage	Classification
Forbs					
Spring draba	*Draba verna*	March	Mar - April	15	Non-native
Turpentine springparsley	*Cymopterus terebinthinus*	May	April - May	2	Native
Yellowbells	*Fritillaria pudica*	April	April	0.5	Native
Long-leafed phlox	*Phlox longifolia*	May	April - June	1	Native
Jim Hill's tumblemustard	*Sisymbrium altissimum*	May	April - June	0.5	Non-native
Carey's balsamroot	*Balsamorhiza careyana*	May	April - May	1	Native
Upland larkspur	*Delphinium nuttallianum*	May	April - May	0.5	Native
Tarweed fiddleneck	*Amsinckia lycopsoides*	May	April - May	2	Native
Wingnut cryptantha	*Cryptantha pterocarya*	May	April - May	0.5	Native
Foothill deathcamas	*Toxicoscordion paniculatum*	May	May	0.5	Native
Threadleaf phacelia	*Phacelia linearis*	May	May - June	0.5	Native
Stalked-pod milkvetch	*Astragalus sclerocarpus*	May	May	0.5	Native
Western yarrow	*Achillea millefolium*	June	May - June	0.5	Native
Buckwheat milkvetch	*Astragalus caricinus*	May	May	1	Native
Douglas' clusterlily	*Triteleia grandiflora*	May	May	0.5	Native
Rosy gilia	*Gilia sinuata*	May	May	0.5	Native
Pale-evening primrose	*Oenothera pallida*	May	May - Sept	0.5	Native
Rush skeletonweed	*Chondrilla juncea*	July	July - Sept	1	Non-native
Douglas' dustymaiden	*Chaenactis douglasii*	August	July - Aug	0.5	Native
Hoary tansyaster	*Machaeranthera canescens*	Sept	Aug - Oct	3	Native
Shrubs					
Green rabbitbrush	*Chrysothamnus viscidiflorus*	Sept	Sept - Oct	3	Native
Ericameria nauseosa	*Ericameria nauseosa*	Sept	Sept - Oct	1	Native

The SG-2 site was home to a diverse array of native plants (Figure 30). SG-2 had 20 blooming forbs with coverage over 0.5% and 2 blooming shrubs. Only three of these plants were non-native species. There were two large pulses in bloom coverage, one in May and one in late September. The maximum bloom coverage was 10.25% coverage, which occurred in mid-May. Twenty-three bees and two butterflies were observed foraging at this site. Tarweed fiddleneck, upland larkspur (*Delphinium nuttallianum*), and rush skeletonweed each had four pollinators observed foraging on them and pale-evening primrose had three. The remaining observations were scattered across various plants.

Two hundred and eighty-three bees, 12 butterflies, and 4 moths were collected from this site over the course of this study. This site had the third greatest amount of pollinators collected. The most bees were collected on June 13, 2017, when 71 bees were collected in 1 week. Bee abundance at this site followed a similar pattern as other sites, peaking in June and gradually decreasing through July (Figure 31). A slight increase in abundance was seen in August. A significant, negative correlation between bloom coverage and bee abundance was found at this site (r = -0.39, p = 0.01). Ten groups of bee were found at SG-2 (Figure 32). *Lasioglossum* was the most abundant bee, followed by large groups of both *Megachile* and *Perdita* bees.

Figure 30: Forbs blooming in the Steppe Grassland 2 Site in May.

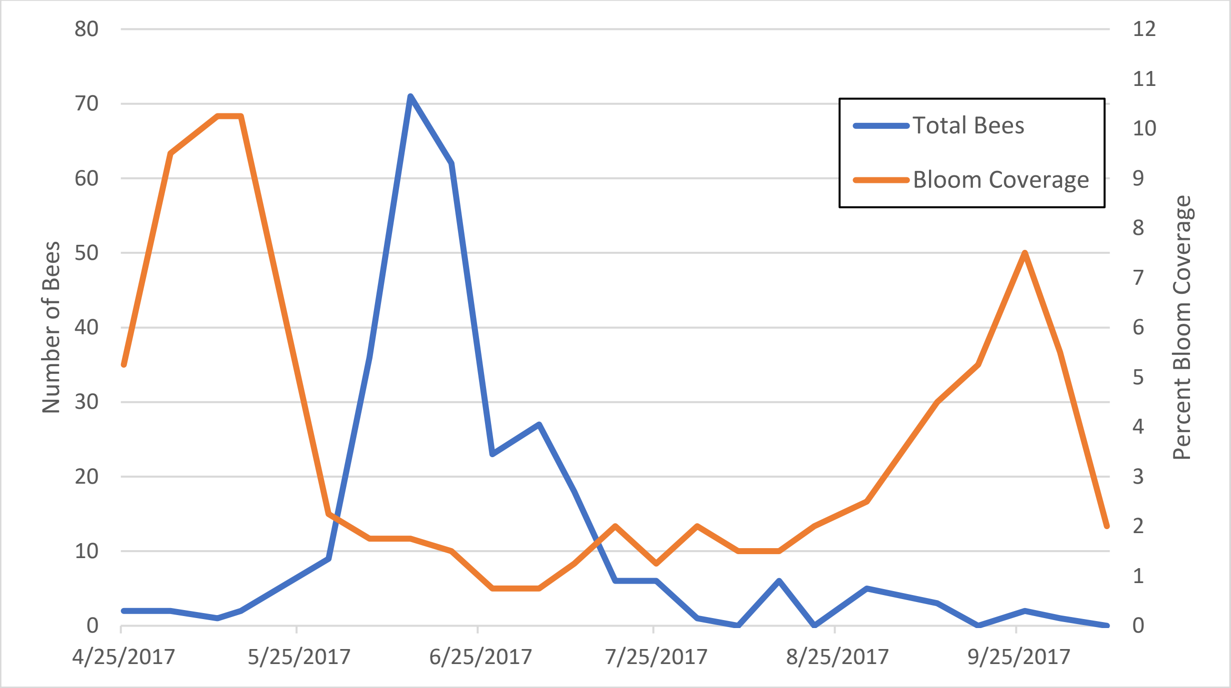

Figure 31. Bloom coverage and bee abundance at SG-2.

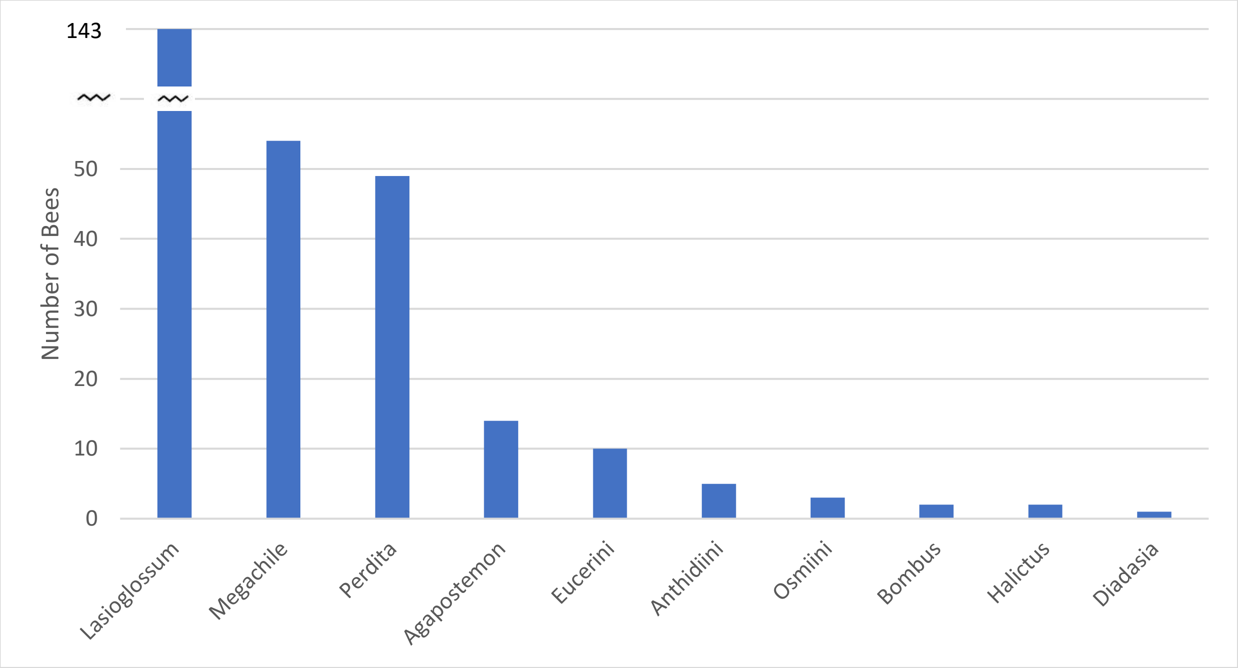

Figure 32. Groups of bees collected at SG-2, 4/25/2017 – 10/10/2017.

4.2.2 Early Colonizing Sites

4.2.2.1 Early Colonizing Site 1 (EC-1). The EC-1 study site is located in the Inter Mountain Basin Semi-Stabilized Dune System. The site is about 2,000 m from the Columbia River, and 9,000 m from farmland. The soil type is split between Quincy Sand to the east and Ephrata Sandy Loam to the west. This site is dominated by snow buckwheat (40% coverage), which bloomed throughout the late summer and fall months. Green rabbitbrush (2% coverage) and grey rabbitbrush (3% coverage) are also present. Cheatgrass has a coverage of 40%. In the spring and summer, Carey's balsamroot (2% coverage) and prairie clover (2% coverage, *Dalea ornata*) provided the majority of the bloom coverage. A few tiny flowering forbs were present in the early spring including spring draba (2% coverage, *Draba verna*), jagged chickweed (2% coverage, *Holosteum umbellatum*), and slender phlox (0.5% coverage, *Microsteris gracilis*). Pale-evening primrose at this site bloomed throughout the majority of the study (1% coverage). The EC-1 site is less diverse than the EC-2 site (Table 7). This site is surrounded by a Bitterbrush – Snow Buckwheat/Bunchgrass mosaic (Easterly et al. 2017).

Table 7. Blooming plants at EC-1 with coverage 0.5% or greater

Common Name	Scientific Name	Peak Bloom	Bloom Period	% Coverage	Classification
Forbs					
Spring draba	*Draba verna*	March	Mar - April	2	Non-native
Jagged chickweed	*Holosteum umbellatum*	April	Mar - April	2	Non-native
Slender phlox	*Microsteris gracilis*	March	Mar - April	0.5	Native
Jim Hill's tumblemustard	*Sisymbrium altissimum*	May	April - May	0.5	Non-native
Carey's balsamroot	*Balsamorhiza careyana*	April	April - May	2	Native
Long-leafed phlox	*Phlox longifolia*	April	April - May	0.5	Native
Turpentine springparsley	*Cymopterus terebinthinus*	May	April - May	0.5	Native
Upland larkspur	*Delphinium nuttallianum*	April	April	0.5	Native
Threadleaf phacelia	*Phacelia linearis*	May	May - June	0.5	Native
Matted cryptantha	*Cryptantha circumscissa*	May	April - May	0.5	Native
Pale-evening primrose	*Oenothera pallida*	May	May - Aug	1	Native
Western yarrow	*Achillea millefolium*	June	May - June	0.5	Native
Prairie clover	*Dalea ornata*	June	May - June	2	Native
Rush skeletonweed	*Chondrilla juncea*	August	July - Aug	1	Non-native
Tufted wirelettuce	*Stephanomeria paniculata*	July	July - Aug	0.5	Native
Snow buckwheat	*Eriogonum niveum*	September	Aug - Oct	40	Native
Shrubs					
Antelope bitterbrush	*Purshia tridentata*	May	April - May	1	Native
Green rabbitbrush	*Chrysothamnus viscidiflorus*	Sept	Sept - Oct	3	Native
Ericameria nauseosa	*Ericameria nauseosa*	Sept	Sept - Oct	1	Native

Figure 33. Snow buckwheat (*Eriogonum niveum*) at the Early Colonizing 1 Site in September.

While the EC-1 site did not have a hugely diverse array of plants, it had two large blooms in the summer and fall that attracted large numbers of pollinators supported by prairie clover and snow buckwheat (Figure 33). This site had 16 blooming forbs with coverage over 0.5%; 4 of these forbs were non-native. Peak bloom coverage at this site occurred September 26, 2017, months later than most of the study sites due to a large population of snow buckwheat that bloomed through September. EC-1 had the highest number of bee observations, mostly due to a healthy population of prairie clover and snow buckwheat present in the study site. Nineteen bees and six butterflies were observed foraging on prairie clover; six bees and nine butterflies were observed foraging on snow buckwheat. Another notable plant at this site was turpentine springparsley, where 17 flies were observed foraging compared to only 1 bee and 3 butterflies.

Ninety-six bees, 13 butterflies, and 6 moths were collected from the EC-1 site over the course of the study. This site had the lowest number of bees collected while having the highest number of bees observed. See Section 5.4 for discussion about the implications of this result. The largest number of bees collected occurred June 13, 2017, in tandem with the prairie clover bloom (Figure 34). This peak was followed by a few increases in August. No bees were collected at EC-1 in September and only one was collected in October despite multiple bees observed foraging on snow buckwheat. A large number of leafcutter bees (*Megachile* sp.) and green sweat bees (*Agapostemon* sp.) were collected at this site outnumbering the *Lasioglossum* bees, which were the most dominant group at the majority of the study sites (Figure 35). Bloom coverage had a significant inverse relationship with both bee diversity and bee abundance at this site (r = -0.4, p = 0.01; r = -0.37, p = 0.02), suggesting as bloom coverage increases, the diversity and abundance of bees collected decreases. This statistic stems mainly from the lack of bees collected at this site during the peak bloom coverage event in September.

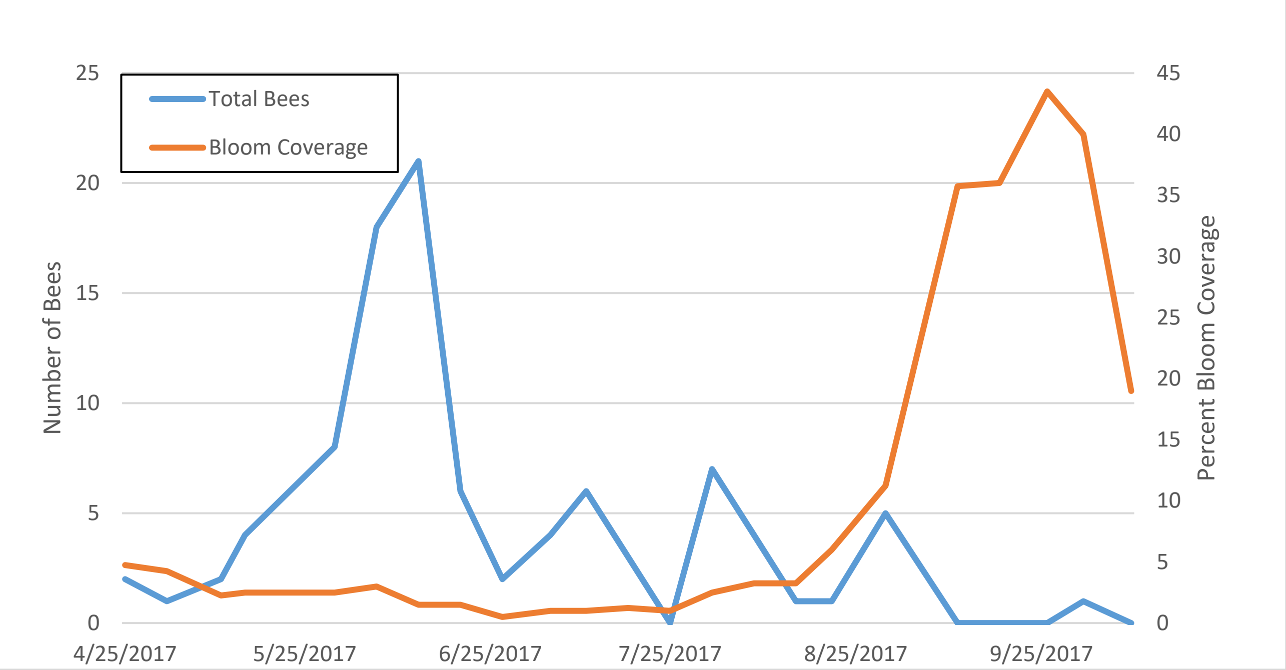

Figure 34. Bloom coverage and bee abundance at EC-1.

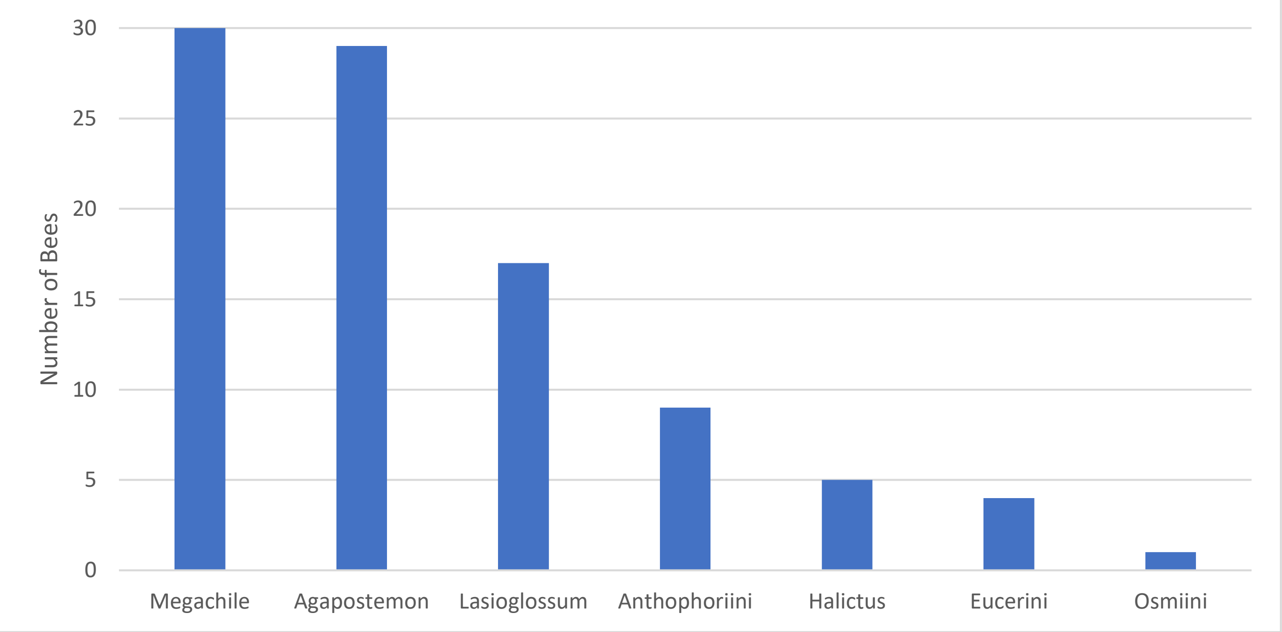

Figure 35. Groups of bees collected at EC-1, 4/25/2017 - 10/10/2017.

