Article

UTILIZING NATURAL HISTORY COLLECTIONS AND DATA MINING TO ASSESS FLOWER ASSOCIATIONS AND PHENOLOGY OF NORTH AMERICAN BEES IN THE GENUS *ANDRENA* (HYMENOPTERA: ANDRENIDAE) SUBGENUS *PLASTANDRENA*

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Abstract—Even though bees are the most frequently discussed and important pollinators, most native species' fundamental ecology including phenology and flower preferences is not known. This is especially true within the mega diverse bee genus *Andrena* Fabricius, 1775 where only a small percentage of species floral associations have been assessed. Here, using label data with associated floral records and collection event dates, the phenology and flower visitations of North American bees in the *Andrena* subgenus *Plastandrena* Heidicke, 1933 is assessed. Results of Shannon–Wiener index, Simpson's diversity index, and occurrences on plant genera, families, and orders demonstrate *Andrena argemonis, Andrena mellea* are polylectic, while *Andrena crataegi, Andrena fracta,* and *Andrena prunorum* are broad polylectic. Plant-pollinator network analyses demonstrated the degree of polylecty within the subgenus, with *Andrena argemonis* being the most specialized towards *Argemone* and *Andrena mellea* being the most generalized. Collection event dates demonstrate all species phenology except *A. mellea* have a unimodal peak. However, the bimodal peaks in *A. mellea* may be due to geographic variation or sampling bias. Each species has peak records at varying times, showing some species are spring associated and others summer associated. This study provides an in-depth update of floral and phenological data of these understudied bee species, providing evidence that these bees may be important native pollinators that require more attention.

Keywords—Polylectic, *Andrena*, *Plastandrena*, Diversity, phenology, floral preferences

INTRODUCTION

Pollination is a crucial process that involves the transfer of male and female gametes to facilitate fertilization and reproduction within most plant species. Pollinators are the main mechanism for how this transfer is completed. Current estimates range between 87.5-90% of all angiosperms rely on animals for pollination (Ollerton et al. 2011; Tong et al. 2023). Bees have been argued as the most important pollinators and are crucial for pollinating many agricultural crops to maintain the food supply, maintaining ecosystem stability, and the preservation of biodiversity (Danforth 2007; Potts et al. 2010; Traveset et al. 2017). Without bee pollination there would be major loss in the food supply and collapse in many ecosystems leading to biodiversity loss.

Despite the fact that bee pollination is crucial, understanding of bee fundamental ecology, pollination, and flower visitation at the species level is not known for most species, especially across their distributions. Fundamental ecology refers to the biology of the bee species, including their life history, nesting habits, phenology, physiology, and flower preferences. Bee pollination simply refers to the plant species a specific bee species is actively foraging for pollen from or visiting to obtain nectar and in doing so, pollinating. Active foraging is done by female bees who gather pollen as provisions for their offspring,

while males do not actively gather pollen. Males do still pollinate however, as they passively obtain pollen during nectar feeding. One study found that male bees deposited more pollen on a per visit basis, while females deposit more pollen in total as they visit more individual flowers (Tang et al. 2019). Flower visitation refers to a record of a bee visiting a flower, which in many cases can correspond to a female bee actively collecting pollen or a male bee feeding, which could result in pollination occurring, but this is not always the case.

The lack of a strong understanding of all this knowledge and especially what bee species are pollinating throughout their ecosystems falls into one of the seven shortfalls of large-scale biodiversity (Hortal et al. 2015; Marshal et al. 2024). The Eltonian shortfall is a lack of knowledge about species interactions, which limits the ability to understand, protect, and predict changes in ecosystems and the organisms within them (Hortal et al. 2015). Continuing efforts to understand these interactions, especially for important pollinators like bees, is crucial knowledge for understanding ecosystems. Especially in the face of anthropogenically driven climate change.

