An Inventory of Native Bees (Hymenoptera: Apiformes)

in the Black Hills of South Dakota and Wyoming

BY

David J. Drons

A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Plant Science

South Dakota State University

2012

An Inventory of Native Bees (Hymenoptera: Apiformes)

in the Black Hills of South Dakota and Wyoming

This thesis is approved as a credible and independent investigation by a candidate for the Master of Plant Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

_____

Dr. Paul J. Johnson
Thesis Advisor Date

_____

Dr. Doug Malo
Assistant Plant Date
Science Department Head

Acknowledgements

I (the author) would like to thank my advisor, Dr. Paul J. Johnson and my committee members Dr. Carter Johnson and Dr. Alyssa Gallant for their guidance. I would also like to thank the South Dakota Game Fish and Parks department for funding this important project through the State Wildlife Grants program (grant #T2-6-R-1, Study #2447), and Custer State Park assisting with housing during the field seasons.

A special thank you to taxonomists who helped with bee identifications: Dr. Terry Griswold, Jonathan Koch, and others from the USDA Logan bee lab; Karen Witherhill of the Sivelletta lab at the University of New Mexico; Dr. Laurence Packer, Shelia Dumesh, and Nicholai de Silva from York University; Rita Velez from South Dakota State University, and Jelle Devalez a visiting scientist at the US Geological Survey. Thank you to John S. Ascher for providing database and record information from the American Museum of Natural History Bee Database Project, as well as providing various tidbits of bee knowledge, Sam Droege of the US Geological Survey for help with bee identification and guidance with methodology, and Dr. Gary Larson from South Dakota State University for assistance with plant identification. Thank you to Black Hills National Forest, Rocky Mountain Research Station, and Stefanie Wacker. Additional thanks to Danielle Brandt, Anya Hartpence, and Salpy Kelian for technical assistance.

Very personal thanks to my family and friends for the encouragement and support and to my parents for instilling my love of the natural world. Lastly, thank you to all my former teachers and professors for my education.

This study is dedicated to all the bees that have died in the name of science.

Abstract

An Inventory of Native Bees (Hymenoptera: Apiformes)

in the Black Hills of South Dakota and Wyoming

David J. Drons

23 July 2012

Bees are an essential component of virtually every ecosystem but have been poorly studied in most of the United States, including South Dakota. The Black Hills has a high degree of historical and current anthropogenic disturbance and has the potential to serve as a model system for examining effects of environmental change and human influence on pollinator populations. This is the first biodiversity inventory of native bees in the Black Hills, with objectives of providing species occurrence records, accurate identification of all native bees, and documentation of floral visitations, all of which can assist in detecting future species composition change, and aide in further studies on pollinators, disturbances and climate change.

Sampling sites were representative of natural and disturbed ecological communities with a focus on flower-rich meadows and habitat diversity over elevation gradients. In 2010 and 2011 approximately 21,910 bees were collected from 94 sites by a combination of pan trap and hand netting (ca. 88,000 trap-hours), 47 exclusively hand netting sites and 35 volunteer collecting sites, resulting in the collection of 296 species representing 40 genera, 118 species not previously recorded in the region, and 102 morphospecies. In addition to 118 new records for the Black Hills, one species of *Dianthidium* was determined to be a new undescribed species. Thirty pan-traps per site were placed approximately every five meters and left for 24 hours to

passively collect bees. Hand netting focused on flowers in bloom to provide host plant data. Results support implementation of a monitoring protocol for native pollinators using this inventory as a baseline data set.

Analysis of pan trap capture data shows that size of bowl (5 ounce and 3.25 ounce) had an influence on number of bees captured. When comparing number of bees collected for each size, regardless of color, there was a significant difference (Large = 9670, Small = 8260, $p = 6.74225\ E\text{-}09$). Pan trap size also showed a significant difference in number of bees collected for large versus small for yellow ($p = 7.71416\ E\text{-}04$) and white ($p = 3.65734\ E\text{-}07$) with blue pan traps being the exception showing no significant difference ($p = 0.69883$). Large pan traps collected 174 bee species with 58 (33 %) of these being unique for that size of trap. Small pan traps collected 157 bee species of which 41 species (26 %) were unique for that size. The results of this analysis indicate that surveys would benefit from using a variety of sizes of pan trap.

Table of Contents

Page

Abstract. iv

List of Figures viii

List of Tables ix

Chapter 1. An inventory of native bees of the Black Hills of South Dakota and Wyoming

Introduction. 1

Objectives. 8

Methods. 9

Site selection 10

Pan trap sampling. 12

Processing pan trap samples 15

Net collection. 17

Records and analysis 19

Identification and taxonomic difficulties. 21

Results 23

Discussion 27

Future work 34

Chapter 2. Effects of size and color of pan trap on numbers and species captured

Introduction 36

Methods 38

Results. 39

Discussion 42

Summary. 45

References Cited. 46

Appendices

Appendix A. 53

Appendix B. 61

Appendix C. 69

Appendix D. 70

List of Figures

Page

Figure 1. 7

Figure 2. 8

Figure 3. 13

Figure 4. 15

Figure 5. 24

Figure 6. 26

Figure 7. 39

Figure 8. 40

Figure 9. 41

List of Tables

Page

Table 1. 40

All material in this document Copyright © David J. Drons 2012.

Chapter 1. An inventory of native bees in the Black Hills of South Dakota and Wyoming.

Introduction

Pollination is the transfer of pollen from anthers to stigmas of flowers and is typically facilitated by wind, water, gravity, or most commonly animals (Buchmann and Nabhan 1996, Kearns et al. 1998, Kevan 1999). Pollination is important for genetic diversity of flowering plants that do not self-pollinate and influences both plant and pollinator species diversity (Michener 2007, Potts et al. 2003). Animal mediated pollination, particularly by insects, is vital to the maintenance of wild ecosystems and many agriculture crops making concern for these pollinators central to the survival of both wildlife and humans (Kearns et al. 1998). In addition to maintaining robust genetic diversity in plant populations, pollination also increases fruit size and seed set, and shapes communities (Greenleaf and Kremen 2006). Some birds, bats, and other animals are important pollinators, but insects account for up to 90% of all animal pollination (Kearns et al 1998). Despite the importance of pollinators to virtually all ecosystems the full extent to which major groups of pollinators have been overlooked and understudied has only recently become apparent (Buchman and Nabhan 1996, National Research Council 2007).

Concern by scientists and naturalists for the health of pollinator communities is increasing due in part to documentation of declines and decreased historical ranges of several pollinator groups (Cameron et al. 2010, Grixti et al. 2009, National Research Council 2007). In addition to documented declines, basic population information is needed for bees (Hymenoptera, Apiformes) which are the most important pollinators in habitats with flowering plants (Buchmann and Naban 1996, Michener 2007, National Research Council 2007). Other insects such as beetles (Coleoptera), flies (Diptera) and wasps (Hymenoptera) regularly visit flowers and are important pollinators, but bees are highly modified for pollination and rely

almost exclusively on pollen and nectar for nutrition. Because bees have such an important role in pollination and ecosystem maintenance, they are often considered a keystone component of terrestrial ecosystems and can be an indicator of the state of environmental conditions (Cane et al. 2006, Carvell et al. 2011, Kearns 2009, Kevan 1999). A 2006 value estimation of the contribution of native bees to fruit and vegetable pollination in the United States was $3.07 billion showing that although they are commonly overlooked, native bees are important contributors to crop systems (Losey and Vaughn 2006). In many crop systems managed non-native honey bees are considered the primary pollinator, but recent declines due to Colony Collapse Disorder (CCD) have raised concern for both honey bees and native bees. Research has shown that with the proper habitat, native bees can help protect against pollen limitation of crops in the absence of honey bees (Knight et al. 2005, Winfree et al. 2007b). In addition to the valuable contribution to crop pollination, native bees are vital to maintaining many wild ecosystems (Buchmann and Naban 1996, National Research Council 2007). However, basic baseline population and occurrence data for bees and other pollinators are absent for many regions, particularly the western United States resulting in sparse knowledge of species distributions (Buchmann and Naban 1996, National Research Council 2007).

Anthropogenic changes such as habitat loss, fragmentation and degradation (hereafter called habitat change or modification) are often implicated as a major cause of declining populations (Cane et al. 2006, Carvell et al. 2011, Kearns 2009, National Research Council 2007, Winfree et al. 2009). Several North American species recently were added to the International Union for Conservation of Nature (IUCN 2012) Red List of species as critically imperiled and vulnerable (Kluser et al. 2010, National Research Council 2007, Xerces Society 2012). Some of the better studied and recognizable bee groups such as bumble bees (*Bombus* spp.), have well

documented signs of decline (Colla and Packer 2008, Goulson et al. 2008, Thorp 2005). Historical and current distribution of eight species of bumble bee in North America show the relative abundance of four species were shown to have declined by as much as 96% and the distribution ranges have also decreased (Cameron et al. 2011). In contrast, one of the best documented bee faunas in Illinois has shown little change over approximately 75 years, which might indicate that other populations that remain unstudied have not changed dramatically (Marlin and LeBerge 2001). Understanding the biology, population dynamics, role in the ecosystem, and distribution of the large diversity of native bee species is imperative because bees are the most important pollinators.

The Black Hills region in western South Dakota and eastern Wyoming is no exception to the serious lack of information on native bee populations. The lack of information on the bee fauna combined with the extensive historical and continued anthropogenic disturbance in the Black Hills and potential shifts in biological events such as plant bloom and bee emergence, has created an urgent need to determine the bee species present in the region. Without essential knowledge of current bee fauna, changes in their populations or even loss of species can go undetected. Changes in bee diversity can reflect signs of habitat degradation and can lead to changes in floral assemblages. Knowing and monitoring bee diversity can help prevent additional loss of biodiversity through early detection of change. To best protect and ensure the persistence of the native bees, species occurrence must be documented.

Prior to the study undertaken for this thesis, a formal inventory of native bees had never been completed for the Black Hills or even most areas in South Dakota. An outlier of the Rocky Mountains and never glaciated, the Black Hills is a unique region surrounded by arid plains (Froiland 1990). This region is home to Mount Rushmore National Monument and the Black Hills

National Forest, the first national forest in the United States and the most popular area in the state for tourism, outdoor recreation and naturalist activities. Dominated by ponderosa pine forest (*Pinus ponderosa* Lawson), it offers a diverse range of forested habitats, meadows, rolling grasslands that rise from 915 to 2,200 meters and include the highest point in North America east of the Rocky Mountains, Harney Peak (Froiland 1990). Despite a richness of biodiversity and the overall popularity of the region, the Black Hills remains biotically unexplored in many scientific aspects (Froiland 1990). The diversity of habitats in the Black Hills provides an opportunity for both bees and floral resources to be diverse and abundant.

Previous sampling of bees from the Black Hills was from a limited variety of independent collection events over roughly the last 170 years, but never an organized survey or inventory. Based on the most recent synoptic catalog of Hymenoptera (Krombein et al. 1979) there should be more than 200 species of bees expected to occur in the Black Hills. In contrast, published species records and unpublished database records from the Severin-McDaniel Insect Research Collection at South Dakota State University (SMIRC) and several major North American museums with significant bee collections provided 149 bee species records from the Black Hills, and 244 species for the entire state of South Dakota (Asher 2010). Many of the available museum specimens collected from the region have minimal or incomplete locality data by modern standards, and even fewer specimens have associated floral hosts or habitat data. With the lack of information on bee populations in addition to the potential effects on bees from anthropogenic changes in the forest it is imperative to learn what native bees exist before the species composition is greatly changed. Current issues that could potentially effect bee populations in the Black Hills include intensive forest management to reduce tree overcrowding and the effects of the Mountain pine beetle (*Dendroctonus ponderosae* Hopkins [Coleoptera:

Curculionidae]), disturbances from mining, recreation, fire, urban sprawl, and rural residential construction, all of which often result in severe habitat modification.

The Black Hills provide a unique opportunity for studying effects of regional and global environmental impacts such as climate change. In addition to a poorly known bee fauna, it is isolated from other mountains and is surrounded by semiarid plains. There is also a high degree of historical anthropogenic disturbance, increased settlement, and urbanization in and around the Black Hills. Because of these factors that the region has the potential to serve as a model system for examining effects of environmental change and human influence on pollinator populations. Overall there is a serious need for understanding the bee fauna of the region to help detect species composition change, and aide in further studies on pollinators, disturbances and climate change.

In recent years, evidence for pollinator declines has been on the rise, as highlighted by two major publications. The 1996 book “The Forgotten Pollinators” by Buchman and Nabhan described several instances of declines, oversight of population knowledge, and mismanagement of pollinators that could have severe long-term consequences. This book raised awareness of pollinator issues and was largely responsible for a subsequent surge in pollinator research. The National Resource Council (2007) published a review of the large body of literature available on pollination and pollinators compiled by a panel of experts. This review concluded that there were several major issues of serious concern with pollinators and coined the term “pollination crisis”, among the issues were multiple cases of pollinators from several taxa showing declines around the globe. More surprising and equally concerning was the abundance of taxa whose populations have not been studied. These understudied groups include native bees and other important pollinator groups in many areas of the United States

with the full distribution, regional diversity, or abundance of many species unknown. Of major concern is a lack of data showing basic presence/absence data, without which, there can be no direct evidence of population change. In a changing modern landscape and the concern for population declines, and species composition change, this is a very serious oversight in need of immediate correction.

Bees are a very diverse group of pollinators with almost 20,000 described species worldwide and nearly 4,000 in North America north of Mexico (Ascher and Pickering 2011). In North America there are seven families and 170 genera of native bees (Mader et al. 2010, Michener et al. 1994). Bees range in appearance from very wasp-like to extremely fuzzy and covered in dense hair. Bees also vary in color and size (Fig. 1) from the smallest, *Perdita minima* Cockerell, which is just less than two millimeters to the largest, *Megachile pluto* Smith, which measures roughly 39 mm (Michener 2007).

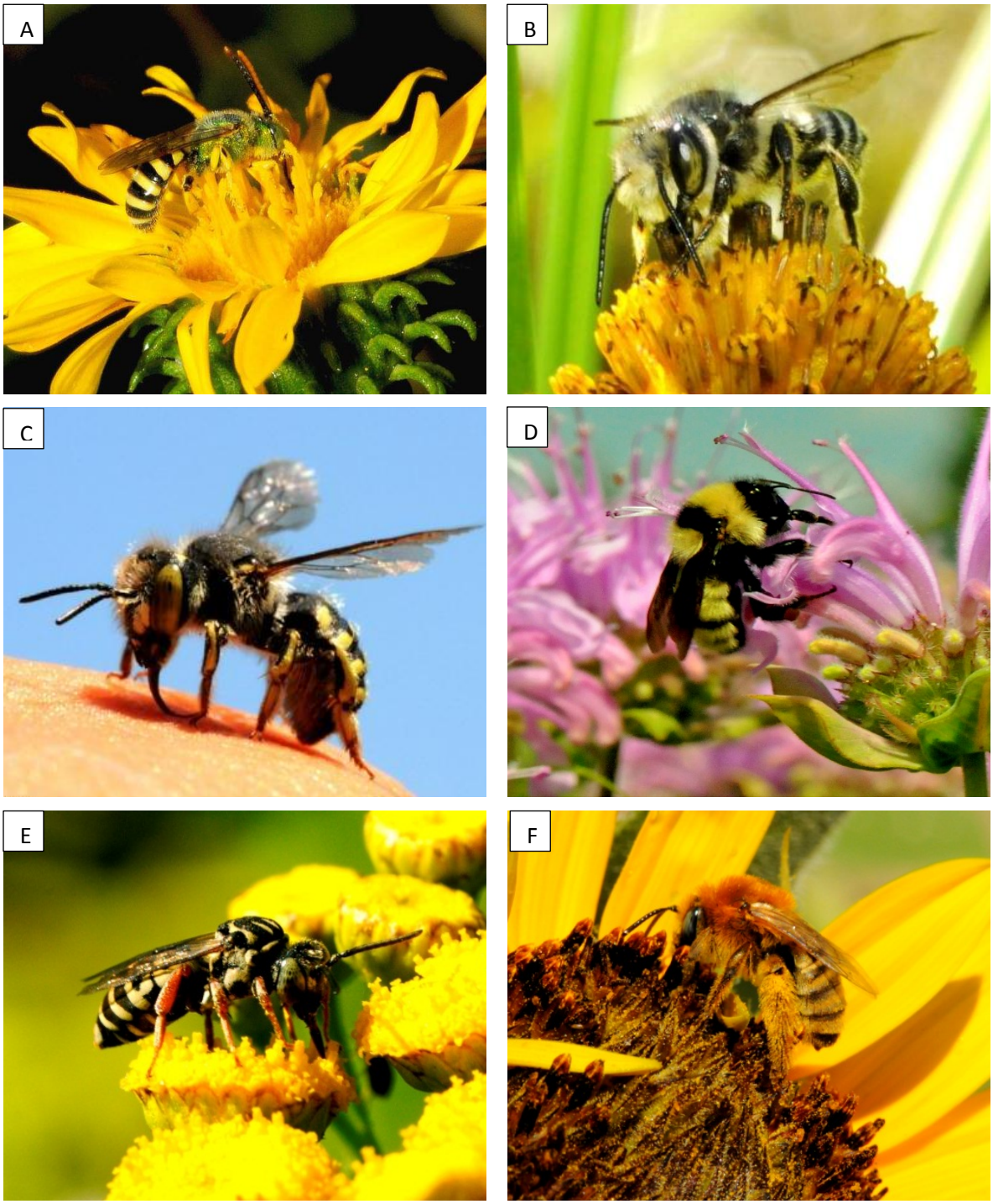

Figure 1. Diversity of native bees found in the Black Hills: **A**: *Agapostemon sp.*, **B**: *Megachile sp.*, **C**: *Anthidium sp.*, **D**: *Bombus sp.*, **E**: *Triepeolus sp.*, **F**: *Melissodes sp.* (all photos © D.J. Drons)

Bees are highly adapted organism for collecting nectar and pollen (Fig 2.) (Michener 2007). One morphological detail that distinguishes bees from wasps is the presence of branching and featherlike setae commonly called hairs. All bees have at least some hairs that are branching or plumose that pollen readily adheres. In addition to feeding solely on pollen (and nectar), females collect pollen to provision for their offspring and are highly adapted for this task, with brushes on their mid and fore legs to help move the pollen to their expanded hind legs that are typically covered in specialized hairs to help transport large amounts of pollen (Michener 2007, Stephen et al. 1969). Females spend the majority of their time collecting and carrying pollen to provision their eggs and rarely interact with males (Michener 2007). The male's main interaction with the female is mating and fertilization. Male bees, which have no role in providing for the young, lack pollen collecting and carrying modifications but are covered in dense pubescence and pollinate by incidental collection and deposition of pollen while feeding on nectar.