4.2.2.2 Early Colonizing Site 2 (EC-2). The EC-2 study site is located along Army Loop Road, south of the 200 Areas. This site is west of the Steppe Grassland 2 site and is located on a semi-stabilized sand dune. The soil type is Quincy Sand. This site is located within a Washington State Plant Community Element Occurrence of Big Sagebrush/Needle-and-Thread Grass (Easterly et al. 2017). Though needle-and-thread grass is a dominant bunchgrass within this site, no sagebrush is present. The shrub overstory is dominated by green rabbitbrush, while cheatgrass has a coverage of 30% in the understory. Dominant blooming plants in this site include Carey's balsamroot (3% coverage) and turpentine springparsley (3% coverage, *Cymopterus terebinthinus*) in the spring, and hoary tansyaster (7% coverage) and green rabbitbrush (20% coverage) in the fall. Yarrow (2% coverage), primrose (1% coverage), stalked-pod milkvetch (1% coverage), and long-leafed phlox (1% coverage) are other blooming plants with significant coverage. The EC-2 site had a diverse array of native flowering plants and an intact plant community with only two non-native forb species present (Table 8). This site is surrounded by a Bitterbrush/Bunchgrass mosaic (Easterly et al. 2017).

Table 8. Blooming plants at EC-2 with coverage 0.5% or greater.

Common Name	Scientific Name	Peak Bloom	Bloom Period	% Coverage	Classification
Forbs					
Spring draba	*Draba verna*	March	March	2	Non-native
Turpentine springparsley	*Cymopterus terebinthinus*	March	Mar - May	3	Native
Yellowbells	*Fritillaria pudica*	April	April	0.5	Native
Carey's balsamroot	*Balsamorhiza careyana*	April	April - May	3	Native
Long-leafed phlox	*Phlox longifolia*	April	April - June	1	Native
Jim Hill's tumblemustard	*Sisymbrium altissimum*	May	April - June	2	Non-native
Tarweed fiddleneck	*Amsinckia lycopsoides*	May	April - May	1	Native
Stalked-pod milkvetch	*Astragalus sclerocarpus*	May	April - May	1	Native
Wingnut cryptantha	*Cryptantha pterocarya*	May	April - June	0.5	Native
Matted cryptantha	*Cryptantha circumscissa*	May	April - May	1	Native
Slender phlox	*Microsteris gracilis*	May	April - June	0.5	Native
Western yarrow	*Achillea millefolium*	June	May - July	2	Native
Bastard toadflax	*Comandra umbellata*	May	May	0.5	Native
Threadleaf phacelia	*Phacelia linearis*	May	May	0.5	Native
Sharpleaf penstemon	*Penstemon acuminatus*	May	May - June	0.5	Native
Pale-evening primrose	*Oenothera pallida*	August	May - Sept	1	Native
Buckwheat milkvetch	*Astragalus caricinus*	May	May	1	Native
Bastard toadflax	*Comandra umbellata*	May	May	0.5	Native
Rosy gilia	*Gilia sinuata*	May	April - June	0.5	Native
Sagebrush mariposa lily	*Calochortus macrocarpum*	June	June	0.5	Native
White sand verbena	*Abronia mellifera*	June	June – July	0.5	Native
Hoary tansyaster	*Machaeranthera canescens*	Sept	Aug - Oct	7	Native
Shrubs					
Green rabbitbrush	*Chrysothamnus viscidiflorus*	Sept	Sept - Oct	20	Native

Figure 36. Blooming plants at the Early Colonizing 2 Site in May.

The EC-2 site is best set apart from the other study sites by the abundance of diverse, native flowers and patches of open sand, clearly indicative of a semi-stabilized sand dune (Figure 36). The diversity in flower species was accompanied by a diversity of bloom times; from March through October there were always floral resources blooming within this site. There were two prominent peaks in bloom coverage, one in mid-May and another in late September (Figure 37). The peak in mid-May was due to a large number of plants reaching full bloom, while the peak in September was due to a large population of hoary tansyaster and green rabbitbrush blooming. Notable observations at this site included a large number of small-bodied bees (10; most likely *Lasioglossum* sp.) foraging on wingnut cryptantha, a forb with miniscule flowers. Four bees were observed foraging on sand beardtongue and three on pale-evening primrose.

At the EC-2 site 447 bees, 8 butterflies, and 6 moths were collected over the course of the study. This was the second highest number of bees collected from any one study site, behind the Steppe Grassland 1 site by only three bees. Bee abundance at this site pulsed in May, greatly increased in June, began to decrease in July, pulsed in August, and tapered off (Figure 37). The largest amount of bees collected at EC-2 were collected the week of June 27, 2017. The dominant group of bees collected at this site was small-bodied *Lasioglossum*, which made up more than 80% of all bees collected (Figure 38). This was followed by leafcutter bees (*Megachile* sp.). Eleven groups of bee were collected at this site, making EC-2 home to a relatively diverse population of bees, despite the collected bees being overwhelmingly dominated by *Lasioglossum*. Bloom coverage had a significant inverse relationship with both bee diversity and bee abundance at this site (r = -0.36, p = 0.03; r = -0.33, p = 0.04), suggesting as bloom coverage increases the diversity and abundance of bees collected decreases. There was no significant relationship detected between bloom diversity and either bee abundance or bee diversity.

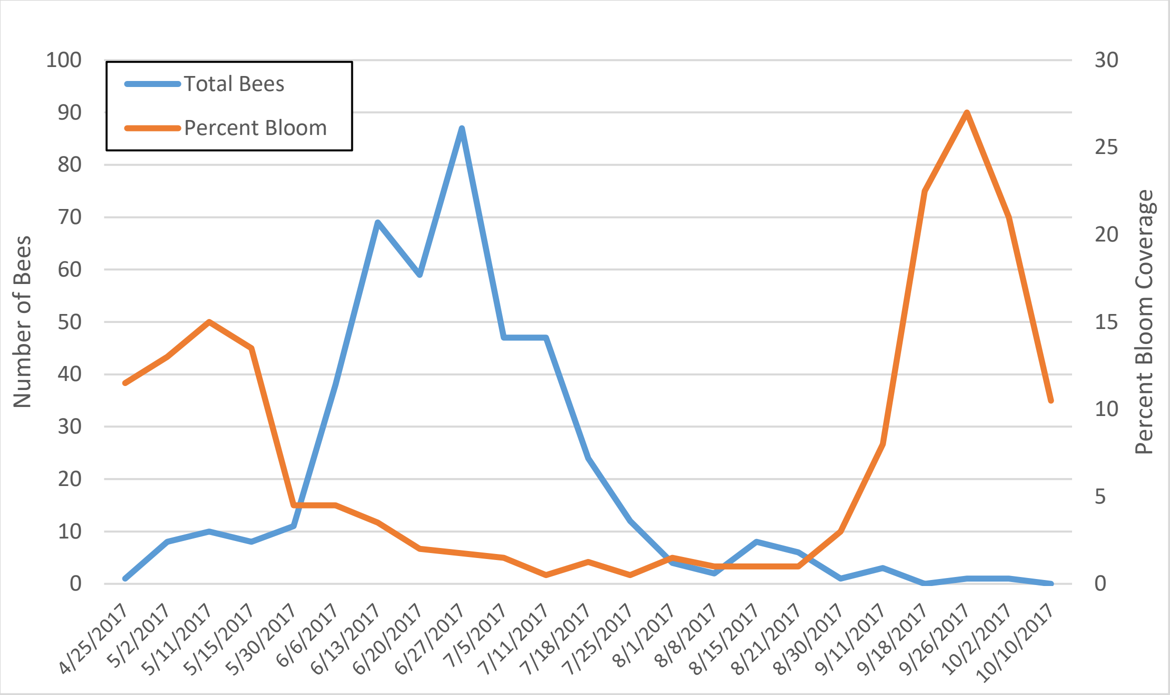

Figure 37. Bloom coverage and bee abundance at EC-2.

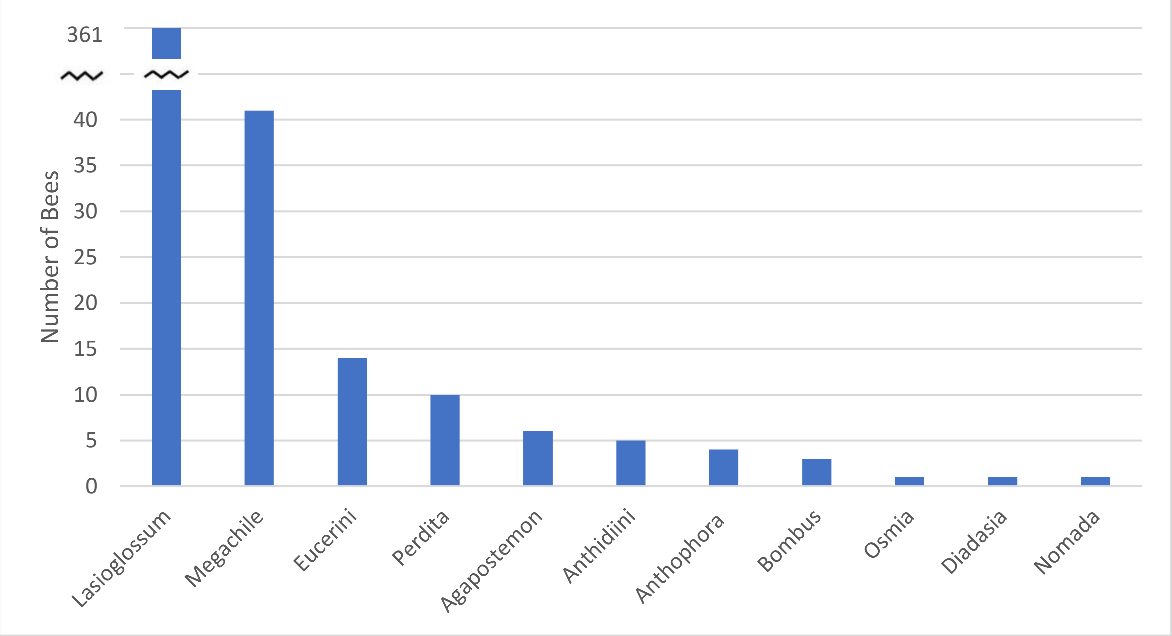

Figure 38. Groups of bees collected at EC-2, 4/25/2017 – 10/10/2017.

4.2.3 Late Successional Mixed Shrub Sites

4.2.3.1 Late Successional Mixed Shrub Site 1 (MS-1). The MS-1 study site is located on the eastern edge of a Washington State Plant Community Element Occurrence (Easterly et al. 2017) of a Bitterbrush/Indian Ricegrass Sand Dune Complex. The soil type is split between Burbank Loamy Sand to the east and Quincy Sand to the west. The overstory of this site is dominated by big sagebrush (15% coverage), antelope bitterbrush (4% coverage), green rabbitbrush (4% coverage), and grey rabbitbrush (4% coverage) (Figure 41). Cheatgrass is the dominant understory plant with a coverage around 40% at its height. Blooming resources were scarce at this site (Table 9). The tiny flowers of spring draba (20% coverage) and matted cryptantha (3% coverage, *Cryptantha circumscissa*) accounted for most of the bloom coverage in the early spring. Antelope bitterbrush (4% coverage) bloomed in May, and prairie clover (1% coverage) bloomed in May and June. In the fall, green and grey rabbitbrush provided the majority of the bloom coverage. his site is one of the least florally diverse of all the study sites.

Table 9. Blooming Plants at MS-1 with coverage 0.5% or greater.

Common Name	Scientific Name	Peak Bloom	Bloom Period	% Coverage	Classification
Forbs					
Spring draba	*Draba verna*	March	Mar - April	20	Non-native
Slender phlox	*Microsteris gracilis*	March	Mar - April	0.5	Native
Annual polemonium	*Polemonium micranthum*	April	Mar - April	0.5	Native
Jim Hill's tumblemustard	*Sisymbrium altissimum*	April	April - May	2	Non-native
Jagged chickweed	*Holosteum umbellatum*	April	April	0.5	Non-native
Matted cryptantha	*Cryptantha circumscissa*	May	April - May	3	Native
Tarweed fiddleneck	*Amsinckia lycopsoides*	May	April - May	0.5	Native
Wingnut cryptantha	*Cryptantha pterocarya*	May	April - May	0.5	Native
Bastard toadflax	*Comandra umbellata*	May	May	0.5	Native
Pale-evening primrose	*Oenothera pallida*	May	May - Aug	0.5	Native
Turpentine springparsley	*Cymopterus terebinthinus*	May	May	0.5	Native
Prairie clover	*Dalea ornata*	June	May - June	1	Native
Slender hawksbeard	*Crepis atribarba*	May	May	0.5	Native
Douglas' dustymaiden	*Chaenactis douglasii*	June	May - June	0.5	Native
Western yarrow	*Achillea millefolium*	June	May - June	0.5	Native
Tufted wirelettuce	*Sephanomeria paniculata*	July	July - Aug	0.5	Native
Hoary tansyaster	*Machaeranthera canescens*	Sept	Aug - Oct	0.5	Native
Bailey's buckwheat	*Eriogonum baileyi*	Aug	Aug	0.5	Native
Shrubs					
Antelope bitterbrush	*Purshia tridentata*	May	May	4	Native
Green rabbitbrush	*Chrysothamnus viscidiflorus*	Oct	Sept - Oct	4	Native
Grey rabbitbrush	*Ericameria nauseosa*	Oct	Sept - Oct	4	Native

Figure 41. Bitterbrush blooming at the Mixed Shrub 1 Site in May.

The MS-1 site is unique due to its lack of floral diversity and low bloom coverage. As there were few plants blooming in this site at any one time, it is easier to tie peaks in bloom coverage with a single plant species. MS-1 experienced two peaks in bloom coverage, one in early May and the other in September, both due to flowering shrubs. The two peaks in bee abundance at this site seem to correspond with two distinct bloom events (Figure 42). The most bees were collected at MS-1 the week of April 25, 2017, the week before the bitterbrush began heavily blooming. The second spike in bee abundance occurs in June, the same month where prairie clover bloomed and a large number of bees were observed foraging on prairie clover. Though prairie clover did not cover a large percentage of the site, it seemed to attract a disproportionately large amount of bees. Of the 18 bees observed at MS-1, 17 of these were observed foraging on prairie clover. Though there was a slight uptick in bee abundance in September, this only represents two bees collected in 1 week and is not necessarily tied to the corresponding rabbitbrush bloom. No correlations existed between bee abundance and bloom coverage.

One hundred and seventeen bees, 32 butterflies, and 1 moth were collected at the MS-1 site. This was the second lowest number of bees collected at any study site but the greatest number of butterflies. Though this site had lower total numbers of bees, 11 groups of bee were collected here, which is a relatively high diversity when compared to the other study sites (Figure 43). No significant correlations between bloom coverage or diversity and bee abundance or diversity were found. The most abundant group collected was *Lasioglossum*, followed by *Agapostemon* and *Halictus.* Additionally, before the official April 25, 2017, study start date, a single specimen of both *Lithurgopsis* and *Melecta* were collected at MS-1. These specimens represented the only individuals of those genus collected throughout the entire study.

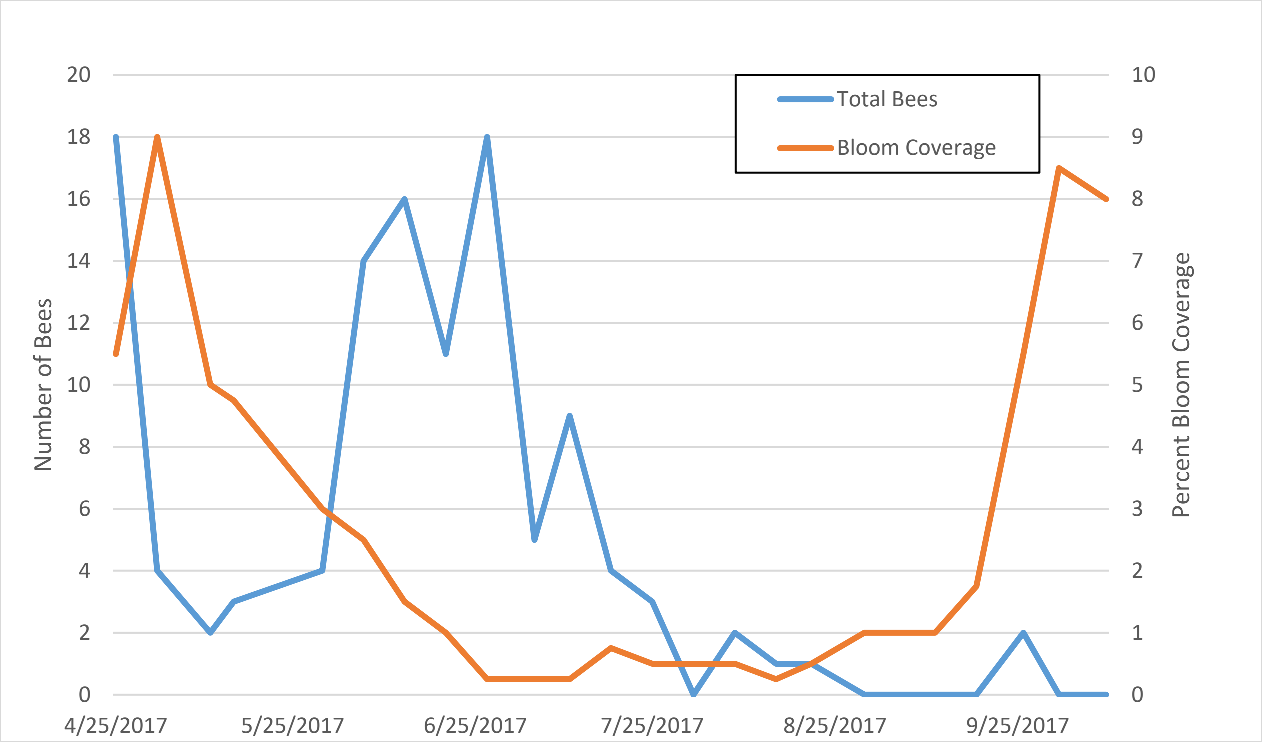

Figure 42. Bloom coverage and bee abundance at MS-1.