A potential step towards mediating this issue lies within natural history museums, published research, and online data repositories, where there are vast amounts of data in the form of associated taxon label data. This data refers to what flower species a bee was found on when collected; in other words, this documents a flower visitation when the bee was alive. In addition to this data the date of collection is also documented, providing a record of when the bee was active. Simply taking advantage of the decades and potentially centuries of label data may be an important way to gauge aspects of the fundamental ecology, pollination, and phenology of bee species. In some cases, bee taxonomic papers have already compiled label data and broadly used this information to describe phenology and plant preferences for bee species (Ribble 1968; LaBerge 1969; Bouseman & LaBerge 1978). However, in these papers the interpretations appear to be rather subjective or too simplistic, as they are described in a single sentence without displaying the data in ways to visualize and test with varying diversity metrics. Additionally, this compiled label data is rarely provided in full, reducing the ability to reassess the interpretations from the paper (Ribble 1968; LaBerge 1969). If this data was gathered and organized into the right form, it could be used to create plant-pollinator network analyses and assess biodiversity indices for each bee species. Many recent studies that conduct this type of research tend to obtain pollen from the leg of museum bee specimens to confirm the plant taxa the bees were actively foraging on through DNA metabarcoding (Bell et al. 2017; Wood & Roberts 2017; Gous et al. 2019; Fang et al. 2024). Other studies utilize melissopalynology where the pollen loads from the bee specimens are obtained and the pollen grains are identified based on morphology utilizing palynological catalogues (Bacab-Pérez et al. 2024). Both of these approaches are much stronger and document direct means of pollen foraging by the bee specimens. However, these approaches are labour intensive and expensive. The current costs are $200 per specimen for melissopalynology study at 500 pollen grains per sample, $56.60 per specimen for single marker DNA metabarcoding, and $98.77 per specimen for two markers of DNA metabarcoding (Wizenberg et al. 2023). While these costs will almost certainly continue to decrease, until then, associated taxa label data is still a viable option.

The terms polylecty and oligolecty are typically used to refer to the different types of foraging behaviours exhibited by bees (Robertson 1925). Polylecty or polylectic bees are those that collect pollen from a variety of different unrelated plant taxa, varying in plant species and families. Oligolecty or oligolectic bees collect pollen from a narrow range of different, closely related plant species, all within the same family. However, these two terms have been shown to be insufficient in describing the large breath of specialization among bee pollen foraging strategies (Cane & Sipes 2006). It is better to view pollen foraging strategies as a continuous spectrum from broad polylectic to monolectic species. For this paper, the terminology from Cane and Sipes (2006) tabular lexicon will be used to describe the class of specialization for bee foraging strategies. Within this terminology there are seven different classes that describe the level of specialization: broad polylecty, polylecty, mesolecty, oligolecty, eclectic oligolecty, narrow oligolecty, and monolecty. Broad polylecty collect and use pollen from most genera and from numerous plant families within their distribution.

For this paper, I designate this as more than 10 families and 30 genera. Polylecty collect and use pollen from more than three families. Mesolecty from more than four genera and one to three families or big tribes. Oligolecty from one to four genera and one family. Eclectic oligolecty from two to four genera and two to three families. Narrow oligolecty from one genus and one family. Monolecty from one species, although this term has problems and little biological meaning (Cane 2021).

As outlined above, this study utilized associated taxa label data, which documents an individual specimens' visitation to a flower species. This visitation can in many cases correspond to pollination or a female bee actively collecting pollen from the plant; however, this is not always the case. The uncertainty around active collection of pollen or passive visitation is an important caveat when it comes to label data usage and is a main limitation of this study. Additional limitations include reliance upon the correct identification of the plant species by the collector, sampling bias of collection event, not documenting the direct pollen loads to determine if the specimen was actively collecting pollen from the plant, and missing assessment of the specimen's sex. Be that as it may, this approach has many benefits, including advantageous use of previously obtained data, relatively cheap or no costs, large sample sizes across species' distributions, and the replicability of the methods. A recent study has shown how visitation data can be used to predict specialist bee species; however, predicting generalists may be difficult (Smith et al. 2024). There are massive amounts of this type of information that can be gathered with "data mining" and used to assess flower visitations by bee species which could correspond to pollen collecting behaviours and plant-pollinator interactions. Additionally, many bee species are exceptionally rare, are difficult to identify, or have been incorrectly identified. Further only a portion of specimens in collections have in-tact pollen loads. A few of the species within this study are rather rare, and due to this there are few specimens with in-tact pollen loads. Limitations posed by specimen availability pose DNA metabarcoding or melissopalynology as less fruitful tools to obtain enough data.