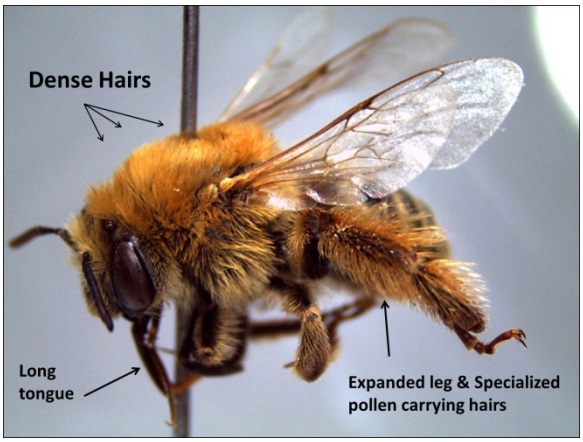

Figure 2. Specialized adaptations of bees a *Melissodes* sp. is shown. (photo © D.J. Drons)

OBJECTIVES

The lack of information on the bee fauna in the Black Hills, and South Dakota as a whole, creates high expectations for numerous new regional and state records as well as the potential for undescribed species. This inventory provides the important baseline data to determine

future changes in species composition in the Black Hills. Due to the lack of basic information on the native bee fauna of the Black Hills, ongoing anthropogenic disturbance, and the worldwide pollinator declines, the following objectives were developed for this study:

1. Complete an inventory of native bees of the Black Hills, including research of published records, databases for unpublished records, and identification of specimens collected.
2. Focus field collections on exemplary meadow, forest, and shrub-steppe habitats in the Black Hills area of Custer, Fall River, Lawrence, and Pennington Counties of South Dakota.
3. Document host flowers.
4. Collect habitat and location data to be associated with voucher specimens to support future assessments of patterns of species occurrence related to land use, habitat type, elevation, or other environmental variables.

METHODS

Sampling of bees was conducted between May and September of 2010 and 2011 throughout the Black Hills of South Dakota and Wyoming. Two complementary inventory methods were implemented: pan trapping and hand netting. Methodology largely followed the bee inventory (BI) plot (LeBuhn et al. 2003) and the methods outlined in “The Very Handy Bee Manual” (Droege 2010 unpublished) with slight modifications. At the start of each field season initial site exploration and sampling coincided with the overall pattern of floral bloom in the spring; generally from south to north and east to west, as well as low elevation to high elevation. Sampling sites were distributed in an attempt to cover the broad geographic area and

represent a diversity of habitats found in the Black Hills. Once bees were active in the spring sampling was executed on a regular basis. Sampling was postponed during conditions not conducive to bee activity, such as cool air temperature or extreme heat, severe storms or extended periods of rain, excessive wind or other inclement weather. This thesis does not endorse any products mentioned herein, products mentioned are for research and educational purposes only.

Site Selection

Sites were distributed throughout the Black Hills until all basic habitat types were sampled in all major portions of the region. Sites were selected subjectively to include an array of representative meadows, forest types and densities, and habitats with unique ecological characteristics that might be missed with a truly randomized protocol.

Sites were chosen based on a combination of spatial distribution, ecological characteristics, location and ease of access. Sites were stratified and pre-selected based on geographic location and expected habitat type prior to sampling. Pre-survey site selection was accomplished by dividing the area into regions that contained habitats of interest and could be accessed by similar routes using maps of the Black Hills National Forest which included forest roads from the United States Forest Service (USFS). Hiking to sites was limited in most cases to approximately 15 minutes duration to allow for sufficient time to sample multiple sites each day. As areas became more familiar, additional sites were added throughout the season as an attempt to increase geographic coverage and include more habitats. The aim of the first season was to gain familiarity with the area and the habitats of the Black Hills and provide initial spatial coverage of collection sites to obtain initial data on bee species present. The focus of the second

year was to increase sampling coverage, complete the species list and inventory, and investigate the seasonal phenology of bees in the Black Hills.

Site selection for the second (2011) field season was based on knowledge of the area gained during 2010. Several sites visited during the first season that contained quality habitat and were easy to access were selected to be resampled during the 2011 season. Additional sites were included during the 2011 season based on the same access and habitat criteria used for all sites, with special attention to filling in known gaps in spatial coverage. In 2011 sampling was modified from the 2010 protocol to include repeat site visits approximately every three to four weeks. This was modified from the two week interval suggested in the BI Plot (LeBuhn et al. 2003) because of the large area to be sampled by one individual.

In addition to spatial distribution and habitat type a requirement for site selection was that transects had to be placed in a single continuous habitat type. Sites had to accommodate all pan traps in one habitat type to avoid crossing environmental gradients to provide more definitive habitat data. Exceptions were transects on steep hills which typically crossed the topographical gradient at an angle to allow collection of bees from all elevations on the hillside, within a single habitat type.

Basic habitat characteristics and location data were recorded for each site sampled. These included directions to the site, GPS coordinates, species of tree and shrubs on site as well as surrounding the site, forest density estimates, evidence of disturbance, and any other notable information. Botanical information recorded was basic and included species or genera currently in bloom as observed by initial site inspection and during trap placement, trap pick up and net collecting. A Garmin® Etrex Vista HCX GPS was used to record latitude and longitude using datum WGS 84. These data were recorded both electronically in the GPS unit and written in field

notes. Weather data during the first year was obtained with a generic outdoor thermometer and estimates of general wind direction and wind speed. During the second field season a Kestrel® 3000 Pocket Wind Meter was used to obtain wind speed and temperature. Site characteristics included qualitative estimates of forest density and size class ("high density" or "low density"). Low density stands of ponderosa pine had trees that were generously spaced with no or minimal crown overlap. High density stands of ponderosa pine had overlapping crowns with individual trees visibly crowded such that growth form was affected. Age and size of trees were also estimated and recorded for each site.

Sites were photographed during the initial visit and often during subsequent visits. Four photos were taken from the approximate midpoint of each transect. The first photo was taken parallel with the transect and contained a bowl in the bottom (foreground) of the photo. Additional photos were taken at 90° intervals until all four directions were photographed. This provided an overview of the transect and the site. Bees were also photographed as time allowed. All images are archived for reference as desired.

Pan Trap Collection

The main collection technique for this inventory made use of current methodology for pan traps or "bee bowls". Two sizes of plastic Solo® brand bowls were used 148 milliliters (5.0 ounce) and 96 milliliter (3.25 ounce), commonly known in the food industry as dessert bowls and soufflé cups, respectively. Bowls were colored with Krylon™ fusion or Ace™ brand fluorescent spray paints in white, fluorescent blue, or fluorescent yellow to be visually attractive to bees. Preparation of bowls was based on information from "The Very Handy Bee Manual" (Droege 2010 unpublished). Each bowl was filled with water and a small amount of dish soap to

break the surface tension allowing for capture of bees. One large squirt (approximately 2 tablespoons or 29.57 ml) of Dawn blue unscented dish soap or generic unscented dish soap was added to a gallon jug (3.785 liters) containing tap water, and then shaken. Each site sampled with pan traps contained 30 bowls placed five meters apart along a straight transect. Bowls were filled to ¾ capacity with soapy water and left for 24 hours. The standard distance between bowls is five meters to eliminate inter-bowl competition for attracting bees, and for this study, was measured by paces (Carboni and LeBuhn Unpublished B, Droege et al. 2010). An equal number of small (96 ml) and large (148 ml) bowls of each color yellow, blue, and white were used for each transect. A large yellow bowl always indicated the start of a transect, and subsequent bowls alternated through all three color uniformly within a transect, though varying in order among transects. The final two bowls of each transect were spaced only two meters apart to indicate the end of the trap line. The correct number and color order of bowls were pre-arranged and pre-packaged with the two sizes separated and stored in plastic bags until needed (Fig. 3). This made the bowls easier to deploy and was a more efficient use of time in the

Figure 3. Pan traps for two transects organized and ready for efficient deployment. (photo © D.J. Drons)

field. After 24 hours samples were collected, strained and stored in 80% EtOH (ethanol) with a field label until further processing in the laboratory.

Physical barriers and uneven ground occasionally required alteration of the transect protocol. For example the transect was angled to avoid dense trees or impassable terrain Dense vegetation affected the stability of bowls as well as obscuring them from foraging bees, which could result in poor capture numbers. To overcome these conditions a small area was trampled by foot and the bowl placed in the middle of the matted vegetation. Another concern was wind as the bowls are very lightweight. However the soapy water provided some weight to keep the bowl in place during breezy conditions.

Pan trap samples were kept separate for each size and color to provide additional data on bowl capture and color preference. Six Whirl-Pak® plastic sample bags were used each for each transect, with a field label indicating site, date, and bowl color and size for each bag. Weather, site conditions, broken or tipped bowls or any other pertinent observations were recorded at the time of the trap pick up. After collection the specimens were stored in 80% EtOH and kept away from excessive heat and direct sun until further processing. The six subsamples for each site were kept together until subsequent processing and labeling of all bees was complete.

The technique used for collection of pan traps during the 2010 field season produced satisfactory results but was inefficient. At each site prior to collection, six field labels with site and bowl data were placed in separate sample bags. As each bowl was collected it was immediately poured into a strainer, and the strainer carefully emptied directly into the associated sample bag then checked to ensure no insects remained attached to the mesh. This was repeated as each bowl was collected, rotating through the bags for each corresponding

Figure 4. Apparatus for collecting bowl samples and keeping size and colors separate. (photo © D.J. Drons)

color and size combination. For the second field season (2011) a simple tool (Fig. 4) was developed to improve the efficiency of collection of pan traps. The collection tool consisted of two wooden survey stakes, both covered in rubber and attached together at one end by a small hinge and contained six straining nets of two sizes and three colors to represent each bowl size and color option. Using this tool, each bowl was poured into the corresponding color and size straining net and repeated until all bowls were collected. After all samples were collected, field labels were placed into the matching nets and the entire contents of each net were carefully emptied into one of the six bags for storage.

Processing Pan Trap Samples

Bees were washed and processed in the lab to achieve clean and natural looking specimens based on widely used methods outlined in “The Very Handy Bee Manual” (Droege 2010 unpublished). Steps included sorting, washing, rinsing, drying and pinning of the bees to yield clean, dry, natural looking bees with fluffed hair. Processing was limited to one subsample

at a time to eliminate potential mixing of specimens from different samples. Variations of this method are common with the use of pan traps, but all methods yield similar results. A downfall of using pan traps is that processing is very time consuming.

The first step of processing samples in the lab was to separate bees from the non-bee bycatch. Bees were then placed into a mason jar for immediate processing with the non-target bycatch placed back into the original sample bag along with a copied field label as a quality control measure and was later re-checked for any bees missed during sorting. The original field label remained with the bees during the entire process to avoid possible errors associated with using duplicated labels. Bees were washed in the mason jar with a double screen on the lid of the jar to ensure that no small bees were lost through any small openings. A very small amount of dish soap was added, and then filled with cold water and the contents shaken for ten seconds to one minute, depending on the number of bees and amount of pollen visible. Once bees appeared clean washing was complete and the bees were rinsed with cold water until suds no longer appeared. The water was emptied, and a small amount of EtOH was then added to replace any water on the bees and decrease drying time. The EtOH was then poured out and shaken from the jar.

After washing, the bees were dried and pinned. Drying is very important to achieving a nice loft to the dense hairs that often cover bees. If bees are not dried completely the hair, which is often a distinguishing characteristic, can remain matted and potentially obscure morphological features that are important for identification. Using a screen lid in place on the mason jar, bees were blown dry with a hair dryer blowing through the screen lid. Care was taken to prevent overheating of the specimens and drying was continued until patches of dense hair were visibly dried and fluffy.

Net Collection

Active collecting was done by aerial insect net and focused on common floral hosts at each site. For this study net collection was considered secondary and complementary to pan trapping and was implemented at independent sites in addition to pan trap sites. At pan trapping sites, the aim was to net collect for a total of one hour when visited during peak bee activity hours. Bees were collected in 15 minute intervals at each site. An attempt was made to collect bees from all species of plant in bloom at each site and was limited to no more than two species of flower at a time, with an attempt to split effort evenly until all flowering species were sampled for bees. After all visible and obvious flower species and patches at the site were sampled, if sampling time remained, plants with a noticeably high rate of bee visitation were returned to for further collection. In instances where weather conditions caused a reduction in bee activity, net collection was not conducted at that particular site and if no improvement in weather or bee activity occurred within 15 minutes. During net collection all bees and any questionable bee-like insects were collected and placed in 118 milliliter (4 oz.) jars containing potassium cyanide. A single jar was used for each plant species which bees were collected from at a site, and included a field label with the site code and number, date, and plant the bee was collected from. Host plant identification was predominantly completed in the field using “Plants of the Black Hills and Bear Lodge Mountains” (Larson and Johnson 1999). Plants that were not immediately recognized or that posed any level of uncertainty were collected, pressed and later identified with assistance from G. Larson, South Dakota State University.

In addition to locations where pan trapping took place, net collection was also opportunistic in areas of suitable habitat. These locations were typically rich in floral resources or contained unique ecological characteristics, but were not suitable for pan trapping. The sites

often included roadside meadows or were along hiking trails. Collection at these sites took place in 15 minute intervals.

Bees from net collections were left in collecting jars for a minimum of one hour to ensure mortality. After one hour, bees were transferred to a plastic vial to avoid excessive desiccation from the potassium cyanide. Bees were pinned as soon as possible, typically the evening of the day of collection.

Slight differences exist in net collection methodology between the two years of sampling. To avoid interfering with collection by the pan traps, in 2010, net collection at pan trap sites was carried out away from the immediate area surrounding the pan traps, even though floral resources were abundant near the transect of pan traps. In 2011 net collection took place before and after pan trap placement and collection, and included the areas immediate and adjacent to each transect. Net collecting typically took place in the vicinity of the transect for a 30-minute period prior to trap placement, and for a 30 minute period immediately before or after bowl collection on the following day.

Citizen volunteer scientists provided specimens to the project during the 2010 season to enhance the overall survey. Kill jars and directions for bee collection and storage were provided to “citizen scientists” in the Black Hills. Volunteers did not use pan traps, but collected in any manner they could from any location within the Black Hills. Volunteers were asked to provide location, collection date, and host plant with the specimens. Bees were kept in separate containers, based on collection date and host plant, and remained frozen until they could be acquired and processed for the project.

Records and analysis

Historical records of bees for the state of South Dakota and the Black Hills were provided by the American Museum of Natural History (AMNH) Bee Database Project and the Severin-McDaniel Insect Research Collection (SMIRC) at South Dakota State University. A preliminary literature search to find published records of bee occurrence yielded no substantial results and verified that no prior bee survey was conducted in the region. A working checklist of bees for the state was developed from the AMNH Bee Database Program, and this included county records when available. This list was based on database records from major university and museum collections, as well as any published records. At the start of the project the checklist of species occurrence contained 244 records for the entire state and as the most authoritative information source, was used as the basis for recognizing new state and regional records. Due to the large volume of current work updating collections and databases, all comparisons are made to this 2010 species list for both state and Black Hills area records. Current taxonomy was used for historical records to avoid confusion and ensure these would not be overlooked and counted as missing species.

The number of species expected for the Black Hills was determined by a conservative interpretation of ranges from the Catalog of Hymenoptera in America North of Mexico (Krombein et al. 1979). Many entries in this catalog simply list states that outline a species range. This is problematic for users because the geographic positions of locality data have a large impact on determining likely species ranges. In the absence of information more precise than a state name, the user must determine exactly where the point sits in the state, which can have a drastically different outcome on the species range depending on the location of these points. For this study, the general midpoints of states were used when ranges were

questionable. If the current range included similar habitat to that in the Black Hills, species were determined to be expected in the region.

Indices used to assess diversity and evenness of species were the Shannon-Wiener Index and species richness (Agosti et al. 2000). Calculations were completed for the entire Black Hills region as well as select sites that were equally sampled. The Shannon-Wiener Index for individual sites were based on pan trap collection only and was calculated using genus level identification, while the calculation for the entire Black Hills was based on all all collection methods and used species level identification. Species abundance was used for the Shannon-Wiener index in combination with the number of species collected during the project. For the calculation of the Shannon-Wiener Index for sampling sites, number of genera and their abundance was used with the exception of *Lasioglossum*. Number of species collected was used to determine species richness. The Shannon-Wiener Index (H') was calculated using the formula listed below where p_i represents the proportion of a single species to the total number of individuals of all species.

$$H' = -\sum p_i \ln p_i$$

The raw species accumulation curve was determined for the entire Black Hills. Using weeks as the unit of time, each species was counted only once when the species first appeared during sampling (Agosti et al. 2000). Each additional species collected was added to the total number of species for each unit of time. For all undetermined taxa, the highest level of determination was used and counted only once. Microsoft Excel was used to plot the species accumulation over time and a trendline was added.