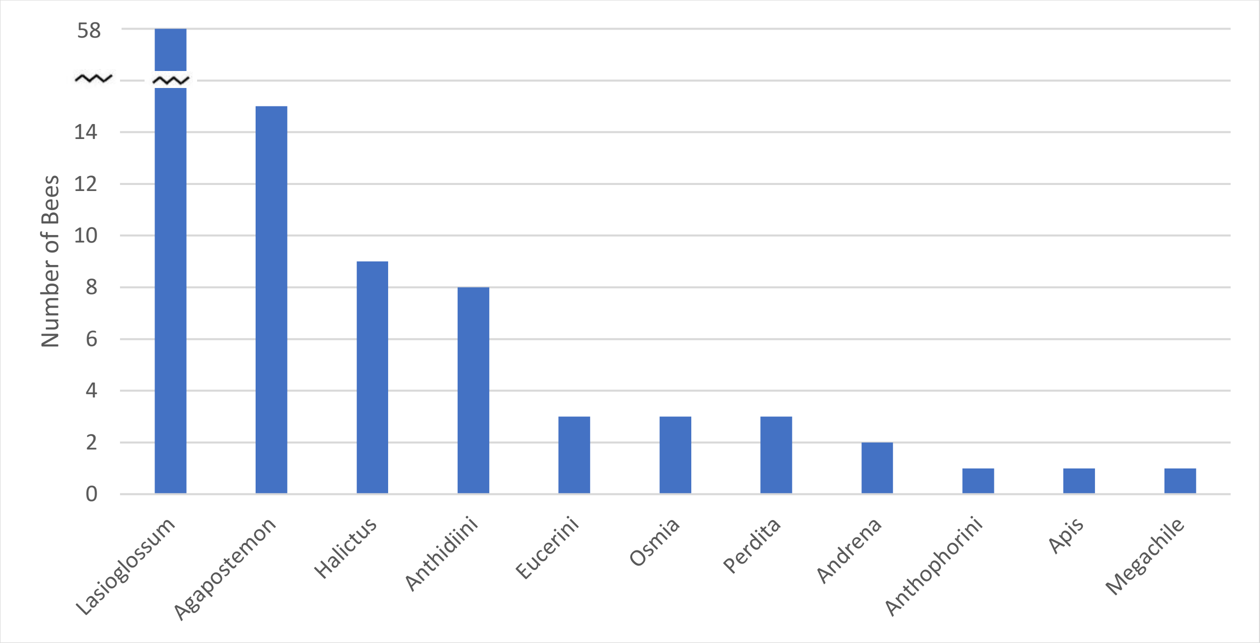

Figure 43. Groups of bees collected at MS-1, 4/25/2017 - 10/10/2017.

4.2.3.2 Late Successional Mixed Shrub Site 2 (MS-2). The MS-2 study site is located in the same semi-stabilized sand dune complex as EC-2 and SG-2. This site is within the same Washington State Plant Community Element Occurrence - Bitterbrush/Indian Ricegrass Sand Dune Complex as MS-1 (Easterly et al. 2017). The soil at this site is mostly Quincy Sand (approximately 85%) with some Loamy Sand (approximately 15%). The overstory of this site is dominated by antelope bitterbrush (15% coverage), big sagebrush (7% coverage), and grey rabbitbrush (6% coverage) (Figure 44). Cheatgrass dominates the understory (about 35% coverage) and this site does not have extensive blooming resources, similar to MS-1 (Table 10). Spring draba provided bloom coverage for a few weeks in the early spring (25% coverage), and buckwheat milkvetch (3% coverage, *Astragalus caricinus*) and Douglas' dustymaiden (1% coverage, *Chaenactis douglasii*) provided blooms in the late spring and summer. Antelope bitterbrush provided blooms (15% coverage) for a few weeks in May. Grey rabbitbrush (6% coverage) and snow buckwheat (3% coverage) bloomed in the fall.

Table 10. Blooming plants at MS-2 with coverage 0.5% or greater.

Common Name	Scientific Name	Peak Bloom	Bloom Period	% Coverage	Classification
Forbs					
Spring draba	*Draba verna*	March	Mar - April	25	Non-native
Jim Hill's tumblemustard	*Sisymbrium altissimum*	April	April - May	2	Non-native
Bulbous woodland-star	*Lithophragma glabrum*	April	April	0.5	Native
Slender phlox	*Microsteris gracilis*	April	April	0.5	Native
Turpentine springparsley	*Cymopterus terebinthinus*	May	April - May	1	Native
Tarweed fiddleneck	*Amsinckia lycopsoides*	April	April	0.5	Native
Upland larkspur	*Delphinium nuttallianum*	May	April - May	0.5	Native
Wingnut cryptantha	*Cryptantha pterocarya*	May	April - May	0.5	Native
Stalked-pod milkvetch	*Astragalus sclerocarpus*	May	May	0.5	Native
Long-leafed phlox	*Phlox longifolia*	May	May	0.5	Native
Carey's balsamroot	*Balsamorhiza careyana*	May	May	0.5	Native
Matted cryptantha	*Cryptantha circumscissa*	May	May	0.5	Native
Buckwheat milkvetch	*Astragalus caricinus*	May	May	3	Native
Western yarrow	*Achillea millefolium*	June	May - June	0.5	Native
Threadleaf phacelia	*Phacelia linearis*	May	May	0.5	Native
Douglas' dustymaiden	*Chaenactis douglasii*	June	May - July	1	Native
Dune scurfpea	*Psoralea lanceolata*	June	June	0.5	Native
Snow buckwheat	*Eriogonum niveum*	Sept	Aug - Oct	3	Native
Hoary tansyaster	*Machaeranthera canescens*	Sept	Aug - Sept	0.5	Native
Rush skeletonweed	*Chondrilla juncea*	August	August	1	Non-native
Shrubs					
Antelope bitterbrush	*Purshia tridentata*	May	May	15	Native
Grey rabbitbrush	*Ericameria nauseosa*	Oct	Sept - Oct	5	Native

Figure 44. Antelope bitterbrush blooming at the Mixed Shrub 2 Site in May.

The MS-2 site had few features that set it apart when compared to the other study sites. The peak in bloom coverage occurred when bitterbrush reached full bloom in early May (Figure 45). Bloom coverage steadily declined until June, then pulsed again in September. Two plant species accounted for the majority of the pollinator observations at this site. Twelve bees were observed foraging on snow buckwheat and six bees were observed foraging on Douglas' dustymaiden. Douglas' dustymaiden was the only plant recorded blooming at this site in July. Snow buckwheat accounted for the peak in bloom coverage in September and may have also accounted for the corresponding increase in bees collected at this site.

One hundred and sixty-four bees, three butterflies, and two moths were collected from MS-2 over the course of this study. The number of bees collected peaked the week of June 13,2017. Ten different groups of bee were collected from this site over the course of the study (Figure 46). The majority of bees collected were *Lasioglossum* followed by *Megachile*. Notably, a large number of *Eucerini* and *Diadasia* bees were collected at this site. No significant correlation was detected between bloom coverage or diversity and bee abundance or diversity.

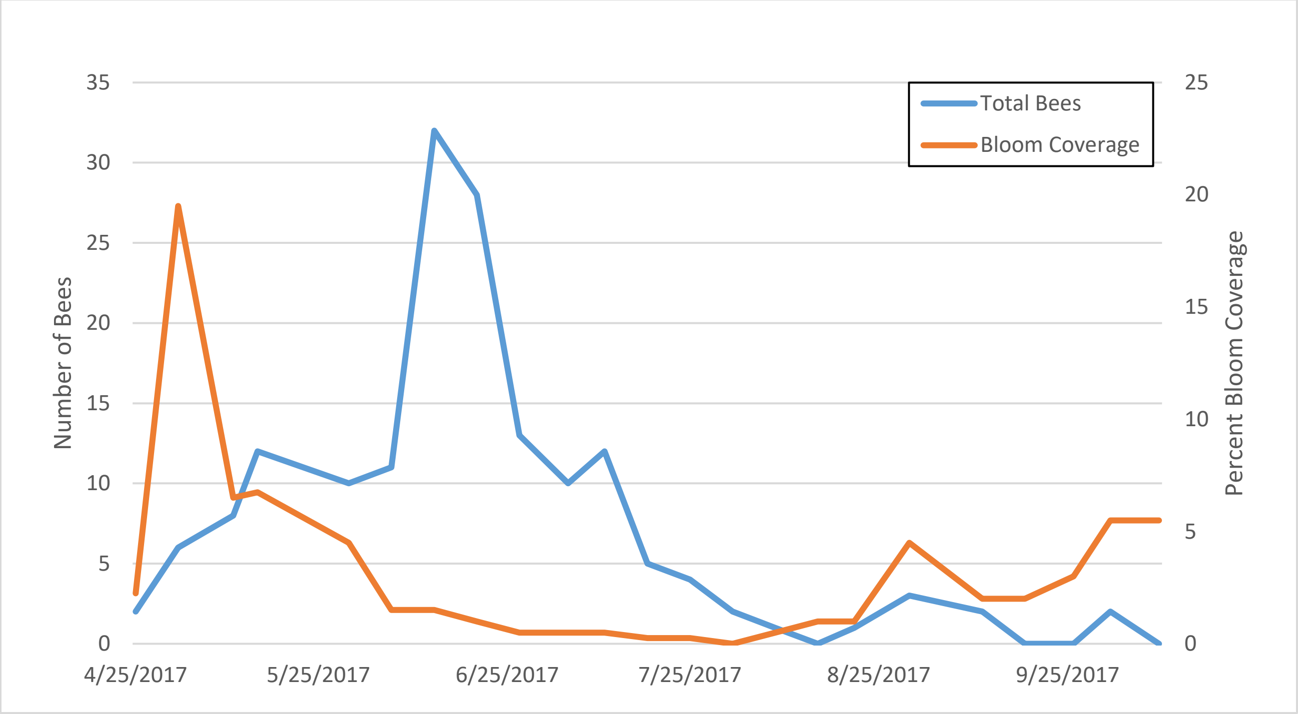

Figure 45. Bloom coverage and bee abundance at MS-2.

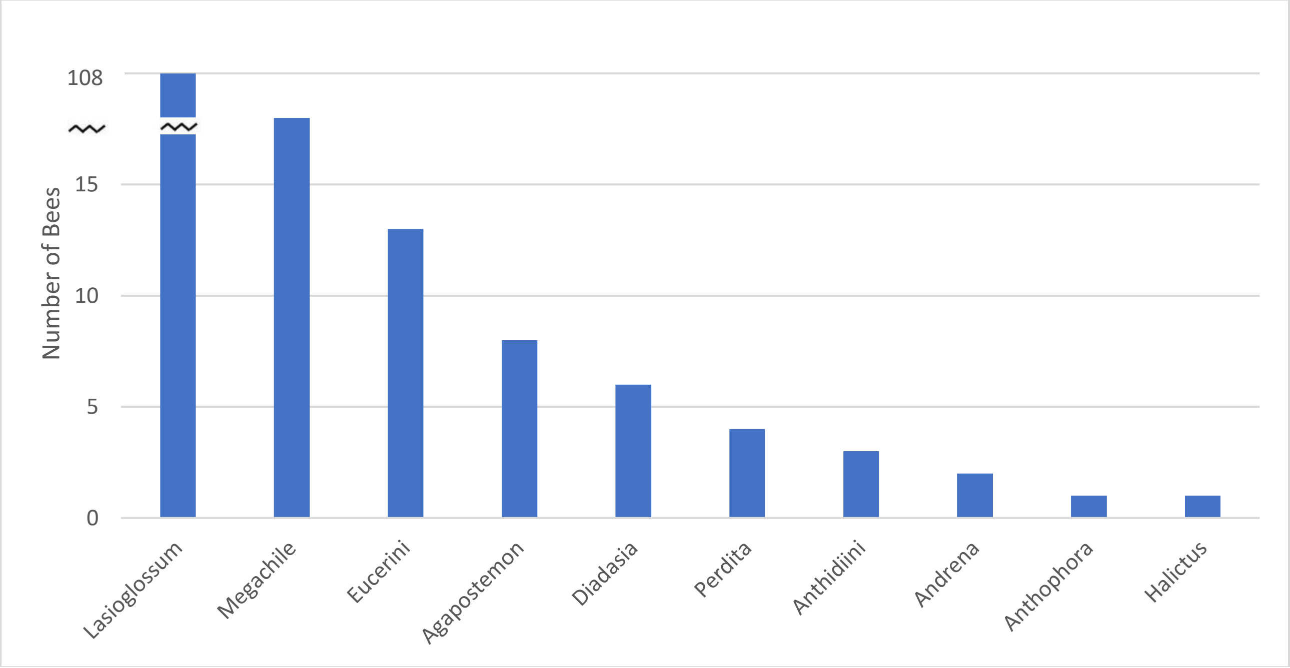

Figure 46. Groups of bees collected at MS-2, 4/25/2017 - 10/10/2017.

4.2.4 Late Successional Sagebrush Sites

4.2.4.1 Late Successional Sagebrush Site 1 (SB-1). The SB-1 study site is located approximately 3,000 m from the Columbia River and 7,500 m from farmland. The soil type is Burbank Loamy Sand. This site is located within a stretch of high quality shrub-steppe habitat southeast of Gable Mountain. The overstory of this site is primarily big sagebrush (30% coverage) with some grey rabbitbrush (3% coverage), green rabbitbrush (2% coverage), and antelope bitterbrush (< 1% coverage). The dominant understory grass was cheatgrass (25% coverage) and Sandberg's bluegrass (7% coverage). The understory of this site hosts a variety of blooming plants throughout all seasons (Table 11). Carey's balsamroot (3% coverage), western yarrow (1% coverage*, Achillea millefolium*), and turpentine springparsley (1% coverage) make up the majority of the understory blooming plants; these plants bloomed in the spring and early summer. Hoary tansyaster (1% coverage) and green and grey rabbitbrush bloomed in the fall. This site is within a Big Sagebrush/Sandberg's Bluegrass–Cheatgrass mosaic (Easterly et al. 2017).

Table 11. Blooming Plants at SB-1 with coverage 0.5% or greater.

Common Name	Scientific Name	Peak Bloom	Bloom Period	% Coverage	Classification
Forbs					
Spring draba	*Draba verna*	March	Mar - April	2	Non-native
Slender phlox	*Microsteris gracilis*	March	Mar - April	0.5	Native
Yellowbells	*Fritillaria pudica*	April	Mar - April	1	Native
Jagged chickweed	*Holosteum umbellatum*	April	April	0.5	Non-native
Jim Hill's tumblemustard	*Sisymbrium altissimum*	April	April - May	0.5	Native
Turpentine springparsley	*Cymopterus terebinthinus*	May	April - May	1	Native
Carey's balsamroot	*Balsamorhiza careyana*	May	April - May	3	Native
Matted cryptantha	*Cryptantha circumscissa*	May	April - May	1	Native
Tarweed fiddleneck	*Amsinckia lycopsoides*	May	April - May	1	Native
Threadleaf phacelia	*Phacelia linearis*	May	April - May	0.5	Native
Long-leafed phlox	*Phlox longifolia*	April	April - May	0.5	Native
Western yarrow	*Achillea millefolium*	June	May - June	1	Native
Bastard toadflax	*Comandra umbellata*	May	May	0.5	Native
Rosy gilia	*Gilia sinuata*	May	May	0.5	Native
Douglas' dustymaiden	*Chaenactis douglasii*	June	May - June	0.5	Native
Slender hawksbeard	*Crepis atribarba*	May	May - June	0.5	Native
Pale-evening primrose	*Oenothera pallida*	June	June - Sept	0.5	Native
Threadleaf fleabane	*Erigeron filifolius*	June	June - July	0.5	Native
Hoary tansyaster	*Machaeranthera canescens*	Sept	Aug - Oct	1	Native
Rush skeletonweed	*Chondrilla juncea*	August	August	0.5	Non-native
Shrubs					
Antelope bitterbrush	*Purshia tridentata*	May	May	0.5	Native
Grey rabbitbrush	*Ericameria nauseosa*	Oct	Sept - Oct	1	Native
Green rabbitbrush	*Chrysothamnus viscidiflorus*	Oct	Sept - Oct	2	Native

Figure 47. Balsamroot at the Late Successional Sagebrush 1 Site in May.