The bee genus *Andrena* Fabricius, 1775 is currently composed of 1,738 described species, 479 of which are in North America, making it one of the top ten most diverse animal genera (Zabinski 2024; Ascher & Pickering 2025; Wood 2025). *Andrena* are very efficient pollinators and likely crucial throughout their distributions for pollination of native plant species, making it a group that requires much more attention (Park et al. 2016; Szczepko-Morawiec et al. 2024). There have been some studies that focus on dietary ecology at the species level for *Andrena* but this is usually locally restricted and only encompasses a small percentage of the overall diversity within *Andrena* (Larsson & Franzén 2007; Larkin et al. 2008; Wood & Roberts 2017). Throughout *Andrena*, there is a spectrum of species ranging from broad polylectic to narrow oligolectic species. Species such as *Andrena astragali* Viereck & Cockerell, 1914 are narrow oligolectic, only collecting pollen from two species of death camas (Cane 2018), while other species, such as *Andrena rudbeckiae* Robertson, 1891 and *Andrena androfovea* Neff, Bossert, & Hung, 2024 are oligolectic, foraging pollen from multiple species but are restricted to a specific plant family (Neff & Simpson 1997; Larkin et al. 2008; Bossert et al. 2024). Many other species are polylectic.

Within *Andrena*, the subgenus *Plastandrena* Heidicke, 1933 is composed of 32 species, five of which are from North America (LaBerge 1969; Gusenleitner & Schwarz 2002; Xu & Tadauchi 2011; Meena & Dey 2019; Pisanty et al. 2022; Gautam et al. 2024; Wood 2025; Ascher & Pickering 2025). There is no real consensus on how many *Plastandrena* species there are due to variation in estimates derived from species concepts, but it is very likely that the number of *Plastandrena* species will change drastically as more specimens are collected and included within genetic studies. North American *Plastandrena* have been an overlooked group of solitary native bees despite the common occurrence of some species and their potential as very important pollinators. Little attention has been given to their ecological understanding. The five North American species include: *Andrena argemonis* Cockerell, 1896, *Andrena crataegi* Robertson, 1893, *Andrena fracta* Casad & Cockerell, 1896, *Andrena mellea* Cresson, 1868, and *Andrena prunorum* Cockerell, 1896. Each species has distinct distributions from one another,

with *A. crataegi* and *A. prunorum* having large distributions compared to the other three species (Ascher & Pickering 2025). LaBerge (1969) provided updated species descriptions, a key to species, and general ecological associations for each of the five species; however, some of the information is incomplete. Specifically, it lacks seasonal activity graphs, floral preferences (for *A. mellea*), and overall plant-pollinator interactions. In this paper, I used floral label data to build upon the information provided by LaBerge (1969) in order to depict phenology, document flower visitations, and quantify the degree of specialization to better understand the ecology of these understudied North American *Plastandrena* bees.

MATERIALS AND METHODS

The methodology of this research is structured into three main steps: data collection, data "cleaning", and data analysis. Data collection entailed gathering data from GBIF.org, natural history museums, and personal communications from bee experts. Data "cleaning" entailed extracting and converting data into useable form for analysis. Data analysis entailed grouping number of genera, families, and orders each bee species was found to visit, and diversity metrics and plant-pollinator network analysis were completed. I provide detailed information on each of the three processes in the following sections.