Identification and Taxonomic Difficulties

Identification of specimens was largely a cooperative effort. Initial identification was accomplished using "The Bee Genera of North and Central America" (Michener et al. 1994), "Bees of the World" (Michener 2007) and online resources found at www.discoverlife.org (2012). Genus identification, when possible, was completed prior to shipping specimens to taxonomists for species level identification. Remaining undetermined specimens not sent to taxonomists were identified to the highest taxonomic level by use of online keys at www.discoverlife.org in combination with reference specimens that had been identified and returned by taxonomists.

Identification of several bee taxa is considered difficult, even for experts. Problematic taxa are mainly members of the Tribe Eucerini (Family Apidae), and members of the families Andrenidae and Halictidae. These groups of bees are notorious for being diverse in species, difficult to identify, and in need of taxonomic revision. Although many specimens were sent to taxonomists, difficult or large groups often contained individuals that were identifiable only to morphospecies or at the highest level of confident identification. In such cases further identification could yield more named species, but the overall species richness for the Black Hills would most likely not substantially change. Several problematic taxa were used in a limited manner for analysis.

The most likely taxon to increase known species diversity for the Black Hills is the Halictidae. Due to the large number of specimens collected from this family, only a small portion could be sent to taxonomists for identification. Species of the genus *Lasioglossum* are historically difficult to identify with keys and few taxonomists work with this group. Although a small proportion of *Lasiglossum* from this inventory were identified by taxonomists, most

specimens in this group at time of writing remain limited to subgeneric identification, i.e. *Lasioglossum (Dialictus), Lasioglossum (Evylaeus) and Lasioglossum (sensu stricto).* These subgeneric identifications were used for analysis, but not for the overall species list of the Black Hills unless referring to a specific morphospecies. Also, because of this small percentage of *Lasioglossum* that are accurately identified, several more species occurrence records can be expected with further examination. In addition to *Lasiglossum*, the brilliantly metallic green bees of the Tribe Augochlorini were found to be rather abundant during the inventory and additional examination is likely to reveal two or more species that are similar in appearance and are taxonomically difficult.

The Eucerini contains the genera *Eucera* Scopoli*, Melissodes* Latreille and *Tetraloniella* Ashmead which are all rather difficult to identify even for many taxonomists, and are in need of revision. Due to time constraints and availability of taxonomists approximately half of the total specimens in this tribe were sent to a taxonomist for identification. Many specimens remain unidentified for this group, with a portion treated as morphospecies.

The family Andrenidae is a large and diverse group with many species that are difficult to accurately identify. During the project there was no taxonomic specialist is available to aide in species level identification. Specimens from this large and diverse group were separated with confidence to morphospecies and a portion identified to species. Males of this family present further difficulty to identify unless confidently associated with females. For occurrence records and analysis, males are assumed to be the same species as most females but were grouped as a single morphospecies.

RESULTS

Two years of sampling for this inventory resulted in the collection of 21,910 bee specimens, 19,522 bees were from pan traps, and 2,388 bees were collected by hand netting from 125 species of plants (Appendix D.). All specimens collected were added to a database and identified to family, with the majority identified to genus and most to species, with the exception of problematic taxa previously mentioned. Specimens collected represent six families, 40 genera, and 296 species as listed in Appendix A. One species in the Family Megachilidae, Genus *Dianthidium* Cockerell, was recognized as an undescribed new species and will be included in a taxonomic revision by T. Griswold (USDA, Bee Biology & Systematics Lab, Logan, UT).

The majority of wild bees collected during the inventory were native, but four non-native species were also collected and are included in Appendix A. Species richness and the Shannon-Wiener Index were calculated for the region, as well as select sites. The total species richness for all pan trap collecting is 231 species. Net collections, including volunteer-collected bees, produced a species richness of 197. Both netting and pan trapping had species in common as well as a group of species that were unique for each method. The Shannon-Wiener Index for the entire sampling effort was determined to be 3.967, and the indices for individual sites ranged from 0.475 to 2.624 with complete results listed in Appendix C. A raw species accumulation curve showing the number of species new to the project per unit of time (week) is shown in Figure 5. The bar height in Figure 5 represents the additional species collected.

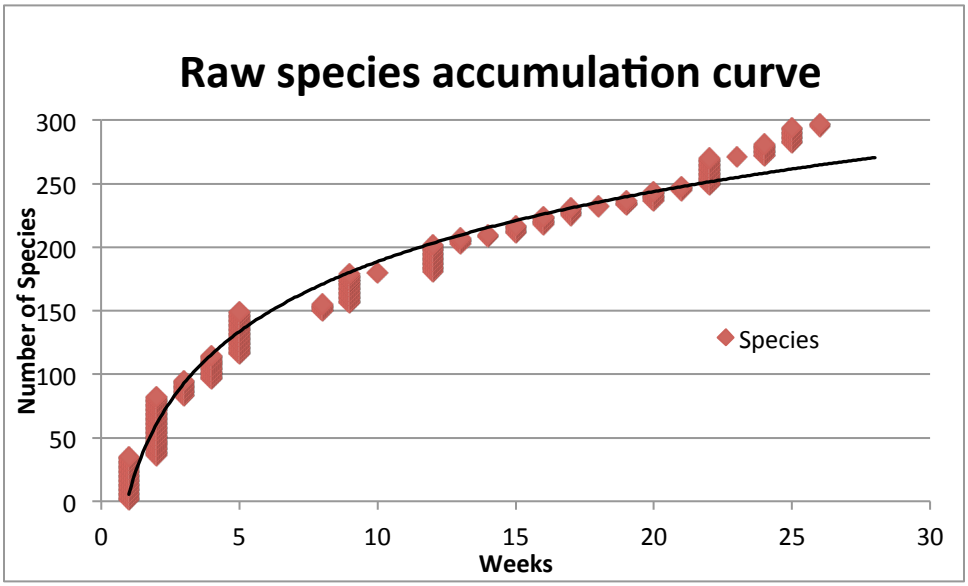

Figure 5. Raw species accumulation curve for the Black Hills.

Species of *Lasioglossum* are often found in large numbers, particularly when sampling with pan traps. In the Black Hills survey this was no exception, *Lasioglossum* accounted for a total of 10,726 specimens that accounted for almost half of all bees collected, and 60% of all bees collected by pan trap.

The historical records supplied by the AMNH and the SMIRC document 244 species for the entire state. Using the most recent taxonomy, 151 species representing 32 genera had been previously recorded from the Black Hills. Historical records from the SMIRC included 98 species, and the AMNH records included 86 species from the Black Hills, with 33 species in common between the two sources. At this point it is not possible to determine how many of these records were published, but literature reviews thus far suggest that the majority remain unpublished. The expected number of species in the Black Hills ranged from 170 to 220 species depending on either a conservative or liberal interpretation of ranges as given in the Synoptic Catalog of Hymenoptera (Krombein et al. 1979). Of the 296 species that were collected during

this project, 102 were determined to morphospecies and are distinctly different from the identified species. From the specimens with confirmed species identification, 118 were new additions to the known Black Hills bee fauna (Appendix A.). The current inventory includes 87 species that had been previously documented in historic records of the Black Hills, but 64 species previously recorded in the region were not collected.

Overall a total of 138 different sites were visited in 2010 and 2011 during the summer months of bee activity (Fig. 6). In 2010 sampling started in late May and continued until late August. In 2011 sampling was performed from late May through mid-September. Of the total sites, 94 were pan trapping sites, 57 of which included net sampling. There were 47 sites that were exclusively net collection sites and 35 volunteer sites at which bees were collected by hand. Of the 94 pan trap sites 32 of them were sampled at regular intervals during the second season to acquire phenology data. Because these sites were sampled in a consistent fashion, they are considered comparable for any ecological and diversity analysis. The average length of day (14.25 hours of daylight for the months sampled) was used to determine the total number of trap hours. Total number of trap hours during the entire project was an estimated 87,637.

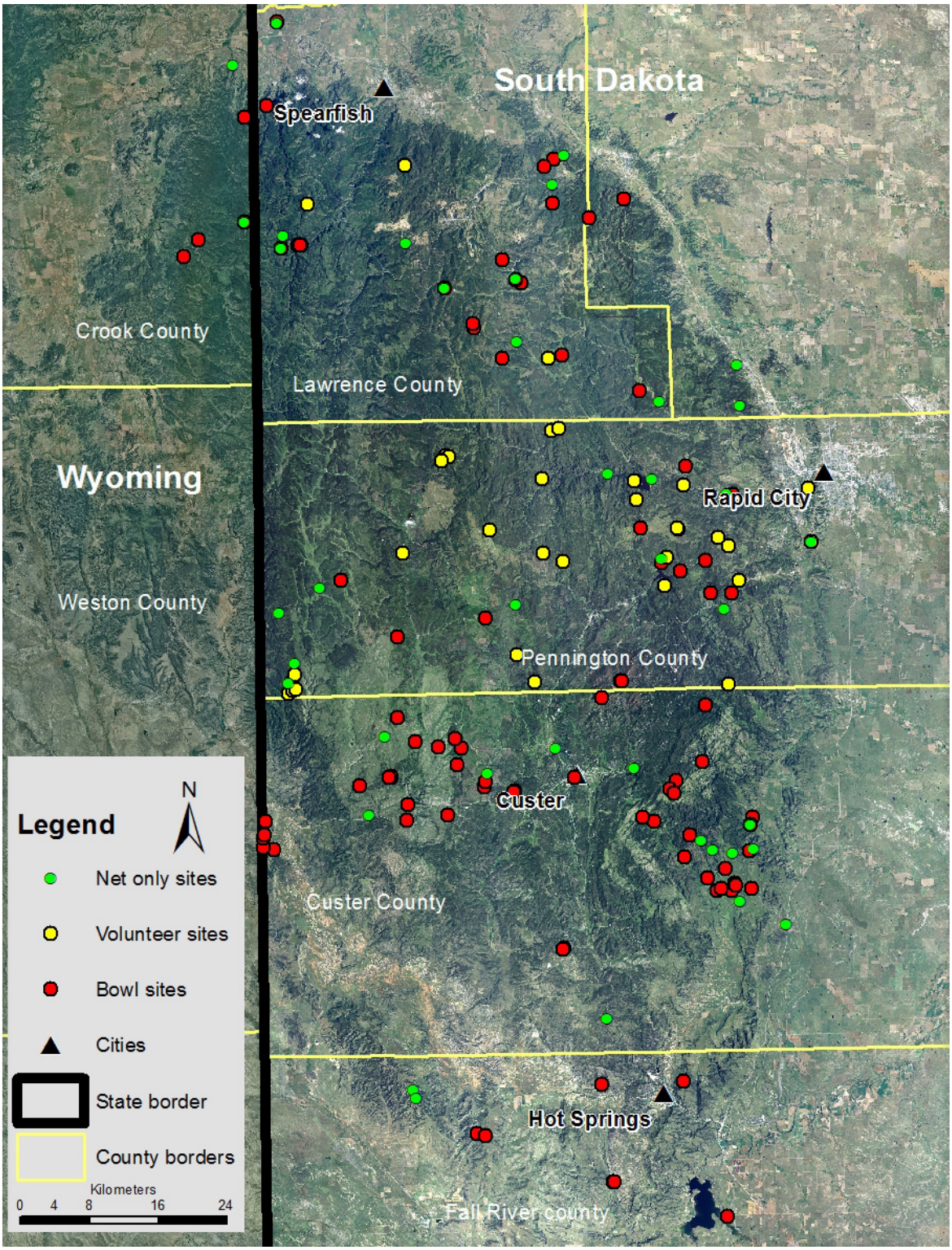

Figure 6. Black Hills sampling sites.

Discussion

The total number of species for the Black Hills exceeded predicted species richness, as did the number of new records for the region. The presence of an undescribed species reinforces the justification of this inventory by showing that there was much to be discovered in regards to the bee fauna of the Black Hills. The species accumulation curve indicates a relative degree of completeness by the inventory, as the trendline implies that additional sampling would yield only a small number of additional of species. To collect additional species at a higher rate would require a significant increase in sampling effort, or a possible change in sampling methods.

Though the total species collected for this survey contains a large number of new records, 64 species from historical records were not found. Taxonomic use of historical names was checked to ensure species names had not changed and were overlooked. Several possible explanations exist for species that were expected or previously recorded, but not collected during this inventory. One possibility is that there has been a shift in species diversity and the uncollected species are no longer present, or have become rare in the Black Hills. Another possibility for the absence is that species that are rare or are not effectively sampled by bowl traps are most likely under sampled and therefore would be under represented. Species with unusually short activity periods could have potentially been missed by the sampling methods used. Unidentified species in this inventory could also be species previously recorded from the region. Lastly, the species that are associated with extensive forest or habitats that were not properly sampled are also potentially under represented.

The species accumulation curve (Fig. 5) suggests that the combined sampling methods used were effective in measuring the bee diversity. The slope of the species accumulation curve,

starting at week 12, shows that fewer species were being collected as sampling continued. There is little change in species accumulation between the last two weeks of collecting, but species continued to be collected at a decreasing rate. Although there is an increase of species numbers toward the end of the species accumulation curve overall the trend line shows that to collect more species an increase in effort or more sampling periods would be needed. This accumulation curve indicates that for this inventory pan trap sampling and net collection was very successful as a standard method.

The species accumulation curve shows an influence by sampling effort, sampling methods, and bee activity periods. Sampling effort is reflected by the species collected when using a unit of time for the horizontal axis of the raw species accumulation curve. The data reflects the decrease in species collected during weeks six to eight, as well as the increase in species starting near week 25 to the end of the sampling. The main reason for the decrease during weeks six to eight is that considerably less sampling took place during weeks six to eight due to scheduling conflicts and extreme weather, and the increase of species collected toward the end of the accumulation curve reflects an increase of sampling effort towards the end of the project. In addition to the variation of sampling effort, the activity periods of bees may have also had an effect on the accumulation rate. Many species are active only during a specific seasonal period such as spring, summer, or autumn. During changes of bee activity due to phenology there would be fewer species accumulated, for example bee species that do have a stratified activity period and are mostly active in the spring generally become less common by mid-June or earlier and species that are active for the summer months are beginning their activity period. Another possibility for variation of species accumulation is the under studied concept of “floral dilution” in which when abundant floral resources are available, bees are

difficult to find and pan traps are less successful in sampling bees (Linsley 1958, Roulston et al. 2007, Wilson et al. 2008). Although “floral dilution” has not been well studied and at least one study shows no evidence of this (Toler et al. 2005), it is a frequent concern among bee specialists (Cane et al. 2001, S. Droege personal comm.). In the Black Hills inventory, the low species accumulation during this period is likely a result of temporarily reduced sampling effort.

Additional sampling methods could have potentially increased the overall species richness. Nest trapping involves providing nesting materials such as nesting blocks for bees, and once eggs are laid and provisioned, the material is moved to a lab where the bees are reared to maturity. The use of vane traps, which are a transparent jug topped with a colored vane to intercept flying insects used in some bee studies (Porter 2010; Stephen and Rao 2005), which can capture large numbers of typically larger and dispersing bees, could have also increased the number of species.

Increased time or effort sampling by net could have yielded higher number of species captured. Net collection was part of the sampling protocol, but effort was often limited by inclement weather or time. A study by Grundel et al. (2011) showed that pan trapping and netting have approximately 50% of species in common and approximately 25% of total species unique for each sampling method. Although not fully analyzed results from the Black Hills inventory show similar trends with each method having both unique species and a number of species in common. Given the uneven effort of pan trapping compared to net collection one could infer that an increase in net collection intensity would yield additional species. Though possibly minimal, out of all bee sampling methods and based on this inventory effort, in the Black Hills net collecting may be the most effective method to capture additional species.

The analysis could benefit from further examination. The Shannon-Wiener Index is a measure that takes into account the evenness of a sample in addition to the species richness. These measures show that although the species richness was high there were many species with similar abundance which resulted in the relatively low numbers, and was also influenced by the number of times a site was visited. This index is best used within areas of equal sampling effort and methods, so this index calculated for the entire region although comparable, has limited use. Compared to other studies the The Shannon-Wiener Index for individual sites ranged from 0.475 to 2.624. The site with the lowest Shannon-Wiener Index was highly disturbed by both fire and human recreation, contained dense vegetation, and is greatly influenced by the uneven abundance of individual species. In contrast the site with the highest Shannon-Wiener Index had relatively low species richness in even abundance, while the site with the overall highest species richness, had an average Shannon-Wiener Index of 1.797. These results indicate that although the Shannon-Wiener Index can be useful in determining heterogeneity, or the evenness of number of species present in combination their abundance, it should not be confused as a measure of diversity which is best represented by species richness.

Given the large area of the Black Hills and limitations of this study there are areas remaining to be surveyed for native bees. As an initial effort over a large and diverse geographic area, efficiency was a major concern for this project, and as a result hiking and exploration of restricted areas and remote areas was limited. Increased sampling in areas of forest and areas further removed from anthropogenic disturbance could potentially yield more species. Since this study was focused on readily accessible bee-rich areas such as meadows, forest specialist bee species and species most sensitive to disturbance that are most likely found farther away from human activity may have been missed. Parts of the Black Hills were under-sampled (Fig. 6) due

to the arrangement of roads and presence of private land. These areas include a portion of the central Black Hills including the 2000 acre Reynolds Prairie, the western areas along the Wyoming border, and areas north of Edgemont in the southern portion of the Black Hills. In addition to these difficult to access areas, several areas were not sampled due to active livestock grazing. Areas with livestock are less attractive for sampling due to the increased chances of crushed bowls and seasonal removal of bee-attractive flowering plants. Unsampled areas have the potential to contain additional species, but compared with the total number of species collected during the inventory, proportionally additional species would be few if they exist.