The SB-1 site is an example of high quality, intact sagebrush habitat with a healthy and diverse forb understory (Figure 47). The majority of the floral resources at SB-1 were available in May and October, leading to two distinct pulses in bloom coverage at this site (Figure 48). This two-pulse pattern in bloom coverage matched the majority of the other sites. The plant community at SB-1 showed fairly low levels of non-native plant invasion. SB-1 had the second lowest number of pollinator observed, second to SB-2. Of the observations, five bees were observed foraging on Carey's balsamroot and three bees were observed foraging on threadleaf phacelia and yellowbells. This site did not have species that seemed to attract a large number of bees (e.g., snow buckwheat and prairie clover).

One hundred and fifty-five bees, 11 butterflies, and 1 moth were collected at SB-1, placing this site on the lower end of total bee abundance when compared to the other study sites. Bee abundance peaked for 2 weeks at the end of June with 17 bees collected each week. As is clear in Figure 48, there is a significant inverse relationship between bloom coverage and bee abundance at this site (r = -0.33, p = 0.04). Despite the relatively low bee abundance, 12 groups of bees were found at this site, which was the second highest diversity found in any site in the study (Figure 49). Notably, 11 *Diadasia* bees were collected at this site. The majority of *Diadasia* bees were collected at the SB-1 and SB-2 sites. *Lasioglossum* was the most common bee at this site and made up 37% of all bees collected.

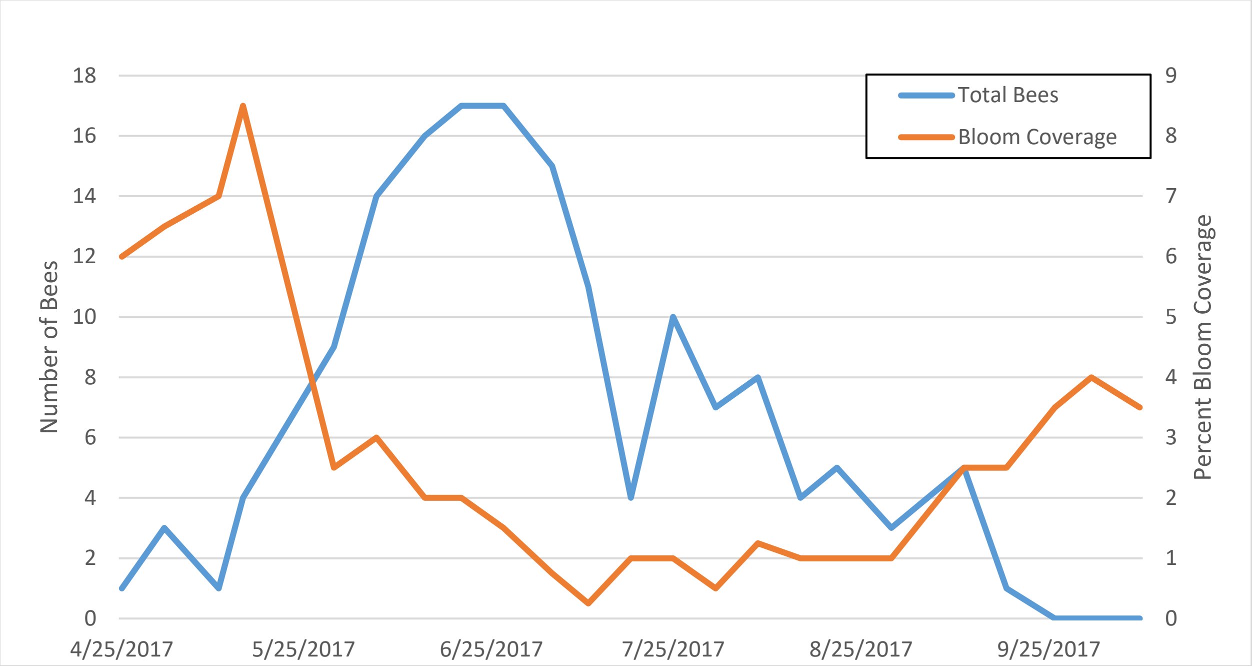

Figure 48. Bloom coverage and bee abundance at SB-1.

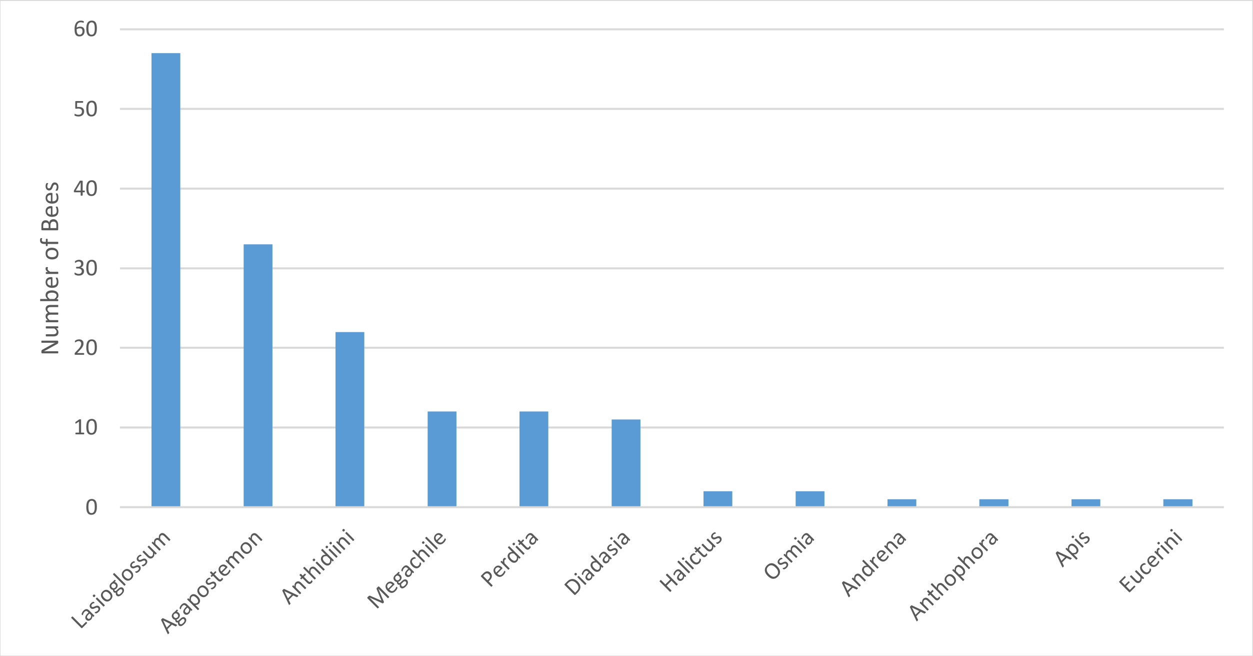

Figure 49. Groups of bees collected at SB-1, 4/25/2017 - 10/10/2017.

4.2.4.2 Late Successional Sagebrush Site 2 (SB-2). The SB-2 study site is located near central Hanford, within a Big Sagebrush/Sandberg's Bluegrass-Cheatgrass mosaic (Easterly et al. 2017). The soil type is Burbank Loamy Sand. The overstory of this site is primarily big sagebrush (35% coverage) with spiny hopsage (2% coverage) interspersed. The understory of this site is primarily cheatgrass (40% coverage). In the spring, spring draba (25% coverage), long-leafed phlox (2% coverage), yellowbells (1% coverage), Carey's balsamroot (1% coverage), whitedaisy tidytips (1% coverage, *Layia glandulosa*), and buckwheat milkvetch (1% coverage) were the main species providing bloom coverage (Figure 50). Douglas' dustymaiden (1% coverage) bloomed into June. Past June, few flowers were available for pollinators at this site (Table 12).

Table 12. Blooming Plants at SB-2 with coverage 0.5% or greater.

Common Name	Scientific Name	Peak Bloom	Bloom Period	% Coverage	Classification
Forbs					
Spring draba	*Draba verna*	March	Mar - April	25	Non-native
Yellowbells	*Fritillaria pudica*	March	Mar - April	1	Native
Slender phlox	*Microsteris gracilis*	March	Mar - April	0.5	Native
Jagged chickweed	*Polemonium micranthum*	March	March	0.5	Non-native
Bigseed desert-parsley	*Lomatium macrocarpum*	April	April - May	0.5	Native
Jim Hill's tumblemustard	*Sisymbrium altissimum*	April	April - June	0.5	Non-native
Long-leafed phlox	*Phlox longifolia*	April	April - May	2	Native
Wingnut cryptantha	*Cryptantha pterocarya*	April	April - May	0.5	Native
Upland larkspur	*Delphinium nuttallianum*	April	April	0.5	Native
Tarweed fiddleneck	*Amsinckia lycopsoides*	April	April - May	0.5	Native
Carey's balsamroot	*Balsamorhiza careyana*	May	April - May	1	Native
Whitedaisy tidytips	*Layia glandulosa*	May	April - May	1	Native
Showy Townsend daisy	*Townsendia florifer*	May	April - June	0.5	Native
Largeflower triteleia	*Triteleia grandiflora*	May	May	0.5	Native
Matted cryptantha	*Cryptantha circumscissa*	May	May	0.5	Native
Buckwheat milkvetch	*Astragalus caricinus*	May	May	1	Native
Slender hawksbeard	*Crepis atribarba*	May	May - June	0.5	Native
Sagebrush mariposa lily	*Calochortus macrocarpus*	May	May	0.5	Native
Douglas' dustymaiden	*Chaenactis douglasii*	June	May - July	1	Native
Western yarrow	*Achillea millefolium*	June	May - June	0.5	Native
Yellow salsify	*Tragopogon dubius*	July	July - Aug	0.5	Non-native
Tufted wirelettuce	*Stephanomeria paniculata*	July	July	0.5	Native
Bailey's buckwheat	*Eriogonum baileyi*	Aug	Aug - Sept	0.5	Native
Hoary tansyaster	*Machaeranthera canescens*	Sept	Aug - Sept	0.5	Native

Figure 50. Phlox and balsamroot at the SB-2 Site in April.

Like SB-1, SB-2 provided a wide array of native floral resources through April and May. SB-2 had a higher cheatgrass cover than SB-1 but had similar bloom coverage. Bloom coverage was still present through most of June, then experienced another slight pulse in September (Figure 51). Bees observed at SB-2 were seen in April, May, and June. Only seven bees were observed foraging at SB-2, making it the study site with the least observations. Two of these bees were observed foraging on showy Townsend daisy. The remainder of the observations were scattered among yellowbells, balsamroot, phlox, whitedaisy tidytips, and yarrow. Like SB-1, this site did not have species that seemed to attract a large number of bees (e.g., snow buckwheat and prairie clover).

One hundred and ninety-four bees, four butterflies, and six moths were collected from SB-2, which lands in the middle-range of all the site abundances. Bee abundance peaked at this site for 2 weeks in mid-June, where 27 bees were collected per week. Bee abundance experienced another peak the first week of August where 22 bees were collected. Ten groups of bee were found at the SG-2 site (Figure 52). There was no significant correlation between bloom coverage or diversity and bee abundance or diversity at this site. *Agapostemon*, or green sweat bees, dominated the bee groups at this site making up 39% of bees collected. The highest number of *Diadasia* were collected at SG-2.

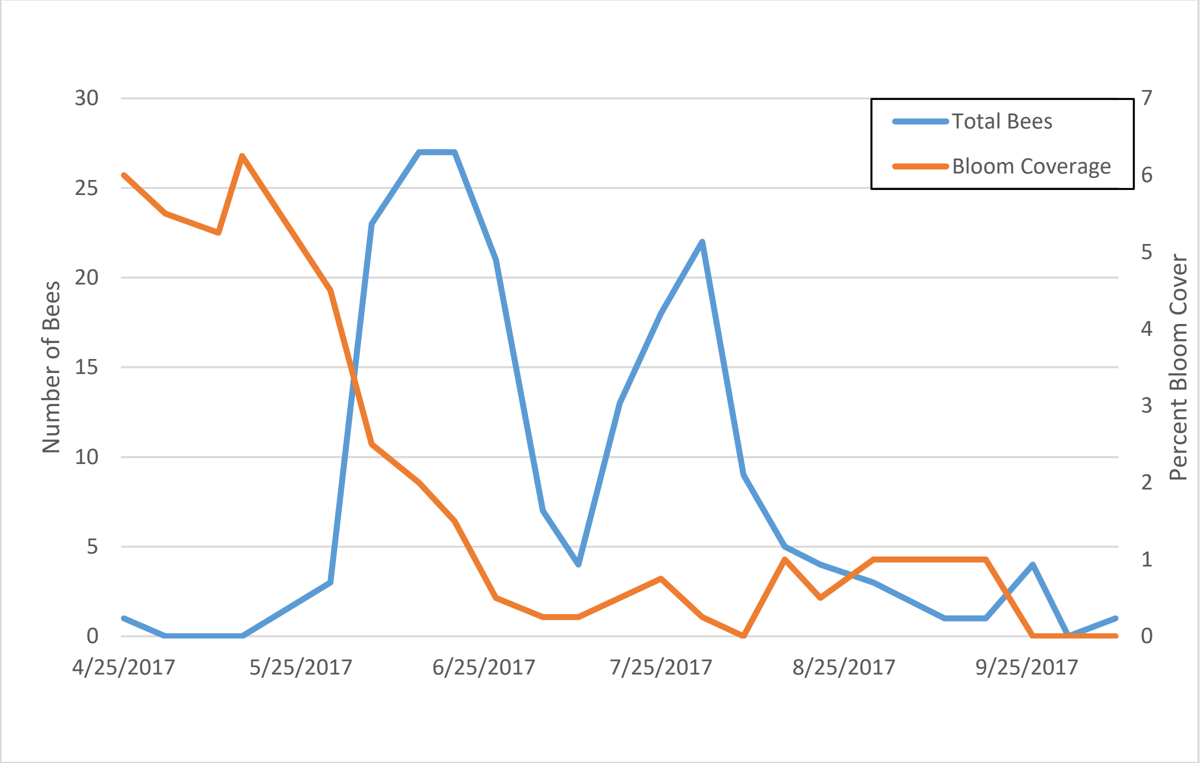

Figure 51. Bloom coverage and bee abundance at SB-2.

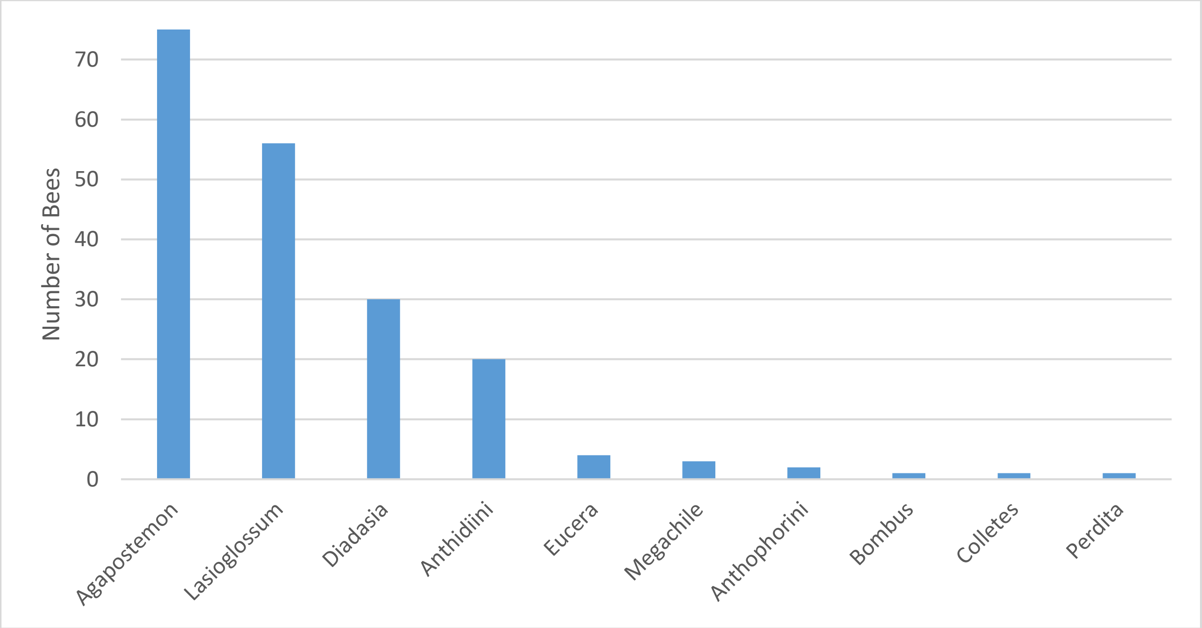

Figure 52. Groups of bees collected at SB-2, 4/25/2017 - 10/10/2017.

5.0 Discussion

This section describes the implications of the results presented in Section 4.0. The goal of this section is to evaluate the data collected throughout the study and describe its significance in terms of increasing understanding about the pollinator populations at the Hanford Site and in impacting biological resource management. This section evaluates how the study results inform future pollinator-focused revegetation and habitat creation efforts. Additionally, this section describes possible biases with the pan trapping method and variables encountered throughout the study.

Each section includes BMPs or general guidelines recommended for use at the Hanford Site that support the health of native bees and other pollinators on the Hanford Site. Though the active footprint of the Hanford Site will continue to shrink as projects are becoming more limited to the 200 Areas, various human-related disturbances still occur throughout the less developed portions of the Hanford Site. The majority of these BMPs, in addition to this entire report, are meant to be taken into consideration when evaluating the biological impacts of a project when determining alternative routes or project areas, and when prescribing mitigation actions to reduce biological impact.

5.1 Bee Abundance and Diversity throughout the Hanford Site

Results from this study suggest that the Hanford Site has abundant and diverse native bee populations, consistent with findings in the report *Entomological Diversity Inventory and Analysis at the Hanford Site* (Zack 1997) and consistent with findings that semi-desert, arid environments support great abundances of native bees (Linsley 1958, Koh et al. 2016). This study identifies native bees as the primary pollinating insect at the Hanford Site, consistent with Tepedino and Griswold's conclusions that native bees are the primary insect pollinators of the Columbia River Basin (Tepedino and Griswold 1995). The presence of natural habitat at the Hanford Site, relatively undisturbed by agriculture and human development, provides refuge for a diverse group of native bees. As such, protecting these bee populations will be vital to the health of the overall environment at the Hanford Site.