DATA COLLECTION

To assess floral associations and phenology, I gathered species occurrences and flower associations on GBIF.org, examined of physical specimens in museum collections, and initiated personal communications with bee specialists. Obtaining, cleaning, and processing data was done using R Core Team 2025 and Microsoft Excel Version 16.77.1. Identifying physical insect specimens was carried out to verify species determinations and facilitated the identification of additional specimens. These specimens were obtained from University of Kansas Snow Entomological Collection (SEMC), The Northern Arizona University Arthropod Collection (NAAC), Museum of Comparative Zoology Harvard University (MCZ), Florida State Collection of Arthropods (FSCA) , University of Texas Insect Collection (UTIC), Arizona State University Hasbrouck Insect Collections (ASUHIC), Ohio State University C.A.Triplehorn Insect Collection (OSUC), and Eastern New Mexico University Dr. Antonio Gennaro Natural History Museum. Personal communications refer to specimen data obtained from bee specialists that had specimens in their own personal collections or housed at smaller museums that do not have data synced with GBIF.org. These include Sam Houston State University Natural History Collections, the personal collection of Dr. John Neff at Central Texas Melittological Institute, USDA Dr. Katherine Parys (SPHC), and Natalie Herbison's personal collection at the University of Kansas. GBIF data was downloaded via SIMPLE_CSV download to obtain all data for each species, including monthly occurrence data (GBIFa 2025). The second download utilized a sql download to pull associatedTaxa, which included floral associations (GBIFb 2025). GBIF data was downloaded using the 'rgbif' package (Chamberlain et al. 2025). After downloading via SIMPLE_CSV a total of 14,664 specimens were obtained. After downloading using sql across all species 2,561 floral associations were obtained.

DATA CLEANING

Once all GBIF data was obtained, it was combined with data from personal communications and physical museum specimens. After compiling the data, additional steps were required to remove unusable data, add institutional code for any specimen to the dataset to ensure future tracking down of specimens, extract flower species name, combine flower data with data from LaBerge (1969), and update flower taxonomy. iNaturalist data was retained from GBIF if I could confidently verify the identification of the bee specimen from photographs, otherwise these records were excluded. If specimens appeared to be geographic outliers, institutions that housed those specimens were contacted to verify identification. However, due to such a large abundance of specimens all specimens were not able to be viewed in person or checked this way to verify identification. For some GBIF specimens I had access to the physical specimens and verified or updated identification. Some GBIF specimens did not have the institutional code or barcode that is tied to an individual specimen. On GBIF an institutional code is labelled as catalogNumber. If the specimen did not have an associated

institutional code identified as catalogNumber, the otherCatalogNumber was substituted, which is an additional institutional code tied to only a single specimen. Some specimens did not have either type. I deemed it important to keep these catalog numbers so any future researchers that would like to reassess this analysis will have the ability to track down nearly every specimen. On GBIF some specimens were duplicated. To prevent counting a single specimen multiple times the duplicate specimens were identified based on catalogNumber, day, month, year, and associatedTaxa. Then one of the duplicates were removed. After cleaning the monthly occurrence data, a total of 10,733 records remained.

For floral records, extra words around genus and species were filtered out using regular expressions. This allowed the extraction of just the scientific name of the species. Records that did not contain any plant species name were removed. Floral records were then combined with data available in LaBerge (1969) to generate complete genera, family, and order level lists of floral records for each *Andrena* species (Table 1). Due to the age of many of the flower association records, some of the plant species' taxonomy has changed, including synonymizing and movement into new or different taxonomic groups. To correct for this, the current taxonomy of floral records was verified using ITIS.org website directly, in combination with R package 'taxize' (Chamberlain & Szocs 2013; Chamberlain et al. 2020). In some cases, data pulled from GBIF had the plant genus name spelled incorrectly, simply due to a typing error resulting in one or multiple letters being out of order, missing, or added. An example of this is the plant genus *Baileya,* which in the raw data was spelled as *Bailyea*. When this occurred, the true genus interpretation from the misspelling was determined based on the location the specimen was collected and the full species name of the specimen. If I was unsure, data was omitted. A complete list of all the plant genera each bee species occurred on is displayed in Table 2. At the end of this step a total of 2,629 flower associations remained.