Unfortunately the effort to identify species was not equal for all groups. Number of species identified by taxonomists was influenced by number of specimens sent to be examined. For many bee groups closer inspection by taxonomists will undoubtedly yield additional species. There is a very high likelihood that there are more species present in the Black Hills than reported. Even with incomplete identifications and survey limitations, the total number of species now known to be present in the Black Hills from the current effort exceeded the number of species anticipated.

In contrast to overall species results the diversity of *Bombus* species was lower than expected for the Black Hills. Bumble bees are one group of several, which are thought to rarely appear in pan traps (Roulston et al. 2007). The low diversity of *Bombus* species could be a result of insufficient net collecting, although they were often present and collected at many sites. This genus is well studied and has shown well documented patterns of decline across North America (Cameron et al. 2011) and has also been shown to be sensitive to landscape changes (Goverde et al. 2002). Although the emphasis on pan traps as the main method of sampling could have influenced the results, results for *Bombus* are lower than anticipated from historical records,

expected ranges and habitat preferences. Several species had potential to be present based on historical records (*B. bifarius* Cresson*, B. morrisoni* Cresson*, B. pensylvanicus* (DeGeer)*,* and *B. suckleyi* (Greene) were not collected during this inventory.

Bees generally are expected to be most abundant in areas with high floral resources and low disturbance. In the Black Hills region, which is dominated by ponderosa pine forest, most bees will be found in floral-rich meadows and roadside clearings (Hopwood 2008). Human disturbance can, in this context, be beneficial to bees by decreasing forest cover and increasing moisture and floral resources (Bohart 1972). Bees are excellent indicators of environmental conditions and habitat degradation (Kevan 1999), and may also be somewhat resilient to landscape level anthropogenic disturbance. Winfree et al. (2007) recently found that several bee groups which were expected to be sensitive to disturbance surprisingly did not have a strong correlation with disturbance. The response of bees to habitat change and environmental disturbance can be anticipated by key life history and behavioral strategies giving expectations of which bees will be present in disturbed areas.

Nesting strategy is important for determining which species are affected and sensitive to different types of disturbance (Williams et al. 2010). Several studies illustrate negative effects of grazing on pollinator communities (Williams et al. 2010, Winfree et al. 2007a). Cattle grazing is common in the Black Hills and may have influenced bee and other pollinator communities. Livestock grazing removes available forage for native pollinators, reducing the carrying capacity of the land for any organism relying on flowering forbs or seeds as forage. A secondary result of cattle grazing is the compaction of soil reducing available nesting sites for ground nesting bees. In addition to soil compaction, livestock also tramples vegetation which is an important substrate for stem nesting bees. With the potential of widespread logging and forest thinning

projects to ultimately have a short and long term benefit to bee populations, the addition of long term or high intensity grazing is a likely negative threat to native bees.

Many of the environmental impacts on native bees are largely based on nesting strategy and potential floral resources (Williams et al. 2010). The overall effect of anthropogenic disturbance on bee populations is difficult to predict and can be beneficial to some species while having a negative effect on others (Cane and Tepedino 2001). Generally livestock grazing has a negative impact on ground nesting bees and fire has a negative effect on bees that nest in plant-cavities (Williams et al. 2010). Long-term or high intensity grazing in portions of the Black Hills could potentially limit or significantly impact native bee diversity on a local basis. One might infer that since most species in the Black Hills are ground nesting, and because the Black Hills region naturally had frequent fire return interval, low intensity or small fires may have had relatively minimal effect on overall bee diversity. A study in hardwood forest (Romey et al. 2007) showed that tree removal increased the floral abundance as well as bee abundance and species richness for at least the short term indicating that some disturbances are beneficial to bees. Although these kinds of studies have not been repeated in the ponderosa pine forests that dominate the Black Hills, a similar effect might be seen as a result of the current efforts to thin large portions of forest. Due to over 100 years of fire suppression, many areas of the Black Hills contain overcrowded forests which have expanded to areas that were historically not forested. In an attempt to reduce the overall density of many forested areas in the region closer to historical densities, the long-term effect of forest management is expected to be beneficial, but the immediate effect of forest management from soil compaction and vegetation damage could have a negative effect due to the nesting strategies of certain bee species.

Future work

Additional studies and analysis from data collected during this study can be initiated in the future. Habitat data and floral records currently associated with bee specimens could be used for future analysis on bees, disturbance and geospatial information. In addition to habitat and biotic data collected, current location data can be used in conjunction with soil maps for further analysis. These analyses would be valuable to the overall information available on native bees, and important to understanding the bees of the Black Hills.

Further examination of the effect of bowl size and bowl color on bee captures could also be undertaken with data collected in the Black Hills inventory. Studies to determine associations with habitat type or potentially floral bloom could also be initiated with the data provided. Although the habitat and floral data collected was qualitative, there is enough associated data for further analysis of habitat and bee associations. In addition, the selection of bowl color and size by bee species could be further studied which could help refine and possibly standardize protocols which use pan trapping for the monitoring of native bees.

Further identification of collected specimens will allow for additional analysis. With a larger number of specimens identified, diversity analysis will be more accurate and can be calculated on a per site basis to provide information on the habitat of sites. The seasonal phenology data collected can also be analyzed with further species identifications, and possibly combined with floral and habitat studies. There is a variety of statistical and ecological analyses that were not fully explored for this study but could be undertaken to reveal more complex discoveries from the data collected. Many analyses would be beneficial and could provide another baseline data set for associated ecological conditions.

Using the baseline data of Black Hills bees provided here for future studies can help detect biotic changes in the region. The loss of bee species demands attention to help uncover causes of decline, but shifts in species composition or abundance in areas can also give a glimpse of possible habitat or environmental quality issues. Climate change has been shown to advance the emergence of bees as well as the bloom of floral resources by as much as 10 days (Bartomeus et al. 2011), but climate change could also potentially cause a shift in local bee distributions. With the location data provided, it is plausible that with future monitoring of bees, changes such as climate and habitat degradation could be detected, giving opportunity for action which could reduce or correct these effects.

This inventory provides critical records of bee species occurrence for the Black Hills, as well as associated floral and habitat data. Many physical specimens have been deposited in insect museums devoted to biodiversity research and will continue to be valuable to the study of native bees. This information is important for filling knowledge gaps of South Dakota bee fauna and for contributing to the larger body of knowledge of the national and world distribution of bees. This study overall is viewed as a success and the inventory complete when considering the number of species collected and new records for the Black Hills, and their contribution to science.

Chapter 2: Pan trap analysis

Several studies have helped to refine various details of sampling bees with pan traps. A series of studies by Sam Droege (U.S. Geological Survey) determined that nectar guides painted on the bowl as well as the size of the bowl both have little effect on capture; several other studies determined the best number, spacing and length of time to sample with pan traps or "bee bowls"(Droege 2012 unpublished). A study by Carboni and LeBuhn (Unpublished 2012 A) showed that a trapping period which included the main portion of bee activity starting in mid-morning and ending in mid-afternoon is sufficient but there is no negative effect on the number of bees when traps are left for a longer duration. The results of a 2011 study showed that 70% of pan traps set collected no bees and reinforces the common methodology and importance of using 30 bowls, ten of each color, to properly sample an area (Grundel et al. 2011). Carboni and LeBuhn (Unpublished 2012 B) concluded the proper distance to place bowls to eliminate inter-bowl competition for bees is five meters but the spacing of bowls does not need to be exact and can be typically measured by paces.

Pan trapping by itself is not sufficient to fully represent the species present in an area. Several studies show that pan trapping and netting are complementary and to fully sample an area both methods are needed (Grundel et al. 2011, Wilson et al. 2008). The two methods often share approximately 50% of species with roughly only one-quarter of species collected appearing in either method. Using just one of the methods would require a dramatic increase in effort to collect the same species composition as both netting and bee bowls together (Grundel et al. 2011).

Although the basis of this study was an inventory, the methodology provided substantial data relevant to pan trap capture analysis. The standard protocol is heavily reliant on pan traps

and net collection. Net collection of bees can vary widely by the ability of the collector, and bees must be active to be collected, which is largely influenced by time of day and weather. In comparison, pan traps are cheap, efficient and require little training or skill to use and yield results consistent across users. Thus, pan traps have become a widely accepted method for inventories (Droege 2010 unpublished, LeBuhn et al. 2003). Many aspects of the bowls or pan traps have previously been studied, including the attractiveness of different colors, assorted killing, attractant and preservation liquids used (Droege 2010 unpublished), competition for bees at various distances between bowls (Carboni and LeBuhn Unpublished B), the effect of bowl size on the numbers of bees captured (Droege 2012 unpublished), and the species selection of the three colors used in the standard protocol (Droege 2012 unpublished, Leong and Thorp 1999). Two disadvantages of pan traps are the time required to process samples (sorting, washing, and drying of specimens), and the under-representation of species not attracted to bowls.

In addition to existing research on the use of pan traps there are several aspects that could benefit from further study and analysis. Although there are published studies on pan traps many important studies on this methodology remain unpublished. Several studies that have looked at number of bees captured were completed in areas of the eastern United States (Droege et al. 2010, Droege unpublished), or in desert areas of the western United States (Cane 2000, Wilson et al. 2008). The Black Hills are unlike either of these areas, and pan traps have not been studied in this habitat in which the flora and bee fauna could produce different results. Size of bowls has been reported as having no significant effect on number of bees captured, but the species selection associated with size has not been examined. Since the Black Hills inventory was able to provide a large sample size, several aspects of pan trap captures can be assessed.

The standard protocol is to use 30 bowls, 10 of each of three colors equally spaced in a continuous habitat type and left for either 24 hours or at minimum a large portion of the day to capture active bees. One aspect of this method that varies by the user is the size of bowl used. Many surveys use 96 ml (3.25 oz.) plastic cups with steep sides, but there is no standard size. The variation in size of bowl used is acceptable based on the consensus within the bee taxonomy and ecology community that size does not significantly affect bee capture. The volume of liquid likely has no influence on capture rate, but the visible area of the bowl may influence capture rate. Bee's might perceive large bowls as large flowers, since smaller bowls generally are closer to the size of common flowers in many habitats which could possibly influence capture rate and species captured.

Methods

Data from the inventory of native bees of the Black Hills were used to assess effects of bowl size and color on bee captures in the region. For the size comparison a paired t-test was used to determine if the total captures of bowl size significantly different using a standard p-value of 0.05. To control for variance introduced by weather and collection date, capture data were kept in pairs (large and small) for each site and date. Species collected by size was also assessed by comparing total number of species in common to both sizes, as well as identifying and determining the percentage of species that were unique to each size.

Capture of unique species by bowl color was also evaluated for the entire inventory. To show unique species for each color, species were separated by color, and duplicate species separated leaving the remaining species species unique for each bowl color. The species in common was separated and a percentage of the total collection determined. Percentage of

species unique to each bowl color was also calculated. This sorting was repeated to show species collected by bowl size as well.

Results

Data from 200 samples showed that large bowls captured more bees than the small bowls (Fig. 7 and Table 1). When comparing number of bees collected by size of bowl, regardless of color, the difference between the sizes was significantly different ($p < 0.05$). Although there was a significant difference in overall capture number for large and small sizes, there was a strong correlation between the number of individuals captured in large and small pan traps (Fig. 8).

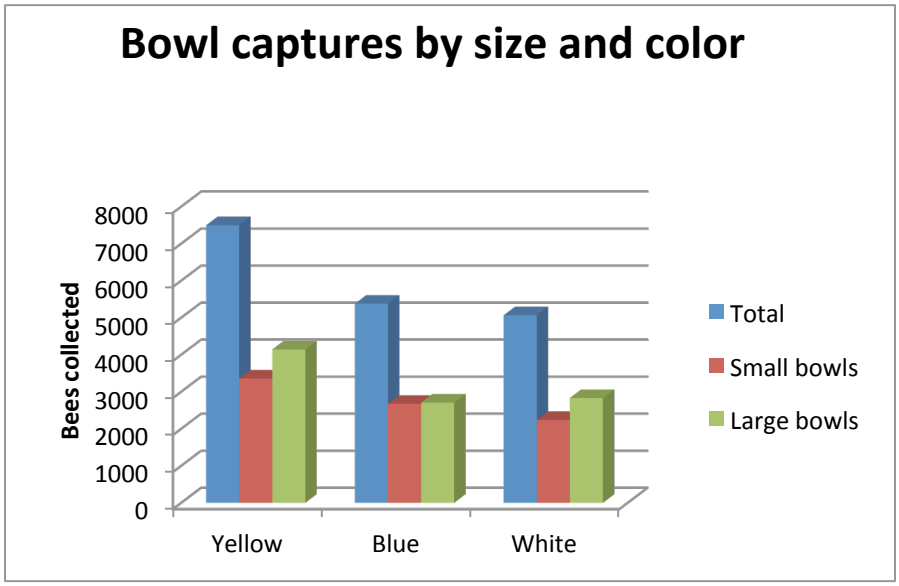

Figure 7. Number of bees from pan trapping, separated by color and size.

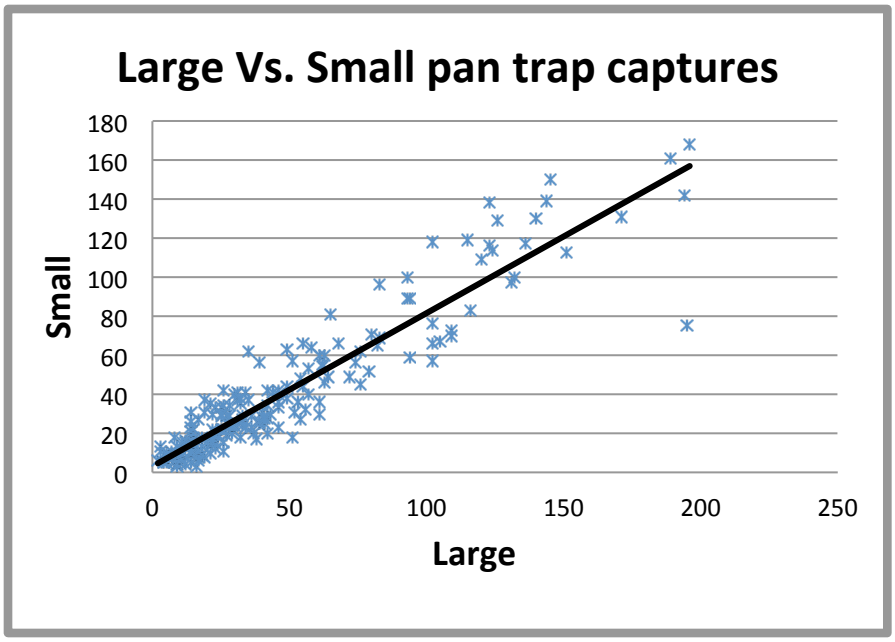

Figure 8. Correlation of large and small pan trap captures

Although the effect of size on bees captured was significant, it was not equally significant for all colors (Table 1.). Yellow and white pan traps showed a significant difference in capture number for small versus large sizes ($p < 0.05$), but there was no significant difference in number of bees captured between sizes of the blue bowls ($p > 0.05$).

Table 1. Pan trap capture comparisons

Comparison of pan traps	**P value**	**Mean**
All colors Large Vs. Small	6.74225 E-09	45.32
Yellow Large Vs. Small	7.71416 E-04	19.39
White Large Vs. Small	3.65734 E-07	13.41
Blue Large Vs. Small	0.698829917	13.11

The color of bowls influenced the species captured. A percentage of bees captured for each bowl color were unique (Fig. 9). Overall, yellow bowls captured the most bees, and the most unique species. Species unique to yellow bowls represented 23.8% of all bees captured in yellow pan traps, while species unique to white accounted for 17.7% and 16.7% for blue of their respective total captures.

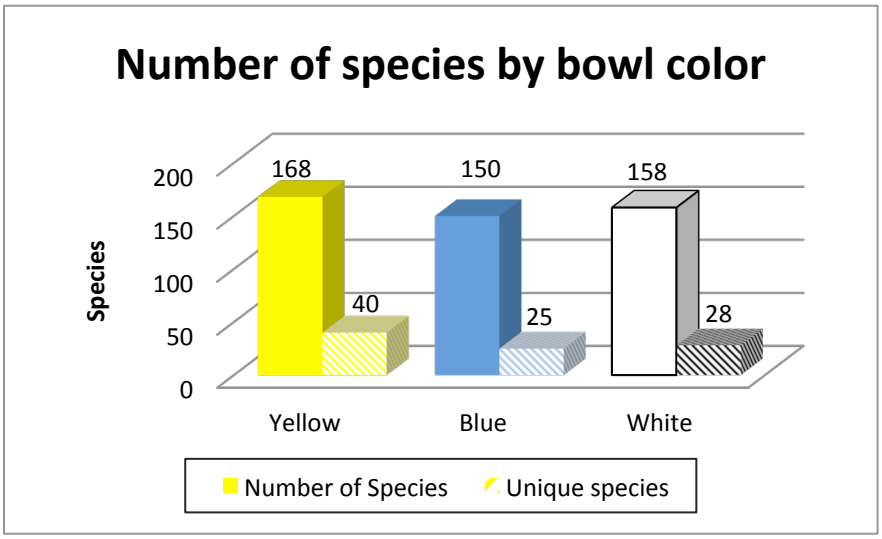

Figure 9. Unique species separated by pan trap color

In addition to species stratification by color, there was a noticeable difference in captures by size. Large bowls collected a total of 174 species, of which 58 (33%) were determined to be only collected in the large pan traps. In comparison 157 species were collected by the smaller size pan trap and 41 species (26%) were only collected in this size.