Twenty-five unique morphological groups of bees were identified over the course of this study. This number underestimates the species diversity seen on the Hanford Site, as bees were identified only to the Tribe or Genus level, and these groups each contain many species. Future studies that identify bees to the species level will provide crucial data regarding species diversity and distribution and will likely identify species that are rare or endemic to the Hanford Site.

Diversity and abundance were significantly positively correlated, suggesting that protecting sites with high numbers of bees will inherently protect diverse groups of bees. This method could act as a simple way to protect both abundance and diversity in important bee habitats but would overlook specialized species of bee that are restricted to the same habitat as their host plant. One specialized group of bees present in our study were *Diadasia* bees, most species of which are specialists on globemallow (*Sphaeralcea* sp.) or cactus (*Cactaceae* sp.). If more bees are identified to the species level, more specialized species of bee will likely be discovered.

When site features were compared, sandy soil sites contained more bees than loamy soil sites. The majority of the sandy soil sites were located in the dune and grassland systems. A number of factors likely contributed to this increase in abundance. The sandy soil and loamy soil sites had similar vegetative diversity but sandy soil sites had more floral resources available. This factor may have contributed to the increased number of bees at sandy soil sites.

Soil substrate is an important habitat feature to ground-nesting bees, which make up the majority of bees collected in this study. A total of 84% of *Lasioglossum* bees, the most abundant group of ground nesting bees in this study, were collected in sandy soil sites, suggesting sandy soil may be preferable to some species of ground nesting bee. Another soil-related factor that may impact bee distribution is the amount of bare ground present. Bare ground acts as nesting habitat for ground-nesting bees. Availability of bare ground may be higher in sandy soil habitats, specifically semi-stabilized dune systems where patches of open sand are an indicator of a healthy dune (Figure 53). Further investigation regarding soil substrate effects on ground nesting bee abundance and diversity is needed before any definite conclusions can be made.

Figure 53. Patches of open sand at the EC-2 site, 5/2/2017.

The only ecological system that had significantly more bees than the other systems was the Columbia Plateau Steppe and Grassland System (represented by SG-1). Though this warrants further investigation, only one study site fell within this ecological system and this finding does not have a strong basis. Other attributes of the SG-1 site likely contributed to the high abundance of bees. When comparing sites by habitat type, both the late successional sagebrush and late successional mixed shrub sites had significantly lower bee abundance when compared to the other habitat types. In the context of this study, this implies that the late successional sites had a relatively lower abundance when compared to the other sites and does not imply that the late successional sites are also not important bee habitat.

The Late Successional Sagebrush sites and Early Colonizing sites both disproportionately supported certain types of bees (e.g., *Anthidiini, Diadasia, Anthophorini,* and *Megachile*). This suggests that local habitat structure, including soil type and vegetation, may be more important to certain groups of bees than others. *Diadasia*, for example, is a specialist bee with a range restricted to that of its host plant, globemallow, which grows in sagebrush habitats and was likely growing near the Late Successional Sagebrush sites. These trends indicate that areas that may not have relatively high bee abundance, like the Late Successional Sagebrush areas, are still greatly important to certain groups of bees. The loss of local habitat would impact different bees in different ways. These trends indicate that more investigation may show greater variation in local habitat use between different groups of bees.

As was presented in Section 4.0, individual sites varied in both pollinator abundance and diversity. The two sites with the greatest bee abundance, Steppe Grassland 1 (SG-1) and Early Colonizer 2 (EC-2), are quite different from one another. The SG-1 site is dominated by non-native plants and has relatively low bloom coverage; there are hardly any bare patches of soil or dead sagebrush stumps to act as nesting areas. Despite this, bees were the most abundant and the most diverse at this site. A few factors may have contributed to this. SG-1 was the closest site to the Columbia River, and water is a rare resource on the Hanford Site and necessary to bees' survival. Despite the lack of blooms at SG-1, bees may have been traversing the site in search of water, especially in the late summer when water resources were rare. Also during the late summer, most of the non-native plants at SG-1 bloomed. During these months few other floral resources were available to pollinators and the non-native species provided nectar and pollen to bees when nothing else was available. This was the only site with bee abundance peaking in July lining up with these events. The combination of close proximity to water and a later peak bloom may have made SG-1 a refuge for bees, especially in the late summer.

The EC-2 site had a diverse array of native plants and few non-native plants. This site is an exceptional example of a healthy, diverse dune ecosystem with patches of open sand providing potential nesting areas to bees. The native plants at EC-2 bloomed throughout the entire season when bees are active, providing a diverse array of floral resources and food to bees. The flowering plants at EC-2 also varied greatly in size and shape. This may have been important in attracting both large and small types of bees. Small native plants like wingnut cryptantha, slender phlox, and rosy gilia were all present and abundant at this site. Small-bodied *Lasioglossum* bees were the dominant group of bee at EC-2, and a group of these bees were observed pollinating wingnut cryptantha at this site. The small native plants may attract and depend on small-bodied bees like *Lasioglossum* for pollination. EC-2 also had various species of plants with large flowers, like pale-evening primrose and sharpleaf penstemon, which are attractive to larger-bodied bees (Figure 54). Also important are moderately-sized flowers, like threadleaf phacelia, which can provide resources to large, medium, and small bees alike (Figure 55). Having diversity within the size of the flowers available to bees may have increased the number of different species this site could support. This, along with the dune habitat structure and diversity of plant bloom times at this site likely supported the abundant bee populations at EC-2.

The Steppe Grassland 2 (SG-2) site was located on the sand dunes and had high native plant diversity, though it had less bloom coverage than the nearby EC-2 site. Similar to EC-2, the SG-2 sites provided floral resources for pollinators in both May and September. SG-2 had higher cheatgrass cover than EC-2 and less patches of open sand. Despite this, SG-2 had a fairly high bee abundance and supports the conclusion that dune habitat structure and diverse blooming resources support abundant bee populations.

Figure 54. A large-bodied bee preparing to pollinate sharpleaf penstemon at EC-2.

Figure 55. A Lasioglossum bee on threadleaf phacelia at EC-2.

Other sites, though they did not have the most bees collected, had notable attributes that warrant discussion. The Late Successional Sagebrush Site (SB-1) had the second highest bee diversity, despite low bee abundance. SB-1 had a low level of non-native plant invasion and is an intact, mature sagebrush community. This site had the lowest cheatgrass cover among all of the study sites and a large amount of bare soil areas throughout and surrounding the site. This suggests that along with native plants, having a low level of cheatgrass invasion, which can result in higher bare ground, is important to hosting a diverse guild of bees. In this case, less cheatgrass may allow patches of loamy soil to be utilized as nesting areas for bees.

The Late Successional Mixed Shrub 1 (MS-1) site is another example of a site with high bee diversity despite low bee abundance. Two unique groups of bees were collected at this site. This study site is within a unique black sand dune formation, which is small in extent and not found elsewhere on the Hanford Site. Though this dune system is small, it has the potential to provide unique habitat for bees that may not otherwise be found on site due to its unique soil properties.

Sites that fell in the middle of bee abundance and diversity measurements were Late Successional Sagebrush 2 (SB-2) and Late Successional Mixed Shrub 2 (MS-2). Though the SB-2 site had a diverse guild of flowering plants, they did not provide much bloom coverage. Past June there were few floral resources available to pollinators at this site and pollinators were rarely observed here. The MS-2 site was similar in that it also had a diverse guild of flowering plants but generally had low bloom coverage with the exception of the bitterbrush bloom in May. The MS-2 site highlighted the importance of flowers that bloom in the summer and fall; the majority of bees observed here were on Douglas' dustymaiden in the summer and snow buckwheat in the fall. Douglas' dustymaiden was the only plant blooming at this site in July, providing floral resources when they were otherwise scarce.

The Early Colonizing Site 1 (EC-1) had the lowest bee abundance of all the sites. The initial peak in bees collected occurred concurrently with the prairie clover bloom and with increased observations of bees at this site. During the snow buckwheat bloom in September, which covered a large area of the study site, few bees were collected. More bees were observed foraging on prairie clover than snow buckwheat. A possible explanation for this is that less bees are active in September than in June, so though snow buckwheat provided abundant floral resources, there were less bees to take advantage of it. Another possible explanation is that bees were more attracted to the snow buckwheat surrounding the pan trap than the pan trap itself. This may have been compounded by the pan trap and snow buckwheat both being white but this is speculative. The potential competition between blooming plants and pan traps is discussed in Section 5.4.

Best Management Practices – Supporting Bee Abundance and Diversity

Protect sandy soil areas to preserve valuable bee habitat.

Explanation: This study indicates that sandy soil areas provide habitat for abundant bee populations.

Implementation: Quincy Sand, Hezel Sand, and Dune Sand soil types make up the majority of the DOE-managed portion of the Hanford Site. The best way to avoid negatively effecting bee populations in these areas will be to avoid removing large areas of native vegetation. If possible, routing construction projects to avoid these areas will be key to keeping these habitats intact. Minimizing off-road traffic in these areas will also reduce bee fatalities and habitat fragmentation. If avoidance is not possible, projects that are required to mitigate for biological impacts should focus part of their mitigation efforts on creating or enhancing bee habitat in a nearby, sandy soil area. Enhancing bee habitat refers to supplementing the area with forb plugs, bee nest boxes, or removing non-native weeds to increase bare soil availability.

Protect unique habitat areas and features.

Explanation: Unique habitat areas, like the Hanford Black Sand Dunes, appear to provide habitat for bees that are not commonly found elsewhere on the Hanford Site. Loss of these habitats may result in a decrease in local bee diversity.

Implementation: The majority of unique habitat areas on the Hanford Site obtain some level of protection from the BRMP. Increasing awareness of the importance of these habitats to bee diversity helps to validate the continued protection of these areas.

Protect vegetated areas within 2,000 m of natural water resources.

Explanation: Sites near the Columbia River had high numbers of both observed and collected bees. Vegetated areas near water resources may be of increased importance to bees in the late summer when water is scarce.

Implementation: The best way to avoid negatively effecting bee populations in these areas will be to avoid removing large areas of native vegetation. If avoidance is not possible, projects that are required to mitigate for biological impacts should focus part of their mitigation efforts on creating or enhancing bee habitat in a nearby area. More research is required regarding pollinator-supporting riparian plants in our region.

Restore both vegetation and nesting areas.

Explanation: Both habitat structure and vegetation availability appear to play a role in supporting abundant and diverse pollinator populations.

Implementation: If habitat is to be removed, take note of the habitat structure and vegetation present previous to disturbance. Restoring the disturbed area by revegetating will be essential to replace lost bee habitat. If the disturbed area cannot be restored, enhancing or creating bee habitat in a nearby area can help support affected pollinators. Habitat creation can be achieved by identifying an area with lower quality vegetation and a high amount of non-native species, as well as restoring the area by controlling non-native species and planting native grasses and forbs. The appropriate native forbs are identified in the BMPs for Section 5.3, and the appropriate native grasses are identified in the *Hanford Site Revegetation Manual*. Habitat can also be improved with the installation of bee nest boxes to replace lost nesting areas for above-ground nesting bees. Bees that nest below ground can be supported by the creation of bare patches of sand for them to nest in. Controlling cheatgrass and other non-native plant invasion will be necessary to maintain these bare patches of sand.

Restore habitat areas near the disturbed site.

Explanation: In some construction projects, avoidance is not possible. The majority of native bees collected in this study are small-bodied bees, which can have small ranges, making local habitat structure important to their survival. Restoring areas within the ranges of these bees can help increase the resilience of the affected population.

Implementation: If the disturbed site cannot be replanted, the project may be required to restore habitat elsewhere. Restoring or enhancing habitat near the removed vegetation (less than 500 m away) will be essential, as native bees have fairly small ranges and changes in local habitat can greatly affect them. Restoring this habitat as quickly as possible will also be important to the health of the bee population.

Aim restoration projects to support locally abundant species.

Explanation: In some habitats, certain groups of bees were found to be more abundant than others. Restoration projects should take this into consideration when planning the vegetation or habitat structures that will be used so that the project best supports the bees in that area.

Implementation: Identify if there are dominant groups of bees in the restoration area. The data from this study can be used to identify dominant groups of bees in certain habitat types. Plan to restore with plants that support the seasonality of these bees by blooming when the bees are active. For example, *Diadasia* bees were more commonly found in sagebrush areas in this study. By replanting sagebrush areas with globemallow, restoration projects would help support this group of bee. It is also important to consider the nesting habits of abundant bees in that habitat. Installing nest boxes for above-ground nesting bees and leaving areas of bare soil for below-ground nesting bees are both important actions to support local bee health.

5.2 Seasonality of Pollinators

Pollinators were collected every week that this study was conducted, with considerable variation in abundance between weeks. Seasonality of bees varied among families and different groups within the same family. Though all bee families peaked in the month of June (with the exception of Colletidae, which had no defined peak), Apidae and Megachilidae peaked in early June, Andrenidae in mid-June, and Halictidae in late June. This may not seem particularly significant but bee families that peak in early June will have access to different floral resources than those that peak in late June. The varied timing of bee family activity demonstrates the need to provide bees with plants that bloom throughout the entire active season.

This variation in bee family activity also existed among genera and tribes. Variation of active periods within families may reduce resource competition as bees within the same family are often similar sizes and may forage on similar flowers, if active at the same time. The genus with the most distinct pulse in abundance is *Diadasia*, which was collected for only 2 weeks. As a floral specialist, *Diadasia*'s abundance correlates with a single plant's bloom time, and a tight pulse in abundance would be expected. Species with tighter pulses may be specialists on a particular plant or group of plants that is in bloom at that time. Other groups of bees vary in the length of time they are active. *Lasioglossum* bees were found throughout the course of the study; as these bees are typically generalists that forage on a variety of plants, this is not unexpected. Another known generalist, *Apis*, was collected periodically throughout the study. The variation in active periods for different groups of bees further enforces the need to provide bees with plants that bloom throughout the entire active season.

Butterfly abundance peaked the first week of May. After this, butterflies and moths were both collected fairly sporadically until the end of the study. Similar to how bee families pulsed in different weeks, Lepidopterans may pulse earlier than bees in order to take advantage of different floral resources.

Best Management Practices – Seasonality of Pollinators

Limit ground disturbance to the season when pollinators are active.

Explanation: Ground-disturbing projects have the potential to destroy the nests of both above and below ground-nesting bees. Bees emerge from their nests in the spring to gather food, build new nests, and lay eggs. Ground-disturbing projects would avoid destroying these nests if work is done when bees are actively searching for an area to build their nests.

Implementation: If possible, limit ground disturbance to the season when most bees are active (May through August). This is especially important in high bee abundance areas, like the dune formations throughout the Hanford Site. If work must be done after nests have been established, restoration activities should occur near the project area and focus on pollinator health and restoring nesting areas in order to support the bee populations that were most affected.

Provide pollinators with plants that bloom from March through October.

Explanation: Bees and butterflies collected on the Hanford Site exhibited variation in seasonality and were active from March until October. These pollinators depend on plants blooming throughout the entire period they are active in order to drink nectar and collect pollen.

Implementation: When restoring or enhancing pollinator habitat, it is essential to include a variety of plants that, when combined, bloom from March to October. Plants that have extended bloom times will be useful to include in this mix. If certain plants are hard to establish by seed, they may be grown out and planted as plugs.

5.3 Pollinator Supporting Plants

One of the goals of this study was to collect information on Hanford Site-specific bloom times of flowering plants. These data, along with pollinator observation and abundance data, is used to determine the best native pollinator supporting plants. Non-native weed effects on pollinators are also considered.

5.3.1 Native Forbs and Shrubs

Results from this study indicate that certain plants are more attractive to pollinators than others, whether it be due to their bloom time, size, or location. The majority of the plants in this study bloomed during the month of May. May can be considered the peak bloom period for the Hanford Site, as a majority of the flowering plants on the Site bloom during this time. There was a wide diversity of plants for pollinators to visit in the month of May. Flowers that bloom outside of the peak bloom period were less common, yet bee abundance increased. For this reason, flowers that bloom outside of the peak bloom period may disproportionately support bee populations. Observations of bees on the Hanford Site have supported this conclusion, as June-blooming prairie clover and September-blooming snow buckwheat each had the highest number of bees and butterflies foraging on them during those periods, respectively.

Forbs with tiny flowers (e.g., spring draba [though non-native], slender phlox, shy gilia, and jagged chickweed [also non-native]) may play a role in supporting small-bodied bees like *Lasioglossum* in March and April when little else is in bloom. Due to the difficulty of collecting these forbs and the ease at which they colonize disturbed areas, they are not generally considered for restoration or habitat enhancement projects. Yellowbells, which bloom in March and April, were visited by early season bees and do not readily colonize disturbed areas, making them a good candidate for restoration projects.

Observations of bees foraging on plants were collected incidentally throughout the course of the study. Though this data set is limited, it provided some insight as to what plants pollinators were frequently visiting. During the month of May, though many plants were blooming, a few plants were visited more frequently than others. These included pale-evening primrose, Carey's balsamroot, and stalked-pod milkvetch. Other highly visited native plants in May included fiddleneck tarweed, threadleaf phacelia, sharpleaf penstemon, and upland larkspur. It is important to include a few of these plants in restoration seed mixes. Since there are multiple options for May-blooming plants, plants that are both suitable for the soil type and will grow successfully in a restoration area should be used.

Observations and data from this study indicate that flowers that support bees outside of the peak bloom period in May are extremely important. Bee abundance peaked in June while at the same time blooming resources became less common. In June, prairie clover attracted and supported pollinators at multiple sites (Figure 56). At MS-1, 17 of the 18 observed bees were foraging on prairie clover, which seems to be an extremely important floral resource, as little else was in bloom at this site. Similar increases in bee observations and collections during the prairie clover bloom were seen at EC-1. Prairie clover blooms gradually up a spike and each plant provides hundreds of flowers for bees. The effects of prairie clover on attracting bees to an area may not be reflected in the site-by-site Bloom Coverage and Bee Abundance graphs, as typically prairie clover did not cover more than 1 to 2% of a site and would not cause a significant spike in bloom coverage yet bee abundance would increase. Anecdotal observations at revegetation sites suggests that prairie clover may establish well in disturbed and restored areas. This plant could act as a foundation of pollinator habitat creation at the Hanford Site.