In order to utilize this cleaned flower association data in the analysis it needed to be converted into count data at the genus level. Genus level was used due to a lack of species-specific identifications in the data. Every flower association was counted once per specimen. Once counts were obtained for each genus, they were compared to the count data in LaBerge (1969). Due to missing notation of specific specimens associated with each floral record in LaBerge (1969), it was impossible to verify if records I gathered were the same specimens used in his study. Therefore, if the count data for a plant genus from LaBerge (1969) comprised a higher number compared to the data I acquired, his count was substituted for that genus. This was to incorporate as much data as possible without counting flower associations multiple times for a specimen. In some cases, LaBerge (1969) only provided if there was a record on a plant genus or species without indicating how many bee specimens were collected on that plant. In this case, it was only counted as one. Genus level counts were then converted into family level counts by grouping each genus count into its family. At the end of this step there was a total of 3,713 flower associations as count data.

Table 1. Number of plant associations for genus, family, and order levels. Shannon-Wiener Index and Simpson's diversity index based on genera floral associations of North American *Plastandrena*

Species	Plant Orders	Plant Families	Plant Genera	Shannon-Wiener Index	Simpson's Diversity Index
Andrena argemonis	6	7	15	1.25	0.48
Andrena crataegi	25	41	102	3.21	0.94
Andrena fracta	11	12	31	2.55	0.88
Andrena mellea	7	8	12	2.15	0.84
Andrena prunorum	24	43	126	3.66	0.96

Table 2. List of plant genera associations for North American *Plastandrena*

Species	Floral Associations Genera
Andrena argemonis	*Acacia, Argemone, Baileya, Brassica, Cleome, Dalea, Erigeron, Eriogonum, Helianthus, Lepidium, Medicago, Melilotus, Monarda, Persicaria, Sisymbrium*
Andrena crataegi	*Acer, Alliaria, Allium, Amelanchier, Amorpha, Angelica, Antennaria, Anthriscus, Apocynum, Aralia, Aronia, Aruncus, Aster, Baptisia, Barbarea, Berteroa, Blephilia, Brassica, Caragana, Cardamine, Carduus, Castanea, Ceanothus, Celastrus, Cercis, Chrysanthemum, Cirsium, Comandra, Conium, Coriandrum, Cornus, Crataegus, Crepis, Cydonia, Dasiphora, Daucus, Deutzia, Elaeagnus, Eriogonum, Euonymus, Euphorbia, Fothergilla, Fragaria, Frasera, Gaylussacia, Gypsophila, Hackelia, Heracleum, Hieracium, Holodiscus, Hydrangea, Hypericum, Ilex, Iris, Juniperus, Kalmia, Leucanthemum, Lomatium, Lonicera, Malus, Malvastrum, Melilotus, Monarda, Narcissus, Pastinaca, Peucedanum, Philadelphus, Physocarpus, Polytaenia, Potentilla, Primula, Prunus, Ptelea, Purshia, Pyracantha, Pyrus, Ranunculus, Raphanus, Rhamnus, Rhododendron, Rhus, Ribes, Rosa, Rubus, Salix, Senecio, Solidago, Sorbaria, Spiraea, Symphoricarpos, Syringa, Taenidia, Tamarix, Taraxacum, Thaspium, Toxicodendron, Trifolium, Tulipa, Vaccinium, Viburnum, Vitis, Zizia*
Andrena fracta	*Acacia, Argemone, Baileya, Brassica, Cryptantha, Descurainia, Dithyrea, Dyssodia, Encelia, Eschscholzia, Fallugia, Geraea, Kallstroemia, Larrea, Lepidium, Malacothrix, Medicago, Nerisyrenia, Oenothera, Opuntia, Parkinsonia, Phacelia, Physaria, Pluchea, Prosopis, Prunus, Pyracantha, Salix, Senecio, Sisymbrium, Sphaeralcea*
Andrena mellea	*Argemone, Asclepias, Baccharis, Ceanothus, Purshia, Descurainia, Fallugia, Lepidium, Melilotus, Prosopis, Prunus, Salix*
Andrena prunorum	*Acer, Actaea, Adenostoma, Amelanchier, Amsinckia, Apocynum, Arabis, Arctostaphylos, Argemone, Artemisia, Asclepias, Asperugo, Astragalus, Baccharis, Balsamorhiza, Berberis, Brassica, Cakile, Calochortus, Calystegia, Ceanothus, Cercocarpus, Chaenactis, Chamerion, Chrysothamnus, Cirsium, Clematis, Cleome, Convolvulus, Crataegus, Crepis, Cryptantha, Cymopterus, Dasiphora, Daucus, Delphinium, Descurainia, Deutzia, Dithyrea, Draba, Drymocallis, Encelia, Erigeron, Eriogonum, Eriophyllum, Erodium, Erysimum, Eschscholzia, Euphorbia, Fallugia, Fragaria, Fraxinus, Geranium, Gilia, Hackelia, Helianthus, Heracleum, Holodiscus, Hymenopappus, Hyptis, Juniperus, Lappula, Larrea, Lepidium, Linaria, Lithospermum, Lomatium, Lupinus, Madia, Malus, Medicago, Melilotus, Mentzelia, Monardella, Nemophila, Nerisyrenia, Oenothera, Opuntia, Pastinaca, Pediocactus, Penstemon, Petasites, Phacelia, Philadelphus, Phlox, Physaria, Physocarpus, Pinus, Platystemon, Plumbago, Potentilla, Prosopis, Prunus, Purshia, Quercus, Ranunculus, Raphanus, Rhamnus, Rhus, Ribes, Rorippa, Rosa, Rubus, Salix, Sambucus, Senecio, Shepherdia, Sisymbrium, Solidago, Sorbus, Spergularia, Sphaeralcea, Spiraea, Stanleya, Stenotus, Streptanthella, Symphoricarpos, Synthlipsis, Syringa, Tamarix, Taraxacum, Thelypodium, Trichostema, Trifolium, Wisteria, Zigadenus*