Discussion

Results from this survey are mixed, reinforcing previous studies that involve pan trapping (Droege et al. 2010, Leong and Thorp 1999) but contradict unpublished findings on the effect of bowl size on capture numbers. Unpublished results indicate that although bowl size does not affect the overall capture (Droege 2012 unpublished), further studies have indicated pan traps are most effective at flower height rather than ground-level (Tuell and Isaacs 2009). Although this is worthwhile to consider depending on the needs of the survey, the major rationale for using pan traps is that they are cheap and efficient. Elevating pan traps greatly increases the time and expense of trapping, and reduces the efficiency of deploying traps. In windy environments such as the Black Hills, this could pose an issue and result in lost contents and be counter-productive. Elevated pan traps may be best suited for permanent or long-term studies in areas where flower height might pose an issue.

The results of the overall size comparison contradict the results of previous studies on the effect of bowl size on number of bees captured. Droege (2012 unpublished) tested several sizes of bowls, all of which indicated no statistical difference in number of bees captured. The lack of statistical difference has been the basis for the lack of a strict requirement for standardized size of bowl to use. The results shown here indicate that trap size does matter by having a statistically significant difference in overall number of bees collected. With the large data set collected over two years, the likelihood of this being an anomaly is low. Additional studies in a variety of habitats are greatly encouraged but results here indicate that of the two sizes used, the larger five ounce dessert bowl captures more individuals.

When looking at results of the influence of bowl color in combination with bowl size on number of bees captured, the results were mixed. Results from the Black Hills show a significant

difference in captures between sizes of both yellow and white bowls, while the number of bees for blue bowls was not statistically affected by bowl size. Although previous studies have shown the importance of using all three colors of pan traps, the influence of color and size combined has not. This is especially important because it highlights the need for further studies in a greater diversity of habitats.

The collection of unique species in each size of bowl was unexpected and leads one to assume that not only individual bee species preference to flower color but also flower size has an influence on pan trap captures. This aspect has not been studied, but the results presented here encourage further examination. The caveat to this aspect of the results is that although there is a very large sample size, species-level identifications remain pending, so further identifications could reduce or possibly increase the proportion of unique species potentially making the difference insignificant or even more dramatic. The implications of these results indicate that using a variety of bowl sizes for surveys will better approach the true species richness and abundance of the local bee fauna.

The color selection at flowers and subsequently pan traps is common with bees, and previous studies have shown trap colors often stratify collection. Bowl colors often have unequal numbers of bees captured (Droege 2012 unpublished) and show color preferences by both species and sex, with a portion of species unique to each color of bowl used (Leong and Thorp 1999). The current results support earlier findings on the influence of bowl color on species captured (Fig. 9). Results of species collected by each color reinforced the importance of using all three colors by showing that each had a proportion of unique species. Using the large sample set ensures that this is not a product of a chance encounter between a bee and a single color, but in fact indicates that certain bee species do have a color preference.

In addition to the interesting results of bowl size on the total number of bees captured, at least 25% of the total species captured were unique for each bowl size. The influence of bowl size on species collected has not been previously studied. The results provided here indicate that to best sample bee species, a combination of bowl sizes should be used. The caveat to this aspect of the results is that although there is a very large sample size, species-level identifications remain pending, so further identifications could reduce or possibly increase the proportion of unique species potentially making the difference insignificant or even more dramatic.

Summary

Results of this two year intensive inventory were an overall success with a large contribution to science and the available information on South Dakota native bee fauna. The 296 regional records, including 118 new records, provide much needed information on the distribution of native bees in North America. Considering that bees are an essential component of all ecosystems in the Black Hills, a study defining the native bee fauna was long overdue. In addition to the valuable occurrence data of native bees, further analysis with the associated data can provide additional information on the status of bees and their associated habitat. Knowing the bee fauna of this region can help predict or even prevent ecological damage provided further monitoring recognizes species shifts based on this valuable baseline data. This study has been an enormous step in regards to native bee information, but it is greatly encourage that this progress does not end and the data be used as a baseline for monitoring.

The results of the study on pan trap use indicates that more studies are needed to further refine use of pan traps as monitoring methods. The use of pan traps was found to be a useful and beneficial method to inventory native bees in the Black Hills and provided a large and valuable data set that allows for further analysis. The indication that bowl size does matter not only to number of bees collected, but also on species collected, is an indication that there is much left to be discovered in regard to the details of methodology for pan traps and their use in different habitats.

References Cited:

Agosti, D., J. D. Majer, L. E. Alonso and T. R. Schultz. 2000. Ants: Standard methods for measuring and monitoring biodiversity. Smithsonian Institution Press, Washington, 280p.

Ascher, J.S. 2010. Personal Communication, Collaborative Databasing of North American Bee Collections Within a Global Informatics Network. NSF-DBI# 0956388.

Ascher, J.S. and J. Pickering. 2011. Discover life bee species guide and world checklist (Hymenoptera: Apoidea: Anthophila). http://www.discoverlife.org/nh/cl/counts/Apoidea_species.html Accessed 2 JUL 2012.

Bartomeus, I., J.S. Ascher, D. Wagner, B.N. Danforth, S. Colla, S. Kornbluth and R. Winfree. 2011. Climate-associated phonological advances in bee pollinators and bee-pollinated plants. Proceedings of the National Academy of Sciences of the United States of America. Early Edition. www.pnas.org/cgi/doi/10.1073/pnas.111555908 Accessed: 6 DEC 2011.

Bohart, G. E. 1972. Management of habitats for wild bees. Proceedings of the Tall Timbers Conference on Ecological Animal Control by Habitat Management 3: 253-266.

Buchmann, S.L. and G.P. Naban. 1996. The Forgotten Pollinators. Island Press, Washington, D.C. 292p.

Cameron, S.A., J.D. Lozier, J.P. Strange, J.B. Koch, N. Cordes, L.F. Solter and T.L. Griswold. 2010. Patterns of widespread decline in North American Bumble bees. Proceedings of the National Academy of Sciences of the United States of America 108(2): 662-667.

Cane, J. H., R.L. Minckley and L.J. Kervin. 2000. Sampling Bees (Hymenoptera: Apiformes) for Pollinator Community Studies: Pitfalls of Pan-trapping. Journal of the Kansas Entomological Society 73(4): 225-231.

Cane, J.H. and V.J. Tepedino. 2001. Causes and extent of declines among native North American invertebrate pollinators: detection, evidence, and consequences. Conservation Ecology 5(1): 1. URL: http:www.consecol.org/vol/iss1/art1 Accessed: 14 FEB 2011.

Cane, J.H., R.L. Minckley, L.J. Kervin, T.H. Roulston and N.M. Williams. 2006. Complex Responses within a Desert Bee Guild (Hymenoptera: Apiformes) to Urban Habitat Fragmentation. Ecological Applications 16(2): 632-644.

Carvell, C., J.L. Osborne, A.F.G. Bourke, S.N. Freeman, R.F. Pywell and M. S. Heard. 2011. Bumble bee species' responses to a targeted conservation measure depend on landscape context and habitat quality. Ecological Applications 21(5): 1760-1771.

Carboni, M. and G. LeBuhn. 2012.a Effect of Length of Sampling Period on Numbers of Bees Captured. Unpublished Data. http://online.sfsu.edu/~beeplot/Accessed: 4 MAR 2012.

Carboni, M. and G. LeBuhn. 2012.b Effect of Distance Among Bowls on Numbers of Bees Captured. Unpublished Data. http://online.sfsu.edu/~beeplot/ Accessed: 4 MAR 2012.

Colla, S.R. and L. Packer 2008. Evidence for decline in eastern North American bumblebees (Hymenoptera: Apidae), with special focus on *Bombus affinis* Cresson. Biodiversity Conservation 17: 1379-1391.

Discover life. 2012. Apoidea, Bees; Apoid Wasps.
http://www.discoverlife.org/mp/20q?search=Apoidea

Droege, S. 2010. The Very Handy Manual: How to Catch and Identify Bees and Manage a Collection. Unpublished. www.bio2.elmira.edu/fieldbio/beemanual.docx Accessed 2010

Droege, S. 2011. Personal Communication. U.S. Department of the Interior, U.S.Geological Survey, Patuxent Wildlife Research Center, Beltsville, MD.

Droege, S. 2012. Impact of Color and Size of Bowl Trap on Numbers of Bees Captured. Unpublished Data. http://online.sfsu.edu/~beeplot/ Accessed: 4 MAR 2012.

Droege, S., V.J. Tepedino, G. LeBuhn, W. Link, R.L Minckley, Q. Chen and C. Conrad. 2010. Spatial patterns of bee captures in North American bowl trapping surveys. Insect Conservation and Diversity 3: 15-23.

Froiland S.G. 1990. Natural History of the Black Hills and Badlands. The Center for Western Studies. Sioux Falls, SD. 225p.

Goulson, D., G.C. Lye, and B. Darvill. 2008. Decline and Conservation of Bumble Bees. Annual Review of Entomology 53: 191-208.

Goverde, M., K. Schweizer, B. Baur and A. Erhardt. 2002. Small-scale habitat fragmentation effects on pollinator behavior: experimental evidence from the bumblebee Bombus veteranus on calcareous grasslands. Biological conservation 104: 293-299.

Greenleaf, S.S. and C. Kremen. 2006. Wild bee species increase tomato production and respond differently to surrounding land use in Northern California. Biological Conservation 133: 81-87.

URL:http://nature.berkeley.edu/kremenlab/Articles/Wild%20bees%20species%20increase%20tomato%20production.pdf Accessed: 14 FEB 2011.

Grixti, J.C., L.T. Wong, S.A. Cameron and C. Favret. 2009. Decline of Bumble Bees (*Bombus*) in the North American Midwest. Biological Conservation 142: 75-84.

Grundel, R., R.P. Jean, K.J. Frohnapple, G.A. Glowacki, P.E. Scott and N.B. Pavlovic. 2010. Floral and nesting resources, habitat structure, and fire influence bee distribution across an open-forest gradient. Ecological Applications 20(6):1678-1692.

Hopwood, J.L. 2008. The contribution of roadside grassland restorations to native bee conservation. Biological Conservation 141: 2632-2640.

IUCN 2012. IUCN Red List of Threatened Species. Version 2012.1. <www.iucnredlist.org>. Accessed on 20 June 2012.

Kearns, C. and D.M. Oliveras. 2009. Environmental factors affecting bee diversity in urban and remote grassland plots in Boulder, Colorado. Journal of Insect Conservation 13: 655-665.

Kearns, C. A., D.W. Inouye and N.M. Waser. 1998. Endangered Mutualisms: The Conservation of Plant-Pollinator Interactions. Annual Review of Ecology and Systematics 29: 83-112.

Kevan, P.G. 1999. Pollinators as bioindicators of the state of the environment: species, activity and diversity. Agriculture Ecosystems and Environment 74: 373-393.

Kluser, S., P. Neumann, M-P. Chauzat, and J.S. Pettis. 2010. UNEP Emerging Issues: Global Honey Bee Colony Disorders and Other Threats to Insect Pollinators. http://www.unep.org/dewa/Portals/67/pdf/Global_Bee_Colony_Disorder_and_Threats_insect_pollinators.pdf Accessed: 14 FEB 2011.

Knight, T.M., J.A. Steets, J.C. Vamosi, S.J. Mazer, M.Burd, D.R. Campbell, M.R. Dudash, M.O. Johnston, R.J. Mitchell and T. Ashman. 2005. Pollen Limitation of Plant Production: Pattern and Process. Annual Review of Ecological Evolution and Systematics 36: 467-497.

Krombein, K.V., P.D. Hurd, D.R.Smith, and B.D. Burks. 1979. Hymenoptera of America North of Mexico Synoptic Catalog. Volume 2. United States Government Printing Office, Washington D.C. 2209 p.

LeBuhn, G., S. Droege, T. Griswold, R. Minckley, T. Roulston, J. Cane, F. Parker, S. Buchmann, V. Tepedino, N. Williams, C. Kremen and O. Messenger. 2003. A Standardized Method for Monitoring Bee Populations the Bee (BI) Inventory Plot. Unpublished Draft. http://online.sfsu.edu/~beeplot/pdfs/Bee%20Plot%202003.pdf Accessed: 6 MAR 2010.

Leong, J.M. and R.W. Thorp. 1999. Colour-coded sampling: the pan trap colour preferences of oligolectic and nonoligolectic bees associated with a vernal pool plant. Ecological Entomology 24: 329-335.

Linsley, E.G. 1958. The ecology of solitary bees. Hilgardia 27(19): 543-599.

Losey, J.E. and M. Vaughan. 2006. The Economic Value of Ecological Services Provided by Insects. Bioscience 56(4): 311-323.

Mader, E., M. Spivak, and E. Evans. 2010. Managing Alternative Pollinators: A Handbook for Beekeepers, Growers and Conservationists. Natural Resource, Agriculture, and Engineering Service Ithaca, New York. 162p.

Marlin, J.C. and W.E. LaBerge. 2001. The Native Bee Fauna of Carlinville, Illinois, Revisited After 75 Years: a Case for Persistence. Conservation Ecology 5(1): 9. http//www.consecol.org/vol5/iss1/art9/ Accessed: 14 FEB 2011.

Michener, C.D., R.J. McGinley and B.N. Danforth. 1994. The Bee Genera of North and Central America. Smithsonian Institution Press. Washington, D. C. 209p.

Michener, C.D. 2007. The Bees of the World 2nd Edition. The Johns Hopkins University Press, Baltimore. 953p.

National Research Council. 2007. Status of Pollinators in North America. The National Academies Press, Washington, D. C. 307p.

Porter, D. A. 2010. AN Investigation of Wild Bee Diversity and Abundance in Plots Managed by *The Nature Conservancy* in South-Central Nebraska and of Beneficial Arthropods Associated with Native Nebraska Flora. Unpublished M.S. Thesis, University of Nebraska-Lincoln. 55p.

Potts, S.G., B. Vulliamy, A. Dafni, G. Ne'eman and P. Willmer. 2003. Linking Bees and Flowers: How do Floral Communities Structure Pollinator Communities? Ecology 84(10): 2628-2642.

Romey, W.L., J.S. Ascher, D. A. Powell and M. Yanek, 2007. Impacts of Logging on Midsummer Diversity of Native Bees (Apoidea) in a Northern Hardwood Forest. Journal of the Kansas Entomological Society 80(4): 327-338.

Roulston, T.H., S.A. Smith, and A.L. Brewster. 2007. A Comparison of Pan Trap and Intensive Net Sampling Techniques for Documenting a Bee (Hymneoptera: Apiformes) Fauna. Journal of the Kansas Entomological Society 80(2): 179-181.

Stephen W.P., G.E. Bohart, and P.F. Torchio. 1969. The Biology and External Morphology of Bees, with a Synopsis of the Genera of Northwestern America. Corvallis, OR: Oregon State University Agriculture Experiment Station 140p.

Stephen, W.P. 2005. Unscented Color Traps for Non-*Apis* Bees (Hymenoptera: Apiformes). Journal of the Kansas Etomological Society 78(4): 373-380.

Thorp, R. W. 2005. Species Profile: *Bombus franklini*. Red List of Pollinator Insects of North America. The Xerces Society for Invertebrate Conservation http://www.xerces.org/pollinator-redlist/ Accessed: 14 FEB 2011.

Toler, T.R., E.W. Evans, V.J. Tepedino. 2005. Pan-trapping for bees (Hymenoptera: Apiformes) in Utah's West Desert: the importance of color diversity. The Pan-Pacific Entomologist 81(3/4): 103-113.

Tuell, J.K. and R. Isaacs. 2009. Elevated pan traps to monitor bees in flowering crop canopies. Entomologia Experimentalis et Applicata 131: 93-98.

Winfree, R., T. Griswold and C. Kremen. 2007 (A). Effect of Human Disturbance on Bee Communities in a Forested Ecosystem. Conservation Biology 21(1): 213-223.

Winfree, R., N.M. Williams, J. Dushoff and C. Kremen. 2007 (B). Native bees provide insurance against ongoing honey bee losses. Ecology Letters 10: 1105-1113.

Winfree, R. R. Aguilar, D.P. Vazquez, G. LeBuhn and M.A. Aizen, 2009. A meta-analysis of bees' responses to anthropogenic disturbance. Ecology 90(8): 2068-2076.

Williams, N.M., E.E. Crone, T.H. Roulston, R. L. Minckley, L. Packer, S.G. Potts. 2010. Ecological and life-history traits predict bee species response to environmental disturbances. Biological Conservation 143: 2280-2291.

Wilson, J.S., T. Griswold and O.J. Messinger 2008. Sampling Bee communities (Hymenoptera: Apiformes) in a Desert Landscape: Are Pan Traps Sufficient? Journal of the Kansas Entomological Society 81(3): 288-300.

Xerces Society 2012. Xerces Society Red List of Bees of North America. http://www.xerces.org/pollinator-redlist/ Accessed: 12 JUN 2012

Appendix A. Bee species found in the Black Hills

(New Black Hills record denoted by [N], non-native species denoted by [E], new undescribed species denoted by *)

Family Andrenidae

Andrena accepta Viereck

Andrena amphibola Viereck

Andrena auricoma Smith [N]

Andrena buckelli Viereck [N]

Andrena carlini Cockerell

Andrena Cnemidandrena sp.

Andrena commoda Smith

Andrena costillensis Viereck & Cockerell [N]

Andrena crataegi Robertson

Andrena cressonii Robertson [N]

Andrena gardineri Cockerell [N]

Andrena helianthformis Vierreck & Cockerell [N]

Andrena hirticincta Provancher

Andrena lupinorum Cockerell [N]

Andrena microchlora Cockerell [N]

Andrena milwaukeensis Graenicher

Andrena (Melandrena) *sp.*

Andrena nasonii Robertson [N]

Andrena nigrocaerulea Cockerell [N]

Andrena nivalis Smith

Andrena nubecula Smith [N]

Andrena shoshoni Ribble [N]

Andrena sp.1

Andrena sp.2

Andrena sp.3

Andrena (Trachandrena) sp.