Figure 56. A green sweat bee (*Agapostemon*) foraging on prairie clover in June at EC-1.

A few other native plants notably supported pollinators during the summer and fall. Douglas' dustymaiden, which was present at most sites, bloomed in June and through most of July, and in some sites bloomed until August. Dustymaiden was the only plant blooming at MS-2 in July; six bees and one butterfly were observed foraging on it. This plant grows in various environments and has been successfully established from seed in revegetation sites at the Hanford Site.

Pale-evening primrose had the longest bloom period of any plant in the study. This plant could be found blooming from May through September, and occasionally was the only plant blooming in study sites. A single plant could vary in which month certain flowers on it blossomed. This unique variation in bloom time and the large white flowers of this plant attracted bees throughout the summer and early fall. This plant was found in various environments and relatively frequently visited.

Hoary tansyaster bloomed in August and September. During August, hoary tansyaster and/or pale-evening primrose were often the only flowers blooming at a study site. Hoary tansyaster provides pollinators with multiple flowers and can grow in somewhat dense mats, offering lots of floral resources to bees and butterflies in a small area.

Snow buckwheat bloomed August through October. The highest number of butterflies and the second highest number of bees were observed foraging on snow buckwheat. This plant supports pollinators when other blooming forbs are scarce and provides one of the last influxes of food for bees before they overwinter or finish fortifying their nests. Snow buckwheat attracted high numbers of pollinators whether it was in a dense stand, as at EC-1, or in small patches, as at MS-2. This plant is highly beneficial to pollinators and is recommended for all pollinator supporting seed mixes. This plant has been successfully established from seed in revegetation sites at Hanford.

Other forbs that were commonly seen in this study are western yarrow and turpentine springparsley. Neither of these plants attracted large numbers of bees but both attracted large numbers of flies. A number of these flies were drone flies, flies that imitate bees. This has the potential to cause confusion when evaluating bee-usage of these plants. Western yarrow is typically included in restoration seed mixes; however, the results of this study do not support using western yarrow in a pollinator-supporting seed mix. Turpentine springparsley bloomed in April and May, and May was the month with the most butterflies collected. Turpentine springparsley did have a fair amount of butterfly observations and could be used to attract butterflies in a pollinator-supporting restoration site (Figure 57).

Figure 57. An Acmon blue butterfly (*Plebejus acmon*) on turpentine springparsley.

There are a number of forbs that were not evaluated during this study. The most notable may be Munro's globemallow, a plant common on the Hanford Site that supports *Diadasia* bees, which were collected in June. Because *Diadasia* bees are specialists on globemallow, these plants are important to include in pollinator-supporting seed mixes, especially for sagebrush areas where the majority of *Diadasia* bees were collected. Forbs that grow in moister, riparian areas were also not evaluated in this study but likely play a large role in pollinator health. Milkweed occurs in riparian areas on the Hanford Site and is important to the lifecycle of Monarch butterfly populations (Oberhauser and Solensky 2004).

A few other factors are important to consider when creating a pollinator-supporting seed mix. Soil type must be considered when selecting forbs to ensure that forb can establish and grow in that soil. As was discussed in Section 5.1, it appears that a variety of plant flower sizes allows a greater amount of bees to take advantage of the floral resources; and body size of bees may be related to plant preference (Stang et al. 2009).

Like forbs, some species of shrubs provide nectar and pollen resources to pollinators. Shrubs can also provide above-ground nesting bees with nesting habitat. The insect pollinated shrubs that occur on the Hanford Site are bitterbrush and both species of rabbitbrush. Bitterbrush, which bloomed in April and May, provided both floral resources and potential nesting resources to twig nesting bees. At MS-1, the first peak in bee abundance aligned with the pulse in bloom coverage from bitterbrush. Rabbitbrush, which bloomed in September and October, provided floral resources through the tail end of the active period for both bees and butterflies. Other wind-pollinated shrubs, like sagebrush and hopsage, may provide important structural nesting resources for bees, but since they do not provide nectar they are not recommended for pollinator-focused restoration projects.

Best Management Practices – Native Forbs and Shrubs

Plant forbs and shrubs that create pollinator habitat.

Explanation: Providing food throughout the entire season pollinators are active will help support healthy pollinator populations. This study recommends the use of pollinator-supporting plants for use in creating or enhancing pollinator habitat.

Implementation: When restoring or enhancing pollinator habitat, use forbs and shrubs recommended by this study in Section 5.3.1 and in Table 13. These plants will best support pollinator populations at the Hanford Site. When creating a seed mix for a restoration area, include a variety of forbs with different bloom times and flower sizes. Evaluate the conditions of the restoration area, including soil type, and choose forbs that naturally occur in that soil type over those that do not. Consult the *Vascular Plants of the Hanford Site* (Sackschewsky and Downs 2011) for plant distribution and soil information, the *Hanford Site Revegetation Manual* (DOE/RL-2011-116) for revegetation guidelines and techniques, and this report for forb and shrub recommendations. The next revision of the *Hanford Site Revegetation Manual* will include a section describing pollinator-focused revegetations. This should be referenced when planning a revegetation or enhancement project. Recommended forbs can make up the entire forb component of the seed mix, or part of it, depending on the goals of the project. Where the site is appropriate for their success, it is recommended to include rabbitbrush and bitterbrush as a component of the shrub mix for pollinator supporting revegetations. Seeding and establishing native grasses is also important, as they can prevent the spread of cheatgrass, which reduces bare ground and can outcompete forbs. Bare ground is an important resource to ground-nesting bees (Sardinas and Kremen 2014).

The following table summarizes the forbs recommended for use in pollinator-focused revegetation projects. Bloom time refers to the time of year the plant was blooming: 'X' indicates the season when the plant reached peak bloom and 'O' indicates a season when the plant was blooming but did not reach peak bloom. In the table below, spring refers to March, April, and May; summer refers to June, July, and August; and fall refers to September and October.

Table 13. Forbs recommended for use in pollinator-focused revegetation projects.

Highly Recommended	**Bloom Time**		
	Spring	**Summer**	**Fall**
Prairie clover (*Dalea ornata*)	O	X	
Pale-evening primrose (*Oenothera pallida*)	X	O	O
Munro's globemallow (*Sphaeralcea munroana*)[a]	O	X	
Douglas' dustymaiden (*Chaenactis douglasii*)		X	
Hoary tansyaster (*Machaeranthera canescens*)		O	X
Snow buckwheat (*Eriogonum niveum*)		O	X
Recommended	Bloom Time		
	Spring	Summer	Fall
Carey's balsamroot (*Balsamorhiza careyana*)	X		
Stalked-pod milkvetch (*Astragalus sclerocarpus*)	X		
Threadleaf phacelia (*Phacelia linearis*)	X	O	

Sharpleaf penstemon (*Penstemon acuminatus*)	X	O	
Upland larkspur (*Delphinium nuttallianum)*	X		
[a] Munro's globemallow was not observed in any study sites. Bloom times taken from the USDA Plant Guide (USDA 2011).			

5.3.2 Non-native Plants

Non-native species played an unexpected role in supporting pollinators. The majority of weeds bloomed in the late summer when few other floral resources were available. Bird vetch, a large and showy non-native plant, had the third highest number of bees observed foraging on it. The SG-1 site had both the highest number of bees collected and the largest proportion of non-native plants (Figure 58 and 59). Non-native species provide important resources to floral generalists, especially during the late summer months. Long term, however, these plants outcompete and reduce the native plant populations that specialist bees depend on. Though the short-term effects of weeds are positive to generalist pollinators, they will ultimately be detrimental to the long term health of bees. Removing weeds may result in a loss of important floral resources for pollinators but in the long term will help native plants establish. Replacing the lost floral resources by seeding or planting native forb species will help the habitat recover, outcompete non-native weeds, and continue providing floral resources to pollinators.

Figure 58. A leafcutter bee on yellow starthistle.

Figure 59. A honeybee on knapweed.

Best Management Practices – Non-native Plants

Manage and remove non-native plants in pollinator habitat.

Explanation: Non-native plants are a threat to pollinator habitat as they outcompete native forbs and reduce plant species diversity where they become dominant. This reduction in plant diversity can negatively impact specialist bees that may rely on a few plants for the majority of their foraging.

Implementation: In both natural pollinator habitat and pollinator-focused revegetation sites, manage non-native plants that invade the area. Carefully hand-pulling or applying herbicide to individual plants will reduce herbicide drift and reduce the risk of accidently killing native species. Thoroughly evaluate the herbicide used to determine it has no negative impact on invertebrate species (bees).

Replace non-native species with native flowering species.

Explanation: Though non-native plants are a long-term threat to pollinator habitat, in the short term they provide floral resources that support generalist pollinators, especially during the late summer. When these species are removed, it will be detrimental to pollinators in the short term. For that reason, areas where non-native plants are removed should be replanted with native forbs.

Implementation: Ensure there is no residual herbicide in the soil that would negatively affect seeds or plugs. After non-native plant removal, and during the appropriate time of the year, reseed or plug the area with native plant species. It is best to select a mix of native plant species and to include a species that blooms during a similar time as the removed species. Consult the *Hanford Site Revegetation Manual* (DOE/RL-2011-116) for revegetation techniques and practices, and plant species recommended in Table 13 of this report. Continue non-native plant management in the area after it is seeded with native species, as non-native seeds will likely still be present in the seed bed. In order to support pollinators, this BMP should be followed both in pollinator-focused revegetation projects and in areas on the Hanford Site where large stands of non-native plants are removed.

5.4 Pan Trapping Method and Unexpected Variables

This section evaluates the pan trapping method used throughout this study. It also discusses other variables that were encountered and variables researchers would expect to encounter if repeating this or a similar study.

5.4.1 Evaluation of the Pan Trapping Method

The pan trapping method was used in this study because it maximized the amount of bees the surveyors were able to collect at multiple sites over a 1-day period. It eliminated the need for identifying bees on the wing and allowed the surveyors to sample multiple locations at the same time. Pan trapping also allowed surveyors to collect bees over the course of an entire day so that timing of bee activity was not a confounding variable. Pan trapping has been shown to have biases, and as it does not directly sample flower-visitors, it cannot be directly linked to pollination (Popic et al. 2013). As was described in Section 4.1.3, a significant negative relationship was found between average bloom coverage and the average number of bees collected when evaluating all sites over the study period. After repeating this test for each site, two of the eight sites had significant negative correlation between bloom coverage and bee abundance (EC-2, SB-1).

This result was unexpected and creates difficulty when analyzing plant-pollinator relationships. Both sites EC-2 and SB-1 were high quality sites that offered a variety of floral resources to bees. A possible explanation is that when there were ample flowers in bloom, bees were less attracted to the pan traps. This may have worked inversely at other sites, like SG-1, where there were few floral resources and bees were more attracted to the pan traps. But, at SG-1, the number of bees collected peaked later in the year, similar to the late peak in bloom coverage at this site. In addition, throughout all sites the most pollinators were observed in June. This matches the greater abundance of pollinators collected in June and is a data point that supports the validity of our pan trap data.

EC-1 had a relatively high number of observations with 19 bees observed foraging on prairie clover and 6 bees observed foraging on snow buckwheat. The peak in bee abundance at EC-1 correlated with the increased bee observations from prairie clover. Yet in September, when the snow buckwheat was in full bloom, there were little to no bees collected at this site. Across all sites, less bees were collected in September than in June; however, with the increased number of observations at EC-1, more were expected to be collected. The snow buckwheat bloom at EC-1 was the largest coverage bloom at any site through this study. It is possible that bees were less attracted to the pan traps during the bloom due to the huge amount of floral resources in the surrounding area. The white color of the pan trap also matched the white flower of the snow buckwheat, further blending the pan trap in to the surroundings. For these reasons, the abundance of pollinators at EC-1 may have been underestimated in this study.

Despite the drawbacks of using pan traps, for the purpose of this study they were the most efficient and effective way to measure bee abundance and diversity throughout different study sites. By evaluating both bee observation data and bee collection data, it seems that though pan traps had slight biases throughout the study, over all they acted as a good way to compare sites.

5.4.2 Variables throughout the Study

Variation in data would be expected if this study was performed over multiple years. A major factor that may have been a source of variation in this study is weather. Differing weather patterns can cause different bloom times, which may or may not effect when bees emerge. The winter previous to this study, December 2016 through March 2017, differed significantly from average weather patterns. That winter had the fifth coldest monthly average temperature since the Hanford Weather Station began recording Hanford Site temperatures in 1945. It also received the fifth most snowfall for the season, and perhaps most impressively, February had the highest snow depth of any February on Hanford Weather Station record. The cold temperatures and high snowfall may have affected bloom time and/or bee emergence, making one or both later in the year than they would typically happen. This may have been a factor behind the slightly separate pulses of peak bloom coverage and peak bee abundance. More research is necessary before making any definite conclusions about the relationship between climate and the results of this study.

Though large differences were not found among most study sites, local trends indicate that more data may reveal greater variation between sites. Performing this study over multiple years would provide better data regarding bloom time, which likely varies slightly due to yearly changes in weather. Bee abundance would also vary year to year, as bees experience natural variation in population levels. Monitoring bees over multiple years would allow researchers to identify problematic decreases in population levels and to intervene before more impacts occurred.

6.0 Conclusion

This section describes the need for future monitoring efforts to expand on both the results of this study and the effectiveness of pollinator-focused revegetation projects. The Hanford Site is home to a diverse array of habitats, each with unique vegetative communities and equally unique pollinator communities. This study investigated more prevalent habitat types on the Hanford Site and was limited to 1 year of data collection, and as such, there are many more questions that remain to be answered.

6.1 Future Directions

As pollinators have not been heavily studied at the Hanford Site or in the shrub-steppe ecosystem as a whole, there are many questions and hypothesis that remain to be investigated. The possibilities for future studies are endless. Summarized below are a limited number of future directions that are relevant to the future of pollinator management at the Hanford Site.

All of the data in this study were collected in a single monitoring season and could potentially represent a single data point in a larger, multi-year study investigating variation in pollinator abundances across the Hanford Site and over time. By repeating this study, in the same locations and over the same time period, researchers could investigate variation in pollinator abundance. This would monitor long-term changes in pollinator populations, provide an opportunity to identify the cause of those changes, and to react if pollinator populations were being negatively impacted. This data set would be an important tool in supporting and monitoring the health of pollinator populations.

In future studies, net sampling in addition to or in place of pan trap sampling, should be considered to directly investigate the relationship between flowers and bees. Net sampling allows the researcher to sample bees from the plants they are visiting; specific plant-bee relationships can be examined directly. This would increase understanding of which bees certain plants are supporting and may lead to the identification of important plant-pollinator relationships, including if certain bees or plants appear to be specialists.

There are many habitats on the Hanford Site; not all habitats were examined over the course of this study. Riparian areas on the Hanford Site likely play a large role in pollinator health and survival but were not investigated in this study. The Hanford Site is bordered to the north and east by the Columbia River, and there is a long stretch of riparian habitat where pollinator-supporting plants like showy milkweed (*Asclepias speciosa*), yellow beeplant (*Cleome lutea*), and western goldenrod (*Solidago occidentalis*) grow (Figure 60). Pollinator-supporting restoration projects would likely have great impact in these areas. Future studies are needed to identify which plants best support pollinators in riparian areas.

There were a few notable variables encountered during this study that warrant further investigation. This study was not initially designed to evaluate habitat impacts on pollinator abundances apart from the forbs present. Results from this study indicate that both soil type and presence of bare ground may play a role in pollinator distribution across the Hanford Site. Investigating the relationship between soil, bare ground, and pollinators further can help researchers better predict high pollinator areas. This information can also be used to improve pollinator-focused restoration projects by indicating where they would be most successful.

Various environmental changes may impact pollinators in the coming years. Fire is one of the most rampant stressors to vegetation on the Hanford Site. Post-fire recovery varies from area to area and depends on several factors, including vegetation present at the site, severity of the fire, history of fires at the site, and geomorphology of the area. For both above and below ground nesting bees, impacts of a fire may be immediate, killing developing larva in their nests or killing adult bees via heat or smoke inhalation (Cane and Love 2016). Long-lasting impacts like the removal of vegetation and potential invasion of cheatgrass will affect surviving pollinators and pollinators in the surrounding areas. Working to restore recently burned areas can help keep the native vegetation intact, prevent the spread of non-native plants, and can reduce the severity of future fires in that area. Restoring these areas will, in both the short and long term, help support pollinator populations.

Figure 60. A suite of pollinators visits a showy milkweed flower near the Columbia River. Photo taken on the Hanford Site by Ecological Monitoring Staff (June 2017).

6.2 Monitoring Pollinator-Focused Revegetation Sites

In order to ensure the success of pollinator-focused revegetation sites, some form of pollinator monitoring is recommended to occur within those areas. This monitoring would focus on pollinator use and the information can be used, if necessary, to refine the list of pollinator-friendly forbs included in seed mixes.

Initial monitoring of pollinator-focused revegetation sites should occur immediately after planting and should consist of two parts, the first focusing on forb growth in the revegetation site and the second on pollinator use of the site. The first part would consist of traditional revegetation site monitoring, where shrub survival transects and Daubenmire plots can be used to determine total site native coverage, non-native coverage, and shrub survival. This monitoring also includes a list of all species found on the revegetation site. Care must be taken while creating this list to note which plants were seeded in the area and to determine if they are present in the revegetation site. This monitoring should take place for 5 years, aligned with protocol for traditional revegetation monitoring on the Hanford Site. It is likely that some of the forbs planted will not emerge by the first-year monitoring effort. By the third year, most of the forbs that were planted should have emerged in the revegetation site, but flower germination is often hard to predict and seeds can lay dormant for many years.