Data Analysis

I used the cleaned monthly occurrence data to visualize temporal patterns of bee activity for each species. To detect within-month phenological trends, I separated specimen records into first half of each month (days 1-15) or second half (days 16-end). Then using R package 'ggplot2' (Wickham 2025), Fig. 1 was constructed. Photographs of female bee specimens within Fig. 1 were made using Macropod Pro 3D photomacrography system from Macroscopic Solutions®, composed of a Canon EOS 6D Mark II camera. Photographs were assembled with Zerene StackerTM software package and edited with Adobe Photoshop® CC.

To assess the diversity of flower associations, I analysed count data using both the Shannon-Weiner Diversity Index and Simpson's Diversity Index with the R package 'vegan' (Oksanen et al. 2025). This was done at plant genus level due to the abundance of records at this level compared to species level. To visualize the degree of specialization within these species and/or overlap in floral resources, I also built a pollinator-plant network, using the R package 'bipartite' (Dormann et al. 2008). The results from these are depicted in Fig. 2, information in Table 3, and supplemental Table 1. Fig. 2 was constructed at the plant genus level and family level. In Fig. 2A, genera that had less than 10 interactions had label removed to reduce cluttering. In Fig. 2B, plant families that have less than 4 interactions had label removed to reduce cluttering.

All data, including original GBIF downloads, cleaned monthly occurrences, cleaned floral