Andrena (Tylandrena) sp.

Andrena wilkella (Kirby) [N] [E]

Andrena wilmattae Cockerell

Andrenidae sp.1

Andrenidae sp.2

Andrenidae sp.3

Andrenidae sp.4

Andrenidae sp.5

Andrenidae sp.6

Andrenidae sp.7

Andrenidae sp.8

Andrenidae sp.9

Andrenidae sp.10

Appendix A. (Continued)

Andrenidae sp.11

Andrenidae sp.12

Andrenidae sp.13

Andrenidae sp.14

Andrenidae sp.15

Andrenidae sp.16

Andrenidae sp.17

Andrenidae sp.18

Andrenidae sp.19

Andrenidae sp.20

Andrenidae sp.21

Andrenidae sp.22

Andrenidae sp.23

Andrenidae sp.24

Andrenidae sp.25

Andrenidae sp.26

Andrenidae sp.27

Andrenidae sp.28

Calliopsis andreniformis Smith

Calliopsis nebraskensis Crawford

Calliopsis sp.1

Calliopsis sp.2

*Panurginus sp.*1

Perdita albipennis Cresson [N]

Perdita sp.1

Perdita sp.2

Perdita sp.3

Protandrena bancrofti Dunning [N]

Pseudopanurgus sp.1

Pseudopanurgus sp.2

Pseudopanurgus sp.3

Pseudopanurgus sp.4

Pseudopanurgus sp.5

Pseudopanurgus sp.6

Pseudopanurgus sp.7

Pseudopanurgus sp.8

Pseudopanurgus sp.9

Family Apidae

Anthophora affabilis Cresson [N]

Anthophora bomboides Kirby [N]

Anthophora occidentalis Cresson

Appendix A. (Continued)

Anthophora sp.1

Anthophora terminalis Cresson

Anthophora ursina Cresson

Anthophora walshii Cresson

Apis mellifera Linnaeus [E]

Bombus appositus Cresson

Bombus californicus Smith

Bombus centralis Cresson

Bombus fervidus (Fabricius)

Bombus flavifrons Cresson [N]

Bombus fraternus (Smith) [N]

Bombus griseocollis (DeGeer)

Bombus huntii Greene

Bombus insularis (Smith)

Bombus mixtus Cresson [N]

Bombus nevadensis Cresson

Bombus occidentalis Greene [N]

Bombus rufocinctus Cresson [N]

Bombus ternarius Say

Bombus vagans Smith

*Ceratina sp.*1

*Ceratina sp.*2

Ceratina sp.3

Diadasia australis (Cresson)

Diadasia sp.1

Epeolus sp.1

Eucera aragalli (Cockerell) [N]

Eucera dubitata (Cresson) [N]

Eucera frater frater (Cresson) [N]

Eucera hamata (Bradley) [N]

Eucerini sp.1

Eucerini sp.2

Holcopasites calliopsidis (Linsley) [N]

Melecta pacifica Cresson [N]

Melissodes agilis Cresson

Melissodes communis Cresson [N]

Melissodes coreopsis Robertson [N]

Melissodes grindeliae Cockerell [N]

Melissodes menuachus Cresson

Melissodes microsticta Cockerell [N]

Melissodes sp.1

Melissodes subillata LeBerge [N]

Appendix A. (Continued)

Melissodes trinodis Robertson [N]

Melissodes verbesinarum Cockerell [N]

Nomada articulata Smith [N]

Nomada maculata Cresson [N]

Nomada sp.1

Nomada sp.2

Nomada sp.3

Nomada sp.4

Svastra obliqua

Tetraloniella sp.1

Tetraloniella sp.1 Ashmead

Triepeolus concavus (Cresson) [N]

Triepeolus helianthi (Robertson) [N]

Triepeolus sp.1

Triepeolus sp.2

Xeromelecta interrupta (Cresson) [N]

Family Colletidae

Colletes aberrans Cockerell [N]

Colletes brevicornis Robertson

Colletes fulgidus Swenk

Colletes kincaidii Cockerell

Colletes petalostemonis Swenk [N]

Colletes ciliatus Patton [N]

Colletes phaceliae Cockerell

Colletes simulans Cresson

Hylaeus annulatus (Linnaeus)

Hylaeus basalis (Smith)

Hylaeus episcopalis (Cockerell)

Hylaeus sp.1 *(Female)*

Hylaeus sp.1 *(Male)*

Hylaeus sp.2 *(Female)*

Hylaeus sp.2 *(Male)*

Hylaeus sp.3 *(Female)*

Hylaeus sp.3 *(Male)*

Hylaeus sp.4 *(Female)*

Hylaeus sp.4 *(Male)*

Hylaeus sp.5 *(Female)*

Hylaeus sp.5 *(Male)*

Family Halictidae

Agapostemon angelicus (Cockerell)

Appendix A. (Continued)

Agapostemon obliquus (Provancher)[N]

Agapostemon splendens (Lepeletier) [N]

Agapostemon texanus Cresson

Agapostemon virescens (Fabricius)

Augochlorella aurata (Smith)

Augochloropsis metallica (Fabricius)

Augochloropsis sumptuosa (Smith)

Dufourea maura (Cresson) [N]

Halictus confusus Smith

Halictus farinosus Smith[N]

Halictus ligatus Say

Halictus parallelus Say

Halictus rubicundus (Christ)

Halictus tripartitus Cockerell

Lasioglossum (Dialictus) sp.1

Lasioglossum (Dialictus) sp.2

Lasioglossum (Evylaeus) sp.1

Lasioglossum (Evylaeus) sp.2

Lasioglossum (Evylaeus) sp.3

Lasioglossum cinctipes (Provancher)

Lasioglossum coriaceum (Smith)

Lasioglossum cressonii (Robertson) [N]

Lasioglossum desertum (Smith) [N]

Lasioglossum divergens (Lovell) [N]

Lasioglossum egregium (Vachal) [N]

Lasioglossum foxii (Robertson)

Lasioglossum heterorhinum (Cockerell)

Lasioglossum incompletum (Crawford)

Lasioglossum lusorium (Cresson) [N]

Lasioglossum laevissimum (Smith) [N]

Lasioglossum mellipes (Crawford) [N]

Lasioglossum ovaliceps (Cockerell) [N]

Lasioglossum paraforbesii McGinley [N]

Lasioglossum pectorale (Smith) [N]

Lasioglossum perpunctatum (Ellis)

Lasioglossum smilacinae (Robertson) [N]

Lasioglossum sp.1

Lasioglossum sp.2

Lasioglossum succinipenne (Ellis) [N]

Lasioglossum texanum (Cresson)

Lasioglossum trizonatum (Cresson) [N]

Lasioglossum truncatum (Robertson[N])

Appendix A. (Continued)

Nomia sp.1 Latreille

Nomia sp.2 Latreille

Sphecodes sp.1

Family Megachilidae

Anthidium clypeodentatum Swenk [N]

Anthidium mormonum Cresson [N]

Anthidium porterae Cockerell

Anthidium tenuiflorae Cockerell

Ashmeadiella bucconis (Say)

Ashmeadiella cactorum (Cockerell) [N]

Ashmeadiella californica (Ashmead)

Ashmeadiella sp.1

Coelioxys alternata Say [N]

Coelioxys funeraria Smith [N]

Coelioxys moesta Cresson [N]

Coelioxys rufitarsis Smith [N]

Coelioxys sodalis Cresson [N]

Dianthidium aff. parvum sp.1 [N]*

Dianthidium concinnum Cresson

Dianthidium curvatum (Smith) [N]

Dianthidium parvum (Cresson) [N]

Dianthidium pudicum (Cresson) [N]

Dianthidium ulkei (Cresson)

Heriades carinatus Cresson [N]

Heriades cressoni Michener [N]

Heriades variolosus (Cresson)

Hoplitis albifrons (Kirby)

Hoplitis pilosifrons (Cresson) [N]

*Hoplitis producta (*Cresson) [N]

Hoplitis spoliata (Provanchier)

Hoplitis truncata (Cresson)

Lithurgus apicalis Cresson [N]

Megachile brevis Say [N]

Megachile campanulae (Robertson) [N]

Megachile casadae Cockerell [N]

Megachile dentitarsus Sladen

Megachile fidelis Cresson

Megachile frigida Cresson

Megachile frugalis Cresson [N]

Megachile gemula Cresson

Megachile inermis Provancher

Appendix A. (Continued)

Megachile manifesta Cresson [N]

Megachile (Megachiloides) sp.1

Megachile melanophaea Smith

Megachile mendica Cresson

Megachile montivaga Cresson

Megachile mucida Cresson

Megachile parallela Smith

Megachile perihirta Cockerell

Megachile pugnata Say

Megachile relativa Cresson

Megachile rotundata (Fabricius)[E]

Megachile subexilis Cockerell [N]

Megachile texana Cresson [N]

Osmia albolateralis Cockerell

Osmia atrocyanea Cockerell [N]

Osmia bruneri Cockerell [N]

Osmia bucephala Cresson [N]

Osmia californica Cresson [N]

Osmia calla Cockerell [N]

Osmia coloradensis Cresson [N]

Osmia cyanella Cockerell [N]

Osmia cyaneonitens Cockerell [N]

Osmia densa Cresson [N]

Osmia distincta Cresson [N]

Osmia dolerosa Sandhouse [N]

Osmia gaudiosa Cockerell [N]

Osmia grindeliae Cockerell [N]

Osmia inermis (Zettersted) [N]

Osmia integra Cresson [N]

Osmia inurbane Cresson [N]

Osmia iridis Cockerell and Titus [N]

Osmia juxta Cresson [N]

Osmia kincaidii Cockerell [N]

Osmia lignaria Say

Osmia longula Cresson

Osmia montana montana Cresson

Osmia (Melanosmia) sp.1

Osmia (Melanosmia) sp.2

Osmia neocyanopoda Rust and Bohart [N]

Osmia nigrifrons Cresson

Osmia phaceliae Cockerell [N]

Osmia proxima Cresson [N]

Appendix A. (Continued)

Osmia pusilla Cresson [N]

Osmia raritatis Michener [N]

Osmia simillima Smith

Osmia subaustralis Cockerell [N]

Osmia tristella Cockerell

Stelis elegans Cresson [N]

Stelis foederalis Smith [N]

Stelis labiate (Provancher) [N]

Stelis lateralis Cresson [N]

Stelis montana Cresson [N]

Stelis nitida Cresson [N]

Family Mellitidae

Macropis nuda (Provancher) [N]

Appendix B. Pan trap sites with location, description and species richness

Site ID	State	County	Lat °	Long °	road-location	Habitat	Number of Visits		Species Richness
							2010	2011	
B01	SD	Custer	43.6802	-103.4450	Wildlife loop , Custer State Park	Sides of Rd. grass w/ dandelion. Short sampling period	**1**	**0**	**4**
B02	SD	Custer	43.7176	-103.4883	Blue bell picnic area, Custer State Park	Post burn, open hillside, adjacent to open Ponderosa forest.	**1**	**1**	**29**
B03	SD	Custer	43.6433	-103.3787	Wildlife loop rd. near Movie draw, Custer State Park	Riparian area in prairie area	**1**	**0**	**16**
B04	SD	Custer	43.7602	-103.4559	Toward badger hole, Custer State Park	Disturbed site, newly constructed homesite. Sparse grasses and mullen. Snow still on ground in morning.	**1**	**0**	**10**
B05*	SD	Pennington	44.0588	-103.3657	Highway 44, 7mi west of Rapid City	Open ponderosa forest, with small meadow patches.	**1**	**5**	**40**
B06	SD	Custer	43.7225	-103.5049	Lower french creek rd. toward Hazelrodt, Custer	Low density Pondo forest	**1**	**0**	**26**
B07*	SD	Custer	43.7520	-103.6897	FS rd. 781-1E, W. of Custer	Thinned Pondo. Forest area, small dia.pondo Clumps left.	**1**	**4**	**65**
B08	SD	Custer	43.7507	-103.6905	FS Rd. 287, W. of Custer,	Pondo meadow in thinning project, light grazing	**1**	**0**	**21**
B09*	SD	Pennington	44.0887	-103.4328	Norris Peak Rd.	Low density Pondo forest small rocky outcrops, thinned and recovered forest	**1**	**4**	**51**
B10*	SD	Custer	43.6852	-103.3519	Wildlife loop rd., Custer State Park	Open rolling prairie	**1**	**4**	**30**
B11	SD	Custer	43.6669	-103.3870	Oak Draw, Custer State Park	Open area, prairie dog town	**1**	**1**	**22**
B12*	SD	Custer	43.5863	-103.6216	FS Rd. 496	Flat open meadow, low/med. density ponderosa; moderate grazing, high forb diversity before cattle grazing	**1**	**6**	**57**
B13	SD	Custer	43.7652	-103.6030	County Rd. 318	Low ridge, burn area low density pondo	**1**	**0**	**24**

B14*	SD	Fall River	43.3935	-103.7512	FS Rd. 379	Small hill, tall grasses surrounded by pondo w some juniper	**1**	**5**	**32**
B15*	SD	Fall River	43.3023	-103.3937	SE leg of Angostoura reservoir	Sagebrush, small hll sandy soils	**1**	**7**	**41**
B16*	SD	Fall River	43.4449	-103.4533	Battle Mtn Preserve, Hot Springs	Low density pondo, rock outcrops, small slope, old burn	**2**	**4**	**75**
B17	SD	Pennington	43.9339	-103.7273	FS Rd. 301	Grassy meadow with aspens, surrounded by lg ponderosa	**1**	**0**	**7**
B18	SD	Pennington	43.9339	-103.7273	FS Rd. 301-1J	Open meadow draw with aspens surrounded by lg ponderosa, grazing evident	**1**	**1**	**22**
B19	SD	Pennington	43.9148	-103.8561	FS Rd. 383	Low density ponderosa, some aspen; grazing	**1**	**0**	**15**
B20*	SD	Pennington	43.9675	-103.9665	FS Rd. 288	Open ponderosa, logging site, heavily disturbed	**1**	**4**	**56**
B21	SD	Lawrence	44.2375	-103.7371	Custer Peak Rd.	Mid slope in E facing aspen forest with some spruce, thick grass;transect N-S	**1**	**1**	**26**
B22	SD	Lawrence	44.3675	-103.6194	FS Rd. 172	Rocky, E facing slope burned 5+ yr ago, some aspen regen w/ oak. Transect @ 220°	**1**	**0**	**15**
B23	SD	Lawrence	44.3088	-103.6950	HWY 385	Lg meadow surrounded by aspen, spruce, ponderosa. Very tall grasses.	**1**	**0**	**10**
B24*	SD	Lawrence	44.3270	-103.9933	FS Rd. 222.3	Rocky slope, SSE, thin soils, low density ponderosa, cliffs	**1**	**3**	**46**
B25	SD	Lawrence	44.3268	-103.9889	FS Rd. 542.1A	N facing, mixed aspen, spruce, ponderosa forest w/ small openings.	**1**	**2**	**42**
B26	SD	Lawrence	44.4140	-103.6172	FS Rd. 542.1A	Low ridge, open area with few ponderosa, oak, tall grasses.	**1**	**0**	**25**
B27	SD	Lawrence	44.4061	-103.6320	FS Rd. 542.1A	Small meadow surrounded by mixed ponderosa, birch, aspen, other deciduous lowland species.	**1**	**0**	**10**
B28	SD	Meade	44.3702	-103.5152	FS Rd. 170-2B	Low density pondo, some ash nearby, old thinned area, transect @ 315°	**1**	**0**	**9**

B29	SD	Meade	44.3514	-103.5674	FS Rd. 171.1	Oak, pondo, ash mixed forest, dense grass, transect NNW, Heavy Rain	**1**	**0**	**1**
B30	SD	Pennington	43.9798	-103.4429	FS Rd. 433	Riparian area, mixed deciduous trees transect NNE near trail	**1**	**2**	**42**
B31*	SD	Lawrence	44.2425	-103.7385	Custer Peak Rd.	S facing slope, thinned 2+yr ago, slash piles present, med density ponderosa, MP Beetle area 15%+ infected, thistle patches. E-W transect	**1**	**3**	**40**
B32*	SD	Lawrence	44.2081	-103.6094	FS Rd. 198	Logged and recovered ponderosa forest, staging area/slash burned, some aspen; transect N-S	**1**	**3**	**33**
B33	SD	Pennington	44.0249	-103.5003	FS Rd. 710-1A	Old burn area, standing dead, small rock outcrops, S facing slope; E-W transect	**1**	**0**	**13**
B34	SD	Lawrence	44.2847	-103.6686	Elk Creek Rd.	Low density pondo, 5% birch, 10% spruce	**1**	**0**	**18**
B35*	SD	Lawrence	44.4742	-104.0358	FS Rd. 131.1	Steppe type, meadow surrounded by oak and low density ponderosa, thin & rocky soils, slope and transect NNW.	**1**	**3**	**48**
B36*	WY	Crook	44.4616	-104.0692	FS Rd. 801	N sloping valley bottom, decidious trees, oak, thorn apple, ash, birch, upland w/ ponerosa, grazing evidence	**1**	**3**	**27**
B37	SD	Custer	43.7794	-103.4164	Hwy 16	Valley bottom, very old burn, tall grasses, rocky outcrops, oak and very sparse ponderosa	**1**	**1**	**36**
B38	SD	Pennington	43.9721	-103.4102	FS Rd. 358.1E	Open ponderosa forest, w/ tall tree like oak, previous burn pile; transect @ 345°	**1**	**1**	**19**
B39	SD	Custer	43.7519	-103.4645	Badger Hole, Custer State Park	Open valley lush w/sm stream, surrounded by pondo few aspen, rocky outcrops upland, rocky soil, burned an estimated 20 yrs ago. Diverse site	**1**	**1**	**49**