The second part of monitoring the pollinator-focused revegetation sites would collect data on pollinator utilization. This should begin before the site is revegetated in order to establish pollinator use prior to the revegetation. In a successful pollinator-focused revegetation, pollinator use prior to revegetation will be less than pollinator use after the revegetation has established. Both pan traps and bee observations may be used to evaluate bee abundance in the area, depending on the experience of the observer. If it appears pan traps are not representative of bees observed in the area, another method may be used to evaluate bee abundance. Pan traps should be situated as close to the center of the site as possible to avoid collecting bees present outside the revegetation area. If the pollinator-focused revegetation site is small (less than 150 m in diameter), pan trapping will likely capture bees from outside the revegetation area as well, and pan trapping is not a good method to use. Pan trapping and observations should begin early in the first spring after planting and continue until fifth year monitoring is complete at the site. One pan trap is suitable per 4.05-hectare area, where the pan trap is placed at least 200 m from any edge. In order to compare the effectiveness of this pollinator site to normal revegetation sites, pan traps may be set up in other normal revegetation sites that are the same planting year as the pollinator site. Diversity of bees can also be noted if the researcher is capable, but as this study had a high correlation between bee abundance and diversity, just a count of abundance will be sufficient to evaluate the site.

6.3 Conclusion

This document provides land managers with baseline data on pollinator populations throughout different habitats of the Hanford Site, with the goal of supporting pollinator populations. By identifying abundance, diversity, and distribution patterns across different habitats, pollinators can be considered when determining both the negative environmental effects of a project and mitigation techniques to offset those effects. The creation of pollinator-supporting habitat will be better informed and can include both plants and nesting areas beneficial to bees and butterflies. At the conclusion of this study, we are left with various questions and topics of study that need investigation in order to further develop our understanding of pollinator use of habitat at the Hanford Site.

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APPENDIX A

Ecological Monitoring Plan

Hanford Site Pollinator Study

E. S. Norris

Contents

1. Introduction

1.1. Purpose and Need

Within the last century, rapid declines in both wild and managed bee populations have been recorded throughout the world (Kearns et al. 1998, Goulson et al. 2005, Biesmeijer et al. 2006). Pollinators are vital to the health of native environments (Potts et al. 2010). The mutualistic relationship of plants and pollinating insects has evolved on every continent, from Antarctica to Australia (Kevan 1972; Potts et al. 2010). By enabling successful plant reproduction, pollinators support the health of nearly all other organisms in the environment that rely on healthy plant populations for food and shelter. Bees are the most important group of pollinators worldwide (Kearns et al. 1998, Michener 2007).

Bee declines are believed to be caused by a combination of stressors including habitat loss, pesticide use, and disease. Habitat loss and fragmentation are major causes of bee population declines, especially for wild bees that rely on flowering plants for forage and nesting (Potts et al. 2010, Winfree et al. 2009). Wild bees with limited ranges can be especially affected by habitat loss. When humans remove native vegetation from the environment they are removing valuable bee habitats, causing pollinator populations to be negatively affected (Biesmeijer et al. 2006).

The greatest abundance of wild bees is suspected to be in semi-desert, arid environments, especially within western North America (Linsley 1958, Koh et al. 2016). This habitat classification matches the Hanford Site environment. Many species of native bees, honey bees, bumble bees, and butterflies have been documented on the Hanford Site; however, site-specific studies focusing on these pollinators are uncommon. Native bees are the primary insect pollinators of the Columbia River Basin (Tepedino and Griswold 1995). Although butterflies and moths play a small role in pollination in the Columbia River Basin, they are much less efficient at transferring pollen and tend to visit flowering species only for nectar (Tepedino and Griswold 1995). Over 600 species of bee are known to occur in this region, with the actual number believed to be much higher due to under sampling (Tepedino and Griswold 1995; Niwa et al. 2001). Arid lands of western North America have high proportions of specialized bees that are typically restricted to small geographic areas, making the Hanford Site and the surrounding region especially vulnerable to species loss when habitats are removed (Tepedino 1979).

The Hanford Site consists of 1,424 km^2 (550 mi^2) of land, most of it steppe or shrub-steppe habitat that is suitable to host a diverse population of pollinators. When land is lost on the Hanford Site, bees and other pollinators lose valuable habitats and population declines are accelerated. Currently, habitat preservation is the best known way to slow the rate of bee population declines (Grixti et al. 2009, Kearns et al. 1998, Tepedino 1979). In areas where habitat has already been lost, revegetation efforts must focus on reestablishing the native plant communities that best support bees.

In order to mitigate pollinator habitat loss on the Hanford Site, and since bees are the most important pollinator in this area, flowering plants that provide nutrition and habitat for bees should be used in revegetation projects. To achieve this, the native plant communities that support local bee species must be identified. Little research exists investigating which habitat types within the shrub-steppe best support pollinator populations.

The purpose of this study is to collect data on Hanford Site pollinators and to identify which plant communities attract a high abundance and diversity of bees. This study will also be used to collect data on Hanford Site-specific bloom times for flowering plants. Plant communities with a variety of plants that bloom in different seasons are essential to supporting bee health throughout the spring, summer, and fall when bees are active. The bloom times will be used to develop a recommended mix of plants that bloom throughout multiple seasons.

After these data are collected, the plants that best support pollinator populations will be recommended for use in revegetation projects and added to the *Hanford Site Revegetation Manual* (HSRM, DOE/RL-2011-116). A long-term goal of this effort is to increase pollinator habitats on the Hanford Site.

1.2. Regulatory Drivers

The U.S. Department of Energy, Richland Operations Office (DOE-RL) conducts ecological monitoring on the Hanford Site to collect and track data needed to ensure DOE-RL compliance with an array of laws and policies. Ecological monitoring data provide baseline information about the plants, animals, and habitats under DOE-RL stewardship required for decision making under the *National Environmental Policy Act* and *Comprehensive Environmental Response, Compensation, and Liability Act*.

DOE-RL's *Environmental Assessment for Proposed Conveyance of Land at the Hanford Site, Richland, Washington* (DOE/EA-1915) resulted in a Finding of No Significant Impact (FONSI). A Mitigation Action Plan is an integral part of the FONSI, and results in the avoidance, minimization, or compensation for potential adverse environmental effects associated with the conveyance of land. Mitigation measures associated with this conveyance of land include conducting a pollinator habitat study for the Hanford Site, "focusing on identifying pollinator species and the plants and habitats they require for their life cycle. The study shall provide data and recommendations needed to carry out habitat enhancement, proper management, and collaboration with other agencies and institutions to ensure this valuable resource is protected." This study meets those guidelines by identifying the main pollinators on the Hanford Site and identifying the plant communities pollinators rely on throughout their life cycles. This study will provide the data required to recommend pollinator-supporting plants to be used in habitat enhancement and will identify areas with high abundances and diversity of bees for future management. Other agencies collaborated with include Washington State Department of Fish and Wildlife, and multiple branches of the Washington State University Department of Entomology.

1.2.1. Federal Laws and Regulations

1.2.1.1. Presidential Guidance and Memoranda.

The 2014 presidential memorandum "Creating a Federal Strategy to Promote the Health of Honey Bees and Other Pollinators" (79 FR 35903-35907) calls for immediate action to be taken by land-owning federal departments to prevent further pollinator population decline (79 FR 35903-35907). This memorandum called for the establishment of a Pollinator Health Task Force that includes representatives from over 15 federal agencies, including the U.S. Department of Energy. This task force developed the *Pollinator Research Action Plan* (Pollinator Health Task Force 2015a) that outlines key priorities and goals to improve pollinator health. One of the goals of this plan is to restore or enhance 2.8 million ha (7 million ac) of pollinator habitat on federally-owned land (Pollinator Health Task Force 2015b). Two sections of the *Pollinator Research Action Plan*, Section II and Section VII, are especially relevant to future revegetation work on the Hanford Site.

Section II: Habitat (Including Stressors) addresses the need for increased and improved pollinator habitat. Current understanding of pollinator habitat requirements is limited. A key priority research theme of this section is "identifying viable approaches to restore and create pollinator habitat." Determining the native plant communities that best support pollinators works toward the goal of restoring and creating pollinator habitats.

Section VII: Native Plant Development and Deployment describes the necessity of native plant use in habitat restoration projects. Identifying the native plant species that provide support for the most pollinators is key for developing regional native seed mixes that are adapted to the climate and will attract native pollinators. Another key priority research theme of this section is identifying local and regional native plant species mixtures that will provide nutrition to pollinators throughout all seasons when they are active.

1.2.2. U.S. Department of Energy Orders and Guidance Documents

The Department of Energy Pollinator Protection Plan (Appendix E, Pollinator Health Task Force 2015b) directs the adoption of Best Management Practices (BMPs) for pollinator health. The U.S. Department of Energy is a land-owning agency and will assess each site to determine if implementing the BMPs is appropriate. As per the plan, the commitment to enhance, preserve, and protect pollinator habitat according to BMPs is consistent with Section 3, Subsection (a) of 79 FR 35903-35907, which calls for

> “the development of a plan to enhance pollinator habitat and the implementation of a plan to manage lands and facilities under the auspices of the Department to enhance pollinator health on those lands.”

1.3. Hanford Site Management Guidance

The *Hanford Site Biological Resources Management Plan* (BRMP, DOE/RL 96-32) is identified by the *Hanford Comprehensive Land-Use Plan* (DOE/EIS-0222-SA-01) as the primary implementation control for managing and protecting natural resources on the Hanford Site. According to the *Hanford Comprehensive Land-Use Plan* (DOE/EIS-0222-SA-01), the BRMP

> “provides a mechanism for ensuring compliance with laws protecting biological resources; provides a framework for ensuring that appropriate biological resource goals, objectives, and tools are in place to make DOE an effective steward of the Hanford biological resources; and implements an ecosystem management approach for biological resources on the Site. The BRMP provides a comprehensive direction that specifies DOE biological resource policies, goals, and objectives.”

DOE-RL places priority on monitoring those plant and animal species or habitats with specific regulatory protections or requirements; that are rare and/or declining (e.g., federal or state listed endangered, threatened, or sensitive species); or are of significant interest to federal, state, or Tribal governments or the public. The BRMP (DOE/RL 96-32) ranks wildlife species and habitats (Levels 0-5), providing a graded approach to monitoring biological resources based on the level of concern for each resource. The data collected as part of this study may be used as guidance in developing future resource levels.

Pollinators are of significant interest to the federal government, as demonstrated by the formation of the Pollinator Health Task Force. The goal is to restore or enhance 7 million ac (2.8 million ha) of pollinator habitat by delegating pollinator supporting tasks to various land-owning federal agencies. The health of pollinators, especially honey bees, is of public concern and has been the focus of increased media and public attention in the past 10 years.

1.4. Scope of Document

This monitoring plan:

- Defines the methods used to monitor pollinator habitat use on the Hanford Site in order to determine the plant communities that best support pollinators
- Guides the selection of plant species best suited for use in pollinator habitat revegetation
- Defines the collection and management of data collected as part of this study
- Outlines future management actions to be taken in response to the monitoring results.

This monitoring plan is meant to provide guidance to the researcher. As the study progresses, changes to the monitoring plan may be necessary to efficiently execute this plan. Major changes to this plan will be footnoted after the conclusion of this study.

2. Biology and Ecology of Organisms to Be Monitored

2.1. General Description of Biology and Ecology

Over 200,000 species of insects and other animals provide pollination services to plants (National Research Council 2007). Order Hymeroptera contains the majority of the insect pollinators as it encompasses wasps, ants, bees, and sawflies. Bees, or insects within clade Anthophila, are the main pollinators of most ecosystems. Bees have evolved with the surrounding plant communities and maintain both the diversity and function of ecosystems (Potts et al. 2003). In the United States alone, it is estimated there are over 4,000 species of bee, many of them not yet known to science (Moisset and Buchmann 2011). Large, important groups of bees native to the United States include leaf-cutter bees (*Megachilidae* sp.), mason bees (*Osmia* sp.), bumble bees (*Bombus* sp.), sweat bees (*Halictidae* sp.), miner bees (*Andrena* sp.), and carpenter bees (*Xylocopa* sp.) (Linsley 1958). Honey bees, although heavily studied and utilized for agriculture, are an introduced species.

2.1.1. Life History

The thousands of different bee species exhibit tremendous variation in sociality, foraging patterns, nesting, and habitat use (Linsley 1958). The majority of solitary bees spend the winter months in nests as pupae and emerge in the spring as adults. Bees are generally active from early spring to fall, the same seasons flowers are in bloom. In arid regions, bee species are typically active either in the spring during the first blooms or in the fall when mass flowering species like rabbitbrush are blooming (Linsley 1958). The majority of solitary bees reach the end of their lifecycle by the winter months, when food sources are scarce to nonexistent.

Bees derive the majority of their nutrition and energy from the pollen and nectar of flowering plants (Michener 2007). Some bees are specialists that forage on only certain species or closely related groups of plants, while other bees are generalists and forage on a wide variety of plants. Different species of flowers produce pollen with varying levels of nutrients; variation in diet is important in maintaining the health of many bees.

2.1.2. Habitat Preferences

The majority of bees nest in the ground, with different bee species preferring to nest in various soil types. Some bees nest in plant stems, debris, and rocks. Many solitary bees live in arid, desert-like areas. If they are ground nesters, they require some amount of bare soil, which is common in arid regions. Bees also require suitable forage and a water source within their flight range around the nest. The ranges of bees are highly variable and it is thought that range generally increases with body size (Gathmann and Tscharntke 2002). Generally, flight ranges for small, solitary species are within a few hundred meters of their nests (Gathmann and Tscharntke 2002). Larger species (e.g., bumble bees) can have flight ranges spanning well over a thousand meters (Zurbuchen et al. 2010).

2.2. Historical Monitoring at Hanford

In 1997, Dr. Richard Zack of Washington State University conducted a study and reported his findings in *Entomological Diversity Inventory and Analysis at the Hanford Site* (Zack 1997). Although this study did not focus specifically on bees or pollinating species, it is the first study investigating the diversity of native bees onsite and provides a baseline for the Hanford Site monitoring effort. Over 140 bee species were recorded in this study, with 7 of those being newly discovered species. The number of bee species actually present on the Hanford Site is likely significantly higher than this, and an intensive monitoring study would provide a more accurate window into the true diversity of bee species on site. Though this study does not act as an intensive monitoring effort, the results can be used to inform such an effort.

3. Plan for Monitoring at Hanford

3.1. Goals and Objectives

The specific objectives of this study are to:

- Investigate the abundance and diversity of bees in different plant communities
- Collect information on pollinator abundance and diversity through different seasons
- Begin collecting information on Hanford Site-specific bloom times of flowering plants.

The end goal of this effort is to create a list of pollinator-friendly plants recommended for use in Hanford Site revegetation projects. This list of plants will be included in an update of the HSRM (DOE/RL-2011-116). The use of these plants will help enhance and increase pollinator habitats at Hanford.

3.2. Sampling Design

The study sites will be within four different habitats that are common throughout the Hanford Site, in order to maximize the applicability of the data collected to future land management on the Hanford Site. These four habitats are defined by the dominant shrub(s) within each habitat, as characterized by the BRMP (DOE/RL-96-32). The four habitat types that will be investigated are as follows:

- **Steppe Grassland.** Habitat is dominated by native bunchgrasses, such as bluebunch wheatgrass (*Pseudoroegneria spicata*), Sandberg's bluegrass (*Poa secunda*), Indian ricegrass (*Oryzopsis hymenoides*), and needle-and-thread grass (*Hesperostipa comata*). Shrubs may be scattered but are not dominant in the area.

- **Early Colonizing Species.**[6] Shrubs present in the habitat are either green rabbitbrush (*Chrysothamnus viscidiflorus*), gray rabbitbrush (*Ericameria nauseosa*), or a combination of the two species.[7] These shrubs have a visually estimated ground-cover of at least 15%. Other shrub species may be scattered, but are not dominant in the area. The understory of this habitat is made up of native bunchgrasses and forbs.

- **Mature Shrub-Steppe (Mixed Shrubs).** The habitat is characterized by a mix of shrub species which may include big sagebrush (*Artemisia tridentata*), antelope bitterbrush (*Purshia tridentata*), spiny hopsage (*Grayia spinosa*), and/or scattered occurrences of rabbitbrush. The understory of this habitat is made up of native bunchgrasses and forbs.

- **Mature Shrub-Steppe (Sagebrush).** The dominant shrub within the habitat is big sagebrush, which has an estimated groundcover of at least 15%. Other shrub species are scarce or non-existent. The understory of this habitat is made up of native bunchgrasses and forbs.

Prior to the beginning of the study and using BRMP (DOE/RL 96-32) habitat characterizations as a guide, Ecological Monitoring staff will perform a pedestrian survey to locate habitat areas within the Hanford Site that meet the above definitions. Once these habitat areas are located, study sites will be placed

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[6] Name changed to Early Colonizing Species from Early Successional Shrub- Steppe to better reflect the species make-up of sites.

[7] Snow buckwheat (*Eriogonum niveum*), considered an early-colonizing subshrub in the interior Pacific Northwest (Tiedemann et al. 1997), was considered along with both rabbitbrush species when classifying areas as Early Successional Shrub-Steppe. Snow buckwheat coverage was included in the ground-cover calculation.

within each of the four habitat areas. There will be a total of eight study sites, two within each of the four habitat types, in order to provide some means of duplication and the ability to test the reliability of results.

Each study site will be described in detail prior to the beginning of the surveys using the Habitat Description Form (Section 6.1). Information recorded will include a plant species list and the dominant vegetation of the study site. The dominant vegetation recorded on the form will be plants with a visually estimated cover of over 10% within the area of the study site. Each study site will have a center point, which will be flagged and recorded with a global positioning system coordinate. The study site will be circular, with a 50-m radius extending from the center point. The total area of each study site will be approximately 7,854 m^2.

3.2.1. Monitoring Schedule

Site surveys will take place once per week throughout the blooming season, from approximately mid-March until October. This will ensure surveys are taking place when pollinators are active and will allow periods of high pollinator activity to be identified.

Previous studies have shown that bees are most active on days where the ambient temperature is above 60 °F, wind speeds are less than 8 miles per hour, and skies are clear enough to where there are very few clouds and you can see your shadow (Ward et al. 2014). When weather conditions allow, surveys will take place on the same day every week. If weather conditions are not ideal for sampling, surveys will take place as close to the originally planned day as possible. During each survey, pan traps and observations will be used to collect data on the abundance and diversity of pollinators.

3.2.2 Resources Needed

Resources needed for monitoring may vary. Resources needed for weekly monitoring include a truck or SUV and basic field gear (GPS, notebooks, measuring tape, clipboard, camera, SPOT device, etc.). In addition to this, gallon jugs of water, dish soap, leather gloves, safety glasses, a mallet, a mesh strainer, Ziploc bags, the pan traps, and paper towels are needed. For bee identification, a field laptop or tablet, digital microscope, and ruler are needed.

3.3. Sampling Methods

3.3.1. Site Characterization

Each survey site will be evaluated using the Pan Trap Site Monitoring Form (Section 6.2). The survey sites will be evaluated approximately once per week, the same day that the pan traps are set out. Information about the weather, including temperature and cloud cover, will be recorded. Cloud cover will be a visual estimate. The high temperature and wind speed for that day will be provided by the Hanford Weather Station. In order to record seasonal changes in the area and to have a visual image to accompany the data, photos will be taken from the center point of the survey site facing north, east, south, and west.

In order to characterize the vegetation of the survey site, information about plant phenology will be recorded on the Pan Trap Site Monitoring Form when applicable (Section 6.2). To ensure the plant species surveyed are within 50 m of the center point, a 50-m measuring tape or rope will be extended from the center point and used as the observer walks around the survey area. In the initial surveys, species that are visually estimated to have a coverage above 10% will be recorded as dominant species along with their estimated percent coverage. Additionally, if any new plant species are found in the survey area that were not initially recorded in the Habitat Description Form (Section 6.1), they will be recorded on the Pan Trap Site Monitoring Form and added to the Habitat Description Form.

All blooming plant species within the survey area will be recorded on page 2 of the Pan Trap Site Monitoring Form (Section 6.2.2). For each species in bloom, observers will estimate the percentage of each species in the plot that are blooming and estimate the percent coverage of the blooming individuals within the survey plot. This information will be used to estimate the bloom times of Hanford Site pollinator-friendly plants while providing a quantitative description of the flowering plants in the area. While recording the number of individuals in bloom, pollinators present on the reproductive structures of the plants will be recorded on an incidental basis.

3.3.2. Pan Traps

Pan traps will be used to measure bee abundance and diversity in the survey site. Pan traps are elevated bowls filled with a diluted soap solution to trap bees, which are attracted to the trap as they would be to a flower (Figure 1). The soap solution will contain approximately 0.1 oz. of dish soap per gallon of water. Pan traps will be designed following Tuell and Isaacs (2009), and will be made up of a 12-oz white plastic bowl that is attached to a coupler. This coupler allows the bowl to securely attach to the top of a piece of PVC pipe, which can be slid over rebar that is stabilized in the ground. The height of the pan traps will be similar to the height of the surrounding vegetation. Elevating pan traps to a similar height as the surrounding vegetative canopy is shown to increase bee catches (Tuell and Isaacs 2009). The traps allow staff to survey bee abundance without requiring staff to be present on the survey site most of the day, as other techniques require. Although pan traps may have some biases (Wilson et al. 2008), they can be standardized and compared across sites, making them suitable for this study.

Figure 3. Pan Trap.

Surveys will begin by placing three pan traps at the center of each survey site.[8] The pan traps will be arranged in a triangle formation, with a pan trap at each point of the triangle and the sides of the triangle equaling 5 m (Figure 2). This distance minimizes competition between traps. The rebar on which the pan traps are placed will remain in the ground throughout the entire study, so pan traps will be set in the same location week after week. Pan traps will be placed at each site after sunrise, filled with diluted soap solution, left out at the site for a minimum of 7 hours and a maximum of 25 hours, and collected in the same order in which they were placed. The amount of time pan traps are left out on the site will be determined after staff determine the amount of time it takes to set out pan traps, collect vegetation data, and collect the pan traps. Once the time period the pan traps will be set out is established, this protocol will be followed for the remainder of the study. [9]

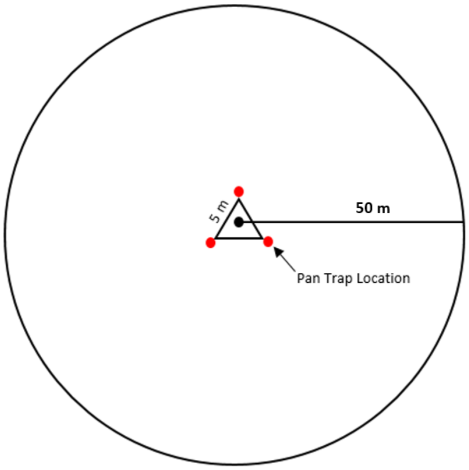

Figure 4. Set-Up of Pan Traps. All Area Within the Circle is Part of the Study Area. Figure is Not to Scale.

The time and temperature when traps are placed and removed will be recorded in the Pan Trap Site Monitoring Form (Section 6.2). This minimum 7-hour sample period will cover the times of day when bees are most active. Pan traps will be removed from the rebar at collection and stored until the next sampling period. Upon collection, the traps will be emptied and the contents strained using a mesh strainer. The solution in the pan traps will be collected and disposed of in an acceptable sewer system. Bees will be sorted from other insects, which will be disposed of. All bees will be checked for radiation by Radiological Controls staff. If any contamination is detected, monitoring will stop until an appropriate path forward is determined. Bees will be stored according to survey site in plastic bags and stored in a freezer. Bags will contain a piece of paper towel to absorb moisture and will be labeled with the following information:

- Site Name
- Date

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[8] Three pan traps were used per site from the weeks of 3/22/2017 until 4/19/2017. After these five weeks of monitoring, it was determined that using three traps resulted in high quantities of bee mortality, and that using one trap per site would be sufficient for collecting the data required. Starting the week of 4/25/2017, only one pan trap was used per site. The single pan trap was placed at the center point of each study site, represented by the black dot in Figure 2. Analysis of the data for this study will require the time periods of 3/22/2017-4/19/2017 and 4/25/2017-10/10/2017 to be analyzed separately in order to account for the change in methods.

[9] Staff determined pan traps would be left out between 23 and 25 hours.

- Time Collected
- Number of individual specimens in bag.

3.3.3. Bee Identification

After all pan traps are emptied, bee bags will be brought to the storage and identification facility. If identification cannot be done on the same day, bees will be placed in the freezer until they can be identified. At this time, bees will be removed from the bags, excess moisture will be removed, and bees will be photographed using a Dino-lite digital microscope. The following photos will be taken as needed for identification:

- Full body, dorsal view
- Full body, lateral view
- Frontal wing
- Abdomen, dorsal view
- Abdomen, ventral view
- Hind leg, lateral view
- Face, front view.

The bees will be identified to at least the family level and recorded on page 3 of the Pan Trap Site Monitoring Form (Section 6.2.3). Unknown specimens will be recorded and stored for possible future identification.

4. Data Collection, Assessment and Analysis

4.1. Data Collection

All data collected during this study will be recorded on the Habitat Description Form (Section 6.1) and Pan Trap Site Monitoring Form (Section 6.2). These forms will be scanned and stored electronically and in PSRP logbooks, and the data on these forms will be manually entered into Excel documents.

4.2. Data Assessment and Analysis

In order to meet the objectives set forward in Section 3.1, the data collected must be carefully organized, assessed, and analyzed.

The first objective is to investigate the abundance and diversity of bees in different plant communities. The plant communities for each study site will be selected based on the dominant vegetation within that community, allowing us to differentiate between four plant communities when analyzing data. These communities are described in Section 3.2. Data from pan trap catches will provide a relative abundance of bees and the diversity of bee families for each plant community. Since the same methods will be used at every site, these data will be standardized and we will be able to compare the relative abundance and diversity of bees between plant communities.

The second objective is to collect information on bee abundance and diversity through different seasons. Our data will include a temporal component since all diversity and abundance information will be linked to the date when the bees were collected. Changes in bee abundance and diversity will be tested to see if the changes correlate with dates. This will be tested with bees collected over all the study sites, as well as with bees collected in specific habitat types. Additionally, it is expected that the plant species in bloom at the study sites will change over time. We will test to see if the changes in bee abundance and diversity over time correlates with changes in available forage, measured by the percent coverage of blooming species.

The third objective is to collect information on Hanford Site-specific bloom times of flowering plants. This will help us begin to understand the phenology of blooming plants on the Hanford Site. The percent of plants in bloom recorded weekly for each species in our study site will increase our understanding of bloom times. When recommending plants for enhancing/creating pollinator habitat, it is necessary to recommend species of plants that bloom in different seasons. Although it is unlikely we will collect enough information to determine exact bloom times for the plants within our study sites, this information can be used when determining which plant species to recommend for pollinators in the HSRM (DOE/RL-2011-116).

5. Estimated Effort

The pollinator study will require a total of 1309 hours from the fall of 2016 through the fall of 2017.

Table 14. Estimated Number of Hours Required for Pollinator Study

Time	Task	Days	Hours per Day	Total Hours
Fall 2016	Literature Review	10	10	100
Fall 2016	Integrate plans with ongoing local research	6	10	60
Winter 2016/2017	Monitoring Plan	20	10	200
Spring/Summer/Fall 2017	Field Work	56	8	448
Spring/Summer/Fall 2017	Bee Identification	29	4	116
Spring/Summer/Fall 2017	Data Management and Analysis	29	5	145
Fall 2017	Monitoring Report	12	10	120
Fall 2017	Develop addendum to HSRM	12	10	120
			Total	**1309**

6. Management Actions to Be Taken in Response to Monitoring Results

6.1. Management Actions

The results of this study will be used to update the HSRM (DOE/RL-2011-116) with pollinator-friendly plant species. These species can be used in mitigation projects in order to enhance and increase pollinator habitats. This supports the implementation of the Department of Energy Pollinator Protection Plan (Appendix E, Pollinator Health Task Force 2015b).

6.2. Future Actions

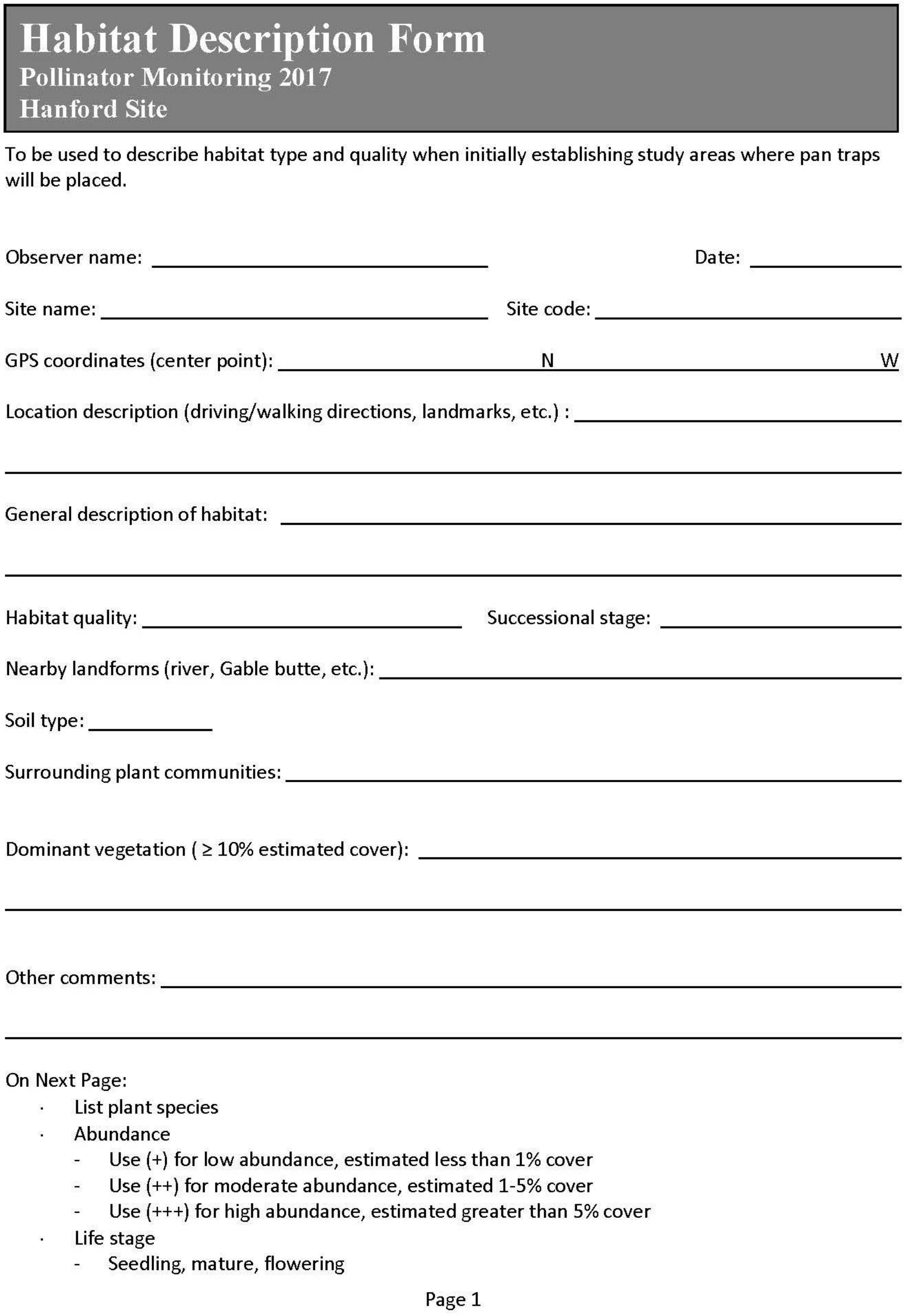
Pollinator abundance and communities vary year to year due to changes in rainfall patterns, forage availability, and reproductive success. Repeating this study for multiple years would allow the researcher to account for these patterns and recognize outlier years with unusual levels of pollinators. Without repeating this study, the researcher cannot assume the data is representative of pollinators year after year.

The same monitoring technique of using pan traps to measure bee abundance and diversity in a study area can be adapted to measure the success of revegetation projects aimed at supporting pollinator populations. This will be an important tool in measuring the success of revegetation projects and the quality of our pollinator-friendly plant recommendations. This monitoring technique will also be an important tool in future pollinator and habitat surveys assessing the abundance and diversity of pollinators in different areas throughout the Hanford Site.

7. Data Collection Forms

7.1. Habitat Description Form

7.1.1. Page 1 – General Habitat Description



Habitat Description Form
Pollinator Monitoring 2017
Hanford Site

To be used to describe habitat type and quality when initially establishing study areas where pan traps will be placed.

Observer name: ______________________ Date: __________

Site name: ______________________ Site code: ______________________

GPS coordinates (center point): ______________ N ______________________ W

Location description (driving/walking directions, landmarks, etc.) : ______________________

____

General description of habitat: ______________________________________

____

Habitat quality: ____________________ Successional stage: ______________

Nearby landforms (river, Gable butte, etc.): ______________________________

Soil type: ________

Surrounding plant communities: ______________________________________

Dominant vegetation (≥ 10% estimated cover): ______________________________

____

Other comments: ____

____

On Next Page:

- List plant species
- Abundance
  - Use (+) for low abundance, estimated less than 1% cover
  - Use (++) for moderate abundance, estimated 1-5% cover
  - Use (+++) for high abundance, estimated greater than 5% cover
- Life stage
  - Seedling, mature, flowering

Page 1

7.1.2. Page 2 – List of All Plant Species in Study Site

Plant Species List **Site Name** ________________

Species Name/Code	Abundance (+/++/+++)	Life Stage (Seedling, Mature, Flowering)

Page 2

7.2. Pan Trap Site Monitoring Form

7.2.1. Page 1 - Weekly Site Description

Pan Trap Site Monitoring Form

Pollinator Monitoring 2017
Hanford Site

To be used to describe changes in plant community, bloom times, pollinator visitation, and weather conditions of survey area, which extends 100m from the center of the pan traps.

Observer(s): ______________________ Site name: ______________

Date: __________ Time trap placed: ________ Time trap pulled: __________

High Temp: _______ Temp when placed: _______ Temp when pulled: _________

Wind speed and direction (approx.): ___________ Cloud cover (%): ___________

Photos taken: ☐ Yes ☐ No

Plant Community

Dominant vegetation with % coverage: ______________________________

New plant species observed: ______________________________

Comments: ______________________________

On page 2:
List all flowering plant species and include the following information for EACH BLOOMING SPECIES:

- Approximate percentage of each species in bloom within the survey area
- Percent coverage estimate of the blooming individuals for the entire survey area
- Presence and type of pollinators on the reproductive structure of flowers

On page 3:
List all bee families collected in the pan trap

Page 1

7.2.2. Page 2 – Blooming Species List

Blooming Species List

Observer: ____________ Site name: ____________ Date: ________ Time: ________

			Pollinator Tally				
Species name	% indiv. in bloom	% coverage of blooming indiv.	Bee	Wasp	Butterfly/Moth	Fly	Other

7.2.3. Page 3 – Bee Identification Record

Bee Identification Record

Identified by: ____________ Site Name: ____________ Date Collected: ________ Date Identified: ________

Total number of bees: ______

Number of Indiv.	Family	Tribe / Genus (opt.)	Picture Taken?

Page 3

7.2.4. Page 4 – Total Insect Count

Count of All Insects Surveyed per Sampling Effort

Tally – Other Insects

Insect Type (Fly, Wasp, Thrip, etc.)	Tally
	Total Number of Non-Bee Insects Collected:
	Total Number of Bees Collected:
	Total Number of Insects Collected:

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