B40*	SD	Custer	43.8478	-103.5607	Sylvan lake Tr.#9, Custer State Park	E facing slope, med density ponderosa forest, sm rock outcrops, some aspen & spruce nearby; N-S transect	**1**	**4**	**52**
B41	SD	Pennington	43.8658	-103.5325	Harney Peak	Open bare rock area at peak; Sample duration- 1 hour	**1**	**0**	**5**
B42	SD	Pennington	43.8652	-103.5312	Harney Peak	Low density pondo w lg rock outcrops at peak. Sample duration- 1 hour	**1**	**0**	**8**
B50*	SD	Fall River	43.4432	-103.5707	Cottonwood recreation area, Hot springs	Open area between reservoir and thinned ponderosa forest, rocky soils with tall grasses	**0**	**5**	**42**
B51*	SD	Custer	43.6509	-103.3733	Bison bunkhouse, Custer State Park	Lawn in rolling grassland with red sandy soils adjacent to NE facing hillside w/ sparse mixed age ponderosa	**0**	**6**	**49**
B52*	SD	Custer	43.6491	-103.3713	Near Bison bunkhouse, Custer	Rolling grassland, sparse young small ponderosa, NE facing hillside w/ red sandy soils, transect N-S	**0**	**5**	**35**
B53	SD	Custer	43.6450	-103.3550	Lame johnny, Custer State Park	Riparian area between road and field; became overgrown early in season	**0**	**1**	**18**
B54	SD	Custer	43.6576	-103.4127	Prairie trail	Riparian forest, Cottonwood dominant w/ Oak; rolling prairie, sandy soils	**0**	**1**	**23**
B55*	SD	Custer	43.5849	-103.6225	FS Rd. 496	Low density, medium sized ponderosa with rocky soils, light cattle grazing, adjacent to B12	**0**	**5**	**29**
B56*	SD	Fall River	43.3917	-103.7388	FS Rd.496	Rolling Grassland with very sparse ponderosa, Southern hills area with sandy soils	**0**	**5**	**36**
B57*	SD	Custer	43.7572	-103.7327	FS Rd.287	Recently logged ponderosa forest with large rock outcrops, high disturbance and surrounded by intensive thinning	**0**	**4**	**49**

B58*	SD	Custer	43.7130	-103.3494	French Creek, Custer State Park	Riparian area with cottonwood and ash-lowland deciduous forest, transect adjacent to stream	**0**	**4**	**30**
B59*	SD	Custer	43.7389	-103.8440	Hwy 16 W-Hell Canyon Trailhead, W of Custer	Riparian zone in burned canyon	**0**	**3**	**43**
B60	SD	Custer	43.7230	-103.8455	Hell canyon Rd. Hwy 16. W of Jewel Cave NP	Jasper Burn, dry open rolling area with standing and downed dead trees	**0**	**2**	**18**
B61	SD	Custer	43.7276	-103.7866	FS Rd. 278-1E, Lithograph Canyon, W of Custer	Former ponderosa forest, Jasper burn, now bare grassland with remnant woody debris	**0**	**2**	**39**
B62	SD	Custer	43.7598	-103.9136	FS Rd. 668- Surveyor hill, W of Custer	Ponderosa forest thinned by Jasper fire, appearing healthy & well-spaced; N facing slope with transect N-S	**0**	**1**	**24**
B63*	SD	Custer	43.6939	-104.0378	FS Rd. 123	Open lowland scrub/grassland with no trees; spotty & sparse vegetation, red sandy soils	**0**	4	32
B64*	SD	Custer	43.6962	-104.0534	FS Rd. 123 - Elk Mtn.	Small patch of mixed age & sized ponderosa surrounded by grassland in Elk Mtn. burn area	**0**	4	32
B65*	SD	Custer	43.7237	-104.0506	FS Rd. 123	Rocky area in burn area near lookout tower, no living or standing trees, sparse dry grasses	**0**	4	32
B66	SD	Custer	43.7067	-104.0535	FS Rd. 123- Elk Mtn. halfway to lookout	Elk Mtn. Burn, Rocky, livestock pond, some bare dirt, floral bloom of yellow asters	**0**	1	13
B67*	SD	Custer	43.7629	-103.7307	FS Rd. 287-North Pole Rd. W of Custer	S. facing hillside meadow, adjacent to large ponderosa thinning area, high floral diversity, grazing	**0**	4	41
B68*	SD	Custer	43.7974	-103.7659	FS Rd. 288	Logged 2+yrs ago with abundant masticated coarse woody debris, large limestone cliff band	**0**	4	37

B69	SD	Custer	43.8077	-103.7745	FS Rd. 284	Wet meadow with abundant tall grasses bordered by dense ponderosa and spruce forest	**0**	1	11
B70	SD	Custer	43.8312	-103.8565	FS Rd. 282	Large, flat, open meadow in ponderosa	**0**	1	11
B71*	SD	Custer	43.8050	-103.8322	FS Rd. 282	Flat with low density Forest with med.- lg. ponderosa	**0**	4	37
B72	SD	Lawrence	44.2060	-103.6969	Custer Crossing	Aspen and spruce along sides of wet meadow/valley bottom, some standing water, cattle present- intense grazing	**0**	1	8
B73	SD	Lawrence	44.2054	-103.6972	Custer Crossing	Dense spruce and aspen zone between wet meadow and thinned ponderosa forest.	**0**	2	8
B74	SD	Lawrence	44.3272	-103.9904	FS Rd. 222.3	Wet canyon bottom w/ stream, spruce & willow	**0**	1	**9**
B75*	SD	Lawrence	44.3239	-104.0170	FS Rd. 105.1I	Mature aspen grove surrounding thinned ponderosa, cattle grazing present	**0**	3	38
B76*	SD	Lawrence	44.3522	-104.0698	FS Rd. 850, Cement ridge	High elevation ridge, abundant wildflowers, low density mature ponderosa, limestone soils	**0**	3	26
B77	SD	Lawrence	44.2876	-103.6750	FS Rd. 560.1B, Nemo	Mixed forest with ponderosa removed, aspen & spruce with woody debris and thistle	**0**	2	23
B78	SD	Custer	43.7679	-103.8678	FS Rd.282	Burn area, no live trees, abundant dead trees on ground & few standing dead; NNE slope, transect@140,	**0**	1	16
B79	SD	Custer	43.7692	-103.8672	FS Rd. 282	Burn area, few live trees-mostly dead standing & dead on ground; SSW slope, transect E-W	**0**	1	16
B80	SD	Custer	43.7682	-103.8710	FS Rd. 282	Ponderosa forest, med. density, large diameter, w/ coarse woody debris; Transect @ 220°	**0**	1	16

B81	SD	Custer	43.7992	-103.7990	FS Rd. 284.2A	Meadow surrounded by cliffs, aspen & ponderosa; Transect adjacent to stream	**0**	1	10
B82	SD	Pennington	43.9554	-103.3697	Silver Mountain Rd.	Open meadow surrounded by low density small ponderosa, bisected by small stream	**0**	1	11
B83	SD	Pennington	43.9555	-103.4002	FS Rd. 358.1B (Closed)	Low density ponderosa/oak mix, rocky soils, forest thinned & recovered; transect cross slope @ 60°	**0**	1	23
B84	SD	Pennington	43.9897	-103.4075	Sheridan Lake Rd.	Riparian area with willow, ponderosa & oak; transect parallel to stream @240°	**0**	1	4
B86	SD	Pennington	43.8949	-103.5354	Willow creek trail; Harney Peak	Grassy area surrounded by spruce & ponderosa near base of Harney Peak	**0**	1	11
B87	SD	Pennington	43.8914	-103.5187	Willow creek trail; Harney Peak	Open area with ponderosa pine	**0**	1	10
B88	SD	Pennington	43.8721	-103.5234	Willow creek trail- Harney Peak	Ponderosa pine, partially up Harney Peak trail	**0**	1	15
B89	SD	Pennington	43.8645	-103.5303	Willow creek trail- Harney Peak	No description	**0**	1	11
B90	SD	Lawrence	44.5617	-104.0196	Mirror lakes, Spearfish	Xeric scrub area, sagebrush, no trees, red sandy soils	**0**	1	26
B91	WY	Crook	44.3345	-104.1387	FS Rd. 868.1	Large flat meadow with low density aspen/ponderosa mix, light cattle grazing	**0**	1	8
B92	WY	Crook	44.3171	-104.1596	FS Rd. 827.1	Edge habitat of meadow/aspen forest, ponderosa, vegetation dense and tall, transect uphill @210°	**0**	1	13
B93	SD	Custer	43.6445	-103.3991	Wildlife Loop Rd., Custer State Park	Open prairie near riparian area, medium-short grasses, deciduous trees; transect @240°	**0**	1	8
B94	SD	Custer	43.6459	-103.3930	Wildlife Loop Rd., Custer State Park	NA	**0**	1	6

B95	SD	Custer	43.7030	-103.4369	N.Lame Johnny Rd, Custer State Park	Thinned ponderosa forest w/ regeneration, small burn piles & woody debris; Transect N-S.	**0**	1	15
B96	SD	Custer	43.7468	-103.4590	N.Lame Johnny Rd, Custer State Park	Valley with small stream, oak, aspen and ponderosa, monarda fistulosa and tall dense grasses abundant	**0**	1	7
B97	SD	Fall River	43.3404	-103.5558	Whitney Preserve, The Nature Conservancy	Wetland & field edge junction in flat valley bottom, cottonwoods and some tall grassy patches	**0**	1	29
B98	SD	Fall River	43.3409	-103.5550	Whitney Preserve, The Nature Conservancy	Wetland-field edge junction in flat valley bottom, cottonwoods w/ some tall grassy patches.	**0**	2	27
B99	SD	Custer	43.7096	-104.0511	Elk Mtn-Unburned site	Adjacent to recently burned area, sparse dry grasses; down & dead trees from 2000 fire, rocky soils	**0**	2	33
B100	SD	Custer	43.7206	-103.3453	Custer State Park, Wildlife Loop Rd	Rolling prairie with ponderosa in valleys, sagebrush, leadplant and bunch grasses, grazed by bison	**0**	**1**	**23**
B101	SD	Pennington	43.9887	-103.4705	FS Rd. 433	Widely spaced, evenly aged thinned and recovered ponderosa forest w/ Sparse grasses	**0**	**1**	**20**
B102	SD	Lawrence	44.2802	-103.7795	FS Rd. 228.1D Engleman springs	Spruce dominated valley with small spring-fed stream, boreal type setting with moist soils.	**0**	**2**	**15**
B103	SD	Lawrence	44.1693	-103.4987	FS Rd. 208	Large flat meadow with thin grasses, & small stream; aspen near stream and spruce uphill	**0**	**1**	**30**

Appendix C. Shannon-Wiener Index for sites sampled 3 or more times.

Site	Shannon-Wiener Index
B05	1.017656675
B07	2.361035352
B09	1.924027259
B10	2.107389539
B12	2.232751038
B14	1.865234553
B15	1.808893345
B16	1.797158757
B20	2.367683018
B24	2.001122344
B31	2.346358645
B32	2.397252183
B35	2.247139343
B36	2.186953035
B40	2.476108634
B50	2.144285249
B51	1.802610902
B52	2.08213309
B55	2.317184756
B56	1.760647834
B57	2.467050767
B58	1.985925728
B59	0.473909407
B63	1.935872371
B64	2.20254489
B65	2.259671684
B67	1.987031823
B68	1.952363175
B71	2.432011138
B75	2.624461352
B76	2.199716489

Appendix D. Bee species from net collection and host plant

Bee species	**Host plant**
Andrenidae	
Andrena accepta	*Laiathrus* sp. *Solidago* sp.
Andrena buckeli	*Dalea purpurea* *Rudbeckia hirta* *Trifolium* sp.
Andrena carlini	*Prunus virginiana*
Andrena carlini	*Rhus aromatica*
Andrena crataegi	*Melilotus officinalis* *Prunus virginiana*
Andrena cressonii	*Achillea millefolium* *Brassicaceae* sp. *Melilotus officinalis* *Prunus virginiana*
Andrena helianthformis	*Achillea millefolium* *Amorpha canescens* *Monarda fistulosa* *Ratibida columnifera*
Andrena hirticincta	*Aster falcatus* *Grindelia squarrosa* *Laiathrus* sp. *Solidago* sp.
Andrena lupinorum	*Achillea millefolium* *Brassicaceae* sp. *Prunus virginiana* *Trifolium* sp.
Andrena milwaukeensis	*Dalea purpurea* *Prunus virginiana* *Rudbeckia hirta* *Trifolium* sp.
Andrena (Melandrena) sp.	*Apocynum androsaemifolium* *Trifolium* sp.
Andrena nasonii	*Prunus virginiana*

Andrena nubecula	*Aster falcatus*
Andrena (Tylandrena) sp.	*Rosa woodii*
Andrena wilkella	*Dalea purpurea* *Melilotus officinalis* *Monarda fistulosa,* *Rudbeckia hirta* *Trifolium* sp.
Andrena wilmaltae	*Melilotus officinalis* *Rosa woodii*
Calliopsis andreniformis	*Asclepias* sp. *Dalea candida* *Trifolium* sp. *Verbena stricta* Sweep netting from Apiaceae, Aster sp. and Campanula sp. No host (in flight)
Calliopsis nebraskensis	*Verbena hastata*
Perdita sp.	*Grindelia squarrosa* *Helianthus* sp. *Nepeta cataria* *Verbena stricta*
Protandrena bancrofti	*Dalea candida*
Pseudopanurgus sp. *1*	*Grindelia squarrosa* *Helianthus* sp.
Pseudopanurgus sp. *2*	*Verbena stricta*
Pseudopanurgus sp. *3*	*Ratibida columnifera*
Pseudopanurgus sp. *4*	*Erigeron* sp. *Solidago* sp. No host (in flight)
Pseudopanurgus sp. *6*	*Helianthus* sp.
Pseudopanurgus sp. *7*	*Grindelia squarrosa*
Pseudopanurgus sp. *8*	*Helianthus* sp.
Pseudopanurgus sp. *9*	*Helianthus* sp.

Apidae	
Anthophora terminalis	*Agoseris glauca* *Antennaria* sp. *Campanula rotundifolia* *Erigeron* sp. *Erigeron strigosus* No host (fence post aggregation) *Grindelia squarrosa* *Ipomoea leptophylla* *Melilotus officinalis* *Monarda fistulosa* No host (in flight) No host (stream edge) *Penstemon albidus* *Ribes cereum* *Rosa woodii* *Thermopsis rhombifolia* *Trifolium* sp. *Verbena stricta*
Anthophora ursina	*Penstemon grandiflorus*
Anthophora walshii	*Iiatris punctata* *Nepeta cataria*
Bombus appositus	*Cirsium* sp. *Cirsium undulatum* *Delphinium bicolor* *Delphinium* sp. *Erigeron strigosus* *Helianthus nuttallii* *Linaria vulgaris* *Monarda fistulosa* No host (in flight) *Potentilla fruticosa* *Tradescantia* sp. *Trifolium* sp.
Bombus californicus	*Delphinium bicolor* *Monarda fistulosa*
Bombus flavifrons	*Trifolium* sp.
Bombus fraternus	*Laiathrus* sp. *Solidago* sp.

Bombus griseocollis	*Apocynum androsaemifolium* *Chrysopsis Villosa* *Cirsium* sp. *Dalea purpurea* *Geum triflorum* *Helianthus nuttallii* *Helianthus* sp. *Ipomoea leptophylla* *Laiathrus sp* *Linaria vulgaris* *Malus* sp. *Monarda fistulosa* *Nepeta cataria* No host (in flight) *Oxytropis lambertii* *Potentilla glandulosa* *Solidago* sp. *Symphoricarpos* sp. *Tradescantia* sp. *Trifolium* sp. *Verbena stricta*
Bombus huntii	*Cirsium arvense* *Cirsium* sp. *Monarda fistulosa* *Nepeta cataria* *Potentilla glandulosa* *Solidago* sp. Sweep netting from Apiaceae, Aster sp. & Campanula sp. *Trifolium* sp.
Bombus insularis	*Brassicaceae* sp. *Cirsium* sp. *Cynoglossum officinale* *Epilobium angustifolium* *Epilobium* sp. *Erigeron* sp. *Grindelia squarrosa* *Iris missouriensis* *Laiathrus spp.* *Prunus virginiana* *Solidago* sp. Sweep netting from Apiaceae, Aster sp.& Campanula sp. *Tanacetum vulgare*

Bombus insularis (continued)	*Verbena stricta*
Bombus mixtus	*Linaria vulgaris*
Bombus nevadensis	*Astragalus* sp. *Chrysopsis villosa* *Cirsium arvense* *Latris punctata* *Monarda fistulosa* *Nepeta cataria* *Solidago* sp. *Trifolium* sp.
Bombus occidentalis	*Campanula rotundifolia* *Linaria vulgaris*
Bombus rufocinctus	*Apocynum androsaemifolium* *Calochortus* sp. *Campanula rotundifolia* *Cirsium arvense* *Cynoglossum officinale* *Dalea candida* *Dalea purpurea* *Erigeron* sp. *Glycyrrhiza lepidota* *Grindelia squarrosa* *Helianthus* sp. *Linaria vulgaris* *Melilotus officinalis* *Monarda fistulosa* *Trifolium* sp. *Rosa woodii* *Tanacetum vulgare* *Trifolium* sp. *Verbena stricta*
Bombus tenarius	*Agoseris glauca* *Astragalus* sp. *Chrysopsis Villosa* *Cirsium arvense* *Cirsium* sp. *Cirsium undulatum* *Cynoglossum officinale* *Dalea candida* *Grindelia squarrosa* *Helianthus nuttallii*

Bombus tenarius (Continued)	*Iris missouriensis* *Linaria vulgaris* *Monarda fistulosa* *Prunus virginiana* *Aster* sp. *Solidago* sp. *Solidago* sp. *Tanacetum vulgare* *Thermopsis rhombifolia* *Trifolium* sp. *Verbena stricta*
Bombus vagans	*Aster* sp. *Astragalus* sp. *Cynoglossum officinale* *Dalea candida* *Delphinium* sp. *Erigeron strigosus* *Grindelia squarrosa* *Iris missouriensis* *liatris punctata* *Linaria vulgaris* *Monarda fistulosa* *Penstemon grandiflorus* *Rosa woodii* *Rubus idaeus, Cynoglossum officinale* *Solidago* sp. *Symphoricarpos* sp. *Tanacetum vulgare* *Trifolium* sp. *Verbena hastata* *Verbena stricta*
Ceratina sp.	*Erigeron* sp. *Grindelia squarrosa*
Diadasia sp.	*Opuntia* sp.
Eucera hamata	*Penstemon grandiflorus*
Eucerini sp.	*Campanula rotundifolia* *Chrysopsis Villosa* *Cirsium arvense* *Cirsium* sp. *Echinacea angustifolia*

Eucerini sp. (Continued)	*Grindelia squarrosa* *Helianthus maximiliani* *Helianthus* sp. *Hymenoxys acaulis* *Lupinus argentus* *Monarda fistulosa* *Oxytropis lambertii* *Ratibida columnifera* *Rosa woodii* *Solidago* sp. *Verbena stricta*
Holcopasites calliopsidis	*Chrysopsis villosa*
Melissodes agilis	*Grindelia squarrosa* *Medicago* sp. *Nepeta cataria*
Melissodes coreopsis	*Centaurea maculosa* *Cirsium* sp. *Erigeron strigosus*
Melissodes grindeliae	*Solidago* sp.
Melissodes sp.	*Chrysopsis Villosa* *Dalea purpurea* *Erigeron* sp. *Grindelia squarrosa* *Helianthus* sp. *Ipomoea leptophylla* *Nepeta cataria* No host (in flight) *Solidago* sp. *Tanacetum vulgare*
Melissodes verbesinarum	*Solidago* sp. *Laiathrus* sp.
Nomada articulata	Sweep netting from Apiaceae, Aster sp. and Campanula sp.
Nomada sp.	*Antennaria* sp. *Melilotus officinalis* No host (in flight) *Potentilla fruticosa* *Prunus virginiana* *Thermopsis rhombifolia* *Toxicodendron radicans*

Nomada sp. (Continued)	*Verbena hastata*
Svastra obliqua	*Grindelia squarrosa* *Helianthus nuttallii* *Helianthus* sp. No host (on grass in sleeping position)
Triepeolus sp.	*Chrysopsis Villosa* *Echinacea angustifolia* *Erigeron* sp. *Grindelia squarrosa* *Tanacetum vulgare* *Verbena hastata* *Verbena stricta*
Xeromelecta interrupta	No host (*Anthophora* sp. nest area)
Colletidae	
Colletes aberrans	*Gutierrezia sarothrae*
Colletes fulgidus	*Aster falcatus* *Solidago* sp.
Colletes kincaidii	*Cirsium arvense* *Dalea purpurea* *Daucus carota* No host (Fence post-multiple spp. aggregation) *Monarda fistulosa* No host (puddle edge) No host (stream edge) *Symphoricarpos* sp. *Tanacetum vulgare*
Colletes petalostemonis	*Chrysopsis Villosa* *Grindelia squarrosa*
Colletes phaceliae	*Apocynum androsaemifolium* *Aster falcatus* *Gutierrezia sarothrae* *Monarda fistulosa* *Symphoricarpos* sp. *Tanacetum vulgare*
Hylaeus annulatus	*Achillea millefolium* *Cirsium undulatum* *Erigeron* sp. *Potentilla sp* *Senecio* sp.

Hylaeus sp.	*Achillea millefolium* *Apocynum androsaemifolium* *Arctium* sp. *Cirsium arvense* *Epilobium angustifolium* *Erigeron* sp. *Eriogonum* sp. *Laiathrus spp.* No host (in flight) No host (puddle edge) No host (stream edge) *Potentilla fruticosa* *Rubus idaeus* *Solidago spp.*
Agapostemon angelicus	*Cirsium* sp. *Nepeta cataria*
Agapostemon obliquus	*Melilotus officinalis*
Agapostemon splendens	*Grindelia squarrosa*
Agapostemon virescens	*Antennaria* sp. *Aster falcatus* *Aster* sp. *Chrysopsis Villosa* *Cirsium arvense* *Grindelia squarrosa* *Gutierrezia sarothrae* *Helianthus* sp. *Hymenoxys acaulis* *Hyoscyamus niger* *Melilotus officinalis* *Nepeta cataria* *Opuntia* sp. *Rosa woodii* *Rudbeckia hirta* *Sphaeralcea* sp. *Toxicodendron radicans* *Trifolium* sp. *Verbena stricta* *Vicia americana*
Augochlorella aurata	*Apocynum androsaemifolium* *Asclepias* sp.

Augochlorella aurata (Continued)	*Aster* sp. *Brassicaceae* sp. *Calochortus* sp. *Cirsium* sp. *Fragaria virginiana* *Loniceria* sp. *Melilotus officinalis* *Monarda fistulosa* No host (puddle edge) *Penstemon grandiflorus* *Taraxacum officinale* *Verbena hastata*
Augochloropsis metallica	*Asclepias* sp. *Melilotus officinalis*
Augochloropsis sumptuosa	*Brassicaceae* sp.
Dufourea maura	*Campanula rotundifolia*
Halictus confusus	*Solidago* sp. *Laiathrus* sp.
Halictus farinosus	*Amorpha canescens* *Potentilla fruticosa*
Halictus ligatus	*Aster* sp. *Cerastium arvense* *Cirsium* sp. *Echinacea angustifolia* *Erigeron* sp. *Grindelia squarrosa* *Melilotus officinalis* *Monarda fistulosa* No host (on human leg) *Ratibida columnifera* *Solidago* sp. *Tanacetum vulgare* *Verbena stricta*
Halictus rubicundus	*Acer negundo* *Aster falcatus* *Chrysopsis Villosa* *Cirsium arvense* *Grindelia squarrosa* *Helianthus* sp. *Ipomoea leptophylla*

Halictus rubicundus (Continued)	*Iris missouriensis* *Lupinus argentus* *Melilotus officinalis* *Mentha arvensis* *Nepeta cataria* No host (in flight) No host (on collectors arm) No host (puddle edge) No host (stream edge) *Prunus virginiana* *Rosa woodii* *Sisyrinchium montanum* *Solidago* sp. *Taraxacum officinale* *Tradescantia* sp. *Trifolium* sp.
Halictus tripartitus	*Dalea candida* *Erigeron* sp. *Melilotus officinalis* No host (stream edge) *Penstemon grandiflorus* *Potentilla fruticosa* *Rosa woodii* *Toxicodendron radicans*
Lasioglossum cinctipes	*Cirsium arvense* *Prunus virginiana*
Lasioglossum coriaceum	*Melilotus officinalis* *Ranunculus longirostris*
Lasioglossum desertum	*Campanula rotundifolia* *Melilotus officinalis* *Rosa woodii*
Lasioglossum (Dialictus) sp.	*Achillea millefolium* *Agoseris glauca* *Antennaria* sp. *Apocynum androsaemifolium* *Argemone polyanthemos* *Arnica* sp. *Asclepias* sp. *Aster* sp. *Brassicaceae* sp. *Calochortus* sp. *Cerastium* sp.

Lasioglossum (Dialictus) sp. (Continued)	*Chrysopsis Villosa* *Cirsium arvense* *Cirsium* sp. *Dalea candida* *Delphinium* sp. *Erigeron* sp. *Erigeron strigosus* *Fragaria virginiana* *Geranium richardsonii* *Grindelia squarrosa* *Helianthus maximiliani* *Helianthus* sp. *Hymenoxys acaulis* *Hyoscyamus niger* *Hypericum perforatum* *Ipomoea leptophylla* *Iris missouriensis* *Leucocrinum montanum* *Lupinus argentus* *Melilotus officinalis* *Monarda fistulosa* No host (Fence post aggregation) No host (in flight) No host (puddle edge) No host (stream edge) *Penstemon grandiflorus* *Potentilla fruticosa* *Prunus virginiana* *Ranunculus longirostris* *Ratibida columnifera* *Rhus aromatica* *Rosa woodii* *Salix* sp. *Sedum* sp. *Solidago* sp. *Taraxacum officinale* *Thermopsis rhombifolia* *Toxicodendron radicans* *Tradescantia* sp. *Trifolium* sp. *Verbena hastata* *Verbena stricta*

Lasioglossum (Dialictus) sp. (Continued)	*Zigadenus venenosus*
Lasioglossum divergense	*Prunus virginiana* *Solidago* sp.
Lasioglossum (Evylaeus) sp.	*Aster* sp. *Cerastium arvense* *Cirsium* sp. *Erigeron* sp. *Geranium richardsonii* *Hymenoxys accaulis* *Hypericum perforatum* *Melilotus officinalis* *Penstemon grandiflorus* *Prunus virginiana* *Rhus aromatica* *Rubus idaeus* *Sisyrinchium montanum* *Solidago* sp. *Taraxacum officinale* *Tradescantia* sp.
Lasioglossum laevissimum	*Erigeron* sp. *Potentilla* sp. *Senecio* sp.
Lasioglossum mellipes	*Hymenoxys acaulis*
Lasioglossum (s.str) sp.	*Acer negundo* *Achillea millefolium* *Agoseris glauca* *Amorpha canescens* *Antennaria* sp. *Aster* sp. *Calochortus* sp. *Cirsium arvense* *Cirsium* sp. *Erigeron* sp. *Fragaria virginiana* *Grindelia squarrosa* *Helianthus* sp. *Hyoscyamus niger* *Melilotus officinalis* *Monarda fistulosa* No host (bare ground)

Lasioglossum (s.str) sp. (Continued)	*Opuntia* sp. *Penstemon grandiflorus* *Rhus aromatica* *Rosa woodii* *Sisyrinchium montanum* *Solidago* sp. *Toxicodendron radicans* *Tradescantia* sp.
Lasioglossum texanum	No host (blacklight at night)
Lasioglossum truncatum	*Cirsium arvense*
Sphecodes sp. *1*	*Antennaria* sp. *Prunus virginiana* *Rhus aromatica* *Solidago* sp.
Sphecodes sp. *2*	*Erigeron* sp. *Eriogonum* sp. *Potentilla* sp. *Senecio* sp. sweep netting from Apiaceae, Aster sp.& Campanula sp.
Megachilidae	
Anthidium mormonum	*Campanula rotundifolia* *Chrysanthemum leucanthemum* *Melilotus officinalis* *Melilotus officinalis* No host (puddle edge) No host (stream edge) No host (yellow tent) *Trifolium* sp.
Anthidium porterae	*Echinacea angustifolia* *Grindelia squarrosa*
Ashmeadiella californica	*Grindelia squarrosa*
Coelioxys alternata	*Helianthus* sp. *Rudbeckia hirta*
Coelioxys modesta	*Helianthus* sp. *Rudbeckia hirta* *Verbena hastata*
coelioxys moesta	*Rudbeckia hirta*

Coelioxys porterae	*Melilotus officinalis*
Coelioxys rufitarsis	No host (in flight)
Coelioxys sodalis	*Epilobium* sp. No host (in flight) *Sedum* sp. *Trifolium* sp.
Dianthidium aff. parvum n. sp. 1 (new species)	*Grindelia squarrosa*
Dianthidium ulkei	*Chrysopsis Villosa* *Grindelia squarrosa* *Helianthus* sp. No host (in flight) *Rudbeckia hirta* *Solidago missouriensis* *Verbena stricta*
Heriades carinatus	*Apocynum androsaemifolium* *Asclepias* sp. *Cirsium arvense* *Dalea candida* *Erigeron* sp. *Fence post aggregation* *No host (leg)* No host (puddle edge) No host (stream edge) No host (yellow tent) *Potentilla sp* Sweep netting from Apiaceae, *Aster* sp. & *Campanula* sp. *Trifolium* sp.
Heriades cressoni	*Aster* sp. *Erigeron* sp. *Grindelia squarrosa*
Hoplitis albifrons	*Melilotus officinalis* No host (in flight) No host (puddle edge) *Verbena stricta*
Hoplitis pilosifrons	*Dalea candida* *Erigeron* sp. *Helianthus* sp. *Melilotus officinalis* *Penstemon grandiflorus*

Hoplitis pilosifrons (Continued)	*Trifolium* sp.
Hoplitis producta	*Erigeron strigosus* No host (stream edge)
Hoplitis spoliata	*Erigeron* sp. *Melilotus officinalis* *Myosotis scorpioides* No host (bare ground)
Hoplitis truncata	No host (puddle edge) No host (stream edge) *Sedum* sp. *Trifolium* sp. *Verbena stricta*
Hoplitis pilosifrons	*Verbena stricta*
Lithurgus apicalis	*Penstemon grandiflorus*
Megachile brevis	*Grindelia squarrosa* *Helianthus* sp. *Melilotus officinalis* No host (bare sandy soil) *Solidago* sp.
Megachile campanulae	No host (fence post aggregation) *Verbena hastata*
Megachile dentitarus	*Helianthus* sp.
Megachile fidelis	*Grindelia squarrosa*
Megachile frigida	*Campanula rotundifolia* *Campanula* sp. *Chrysanthemum leucanthemum* *Epilobium angustifolium* *Monarda fistulosa* No host (fence post aggregation) No host (in flight) *Psoralea argophylla* *Solidago* sp. *Trifolium* sp.
Megachile frugalis frugalis	*Argemone polyanthemos* *Grindelia squarrosa*
Megachile gemula	*Campanula rotundifolia* *Grindelia squarrosa*

Megachile gemula (Continued)	*Monarda fistulosa* No host (bare gravel) No host (fence post aggregation) *Solidago* sp. *Trifolium* sp. *Verbena hastata*
Megachile manifesta	*Grindelia squarrosa*
Megachile sp.	*Aster* sp. *Calochortus* sp. *Campanula rotundifolia* *Chrysanthemum leucanthemum* *Convolvulus* sp. *Dalea purpurea* *Erigeron* sp. *Grindelia squarrosa* *Hyoscyamus niger* *Lupinus argentus* *Melilotus officinalis* *Monarda fistulosa* *Nepeta cataria* No host (bare gravel) No host (fence post aggregation) No host (in flight) No host (stream edge) *Psoralea argophylla* *Ratibida columnifera* *Solidago* sp. *Tanacetum vulgare* *Trifolium* sp.
Megachile melanophaea	*Campanula rotundifolia* *Campanula* sp. No host (bare dirt path) Sweep netting from Apiaceae, Aster sp.& Campanula sp. *Trifolium* sp.
Megachile mendica	*Nepeta cataria* *Psoralea argophylla* *Verbena stricta*
Megachile montivaga	*Verbena stricta*
Megachile parallela	*Cirsium* sp. *Echinacea angustifolia*

Megachile parallela (Continued)	*Grindelia squarrosa* *Helianthus maximiliani* *Helianthus* sp. *Laiathrus* sp. *Monarda fistulosa* *Psoralea argophylla* *Solidago* sp.
Megachile pugnata	*Arctium* sp. *Cirsium* sp. *Erigeron philadelphicus* *Erigeron* sp. *Helianthus* sp. *Monarda fistulosa* No host (in flight) No host (stream edge) *Rudbeckia hirta* *Verbena stricta*
Megachile relativa	*Erigeron philadelphicus* *Erigeron* sp. *Grindelia squarrosa* *Melilotus officinalis* *Monarda fistulosa*
Megachile rotundata	*Nepeta cataria* No host (nest site) *Solidago* sp. *Taraxacum officinale*
Megachile subexilis *Megachile texana*	*Medicago* sp. No host (bare dirt path)
Osmia albolateralis	*Lupinus argentus* No host (bare dirt path) *Taraxacum officinale* *Thermopsis rhombifolia*
Osmia bucephala	*Thermopsis rhombifolia*
Osmia coloradensis	*Grindelia squarrosa*
Osmia cyaneonitens	*Penstemon grandiflorus*
Osmia densa	*Erigeron strigosus* *Lupinus argentus* *Rosa woodii*
Osmia distincta	*Penstemon grandiflorus*

Osmia gaudiosa	*Melilotus officinalis* *Rhus aromatica*
Osmia grindeliae	*Monarda fistulosa* *Trifolium* sp.
Osmia inermis	*Sisyrinchium montanum*
Osmia iridis	*Iris missouriensis*
Osmia kincaidii	*Melilotus officinalis*
Osmia lignaria	*Taraxacum officinale*
Osmia (Melanosmia) sp. *1*	*Lupinus argentus*
Osmia sp.	*Melilotus officinalis* *Monarda fistulosa* *Penstemon grandiflorus* *Trifolium* sp.
Osmia phaceliae	*Melilotus officinalis*
Osmia proxima	*Taraxacum officinale*
Osmia pusilla	*Melilotus officinalis* *Verbena stricta*
Osmia simillima	No host (bare ground)
Osmia subaustralis *Stelis elegans*	*Arnica* sp. *Melilotus officinalis*
Stelis foederalis	*Aster* sp.
Mellitidae	
Macropis nuda	No host (Fence post aggregation)