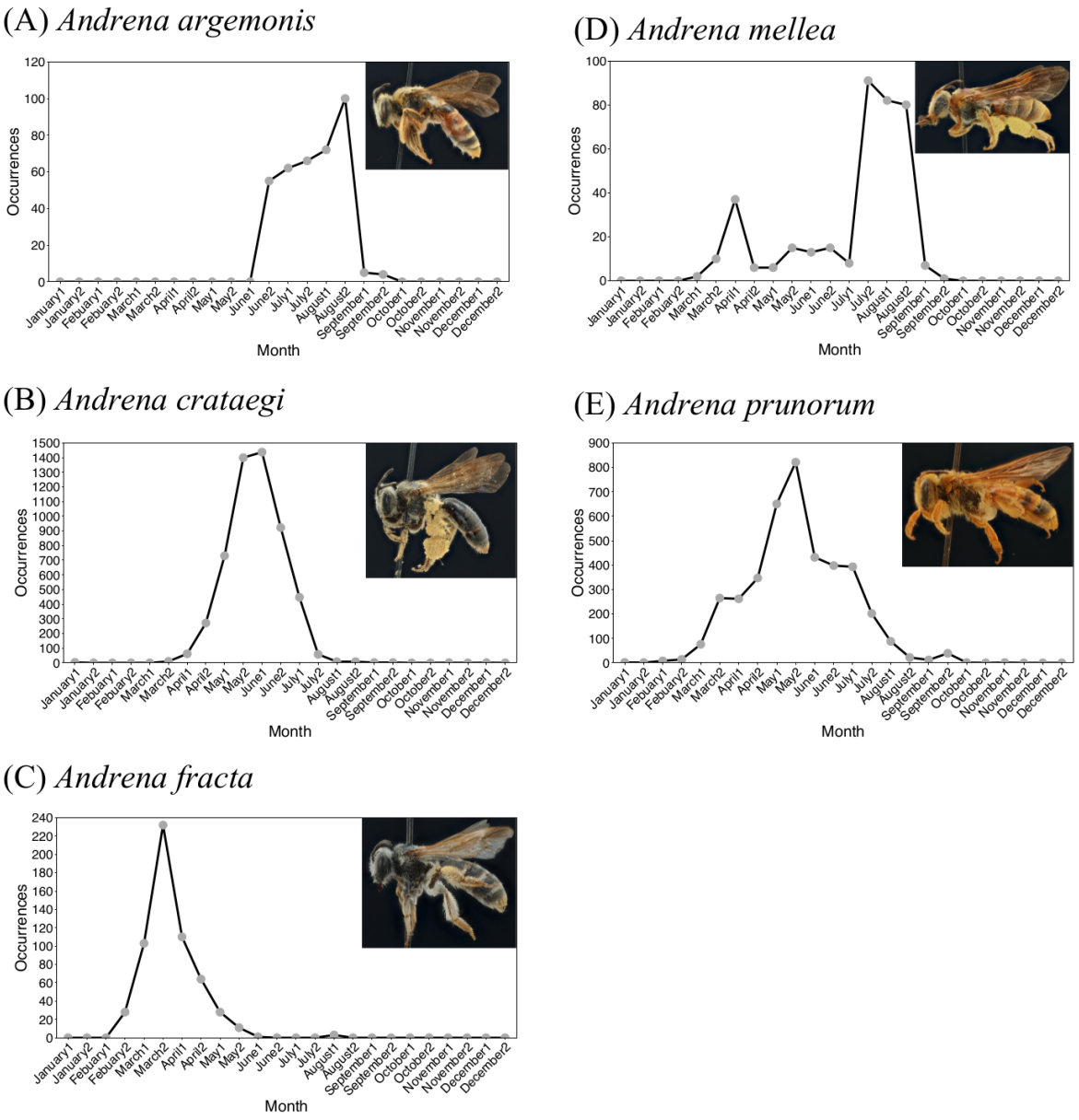

Figure 1. Line graphs of occurrences per month depicting seasonal activity and lateral view photographs of (A) *Andrena argemonis*, (B) *Andrena crataegi*, (C) *Andrena fracta*, (D) *Andrena mellea*, and (E) *Andrena prunorum*. Month followed by 1 represents the first 15 days of that month and 2 represents days 16 to end of that month.

records, and counts data are available via Zenodo. See data availability section below.

Results and Discussion

Species Phenology

Each species demonstrated overlapping phenologies with degrees of variation, with *A. fracta*, *A. prunorum*, and *A. mellea* having many occurrences in the spring, while *A. argemonis*, *A. crataegi*, and *A. mellea* largely occurred in the summer (Fig. 1). *Andrena argemonis* is active from mid-June to late September with a peak in mid to late August (Fig. 1A). *Andrena crataegi* is active from mid-March to late August with peak early to mid-June (Fig. 1B). *Andrena fracta* is active from mid-February to mid-June with peak in mid to late March (Fig. 1C). There are a few records in early to mid-August for *A. fracta* which may be outliers or indeterminations; however, I was not able to look at these physical specimens to determine if identification was correct. It is suspected they may be specimens of *A. prunorum* as the two species are morphologically hard to decipher. *Andrena mellea* is active from early March to late September with

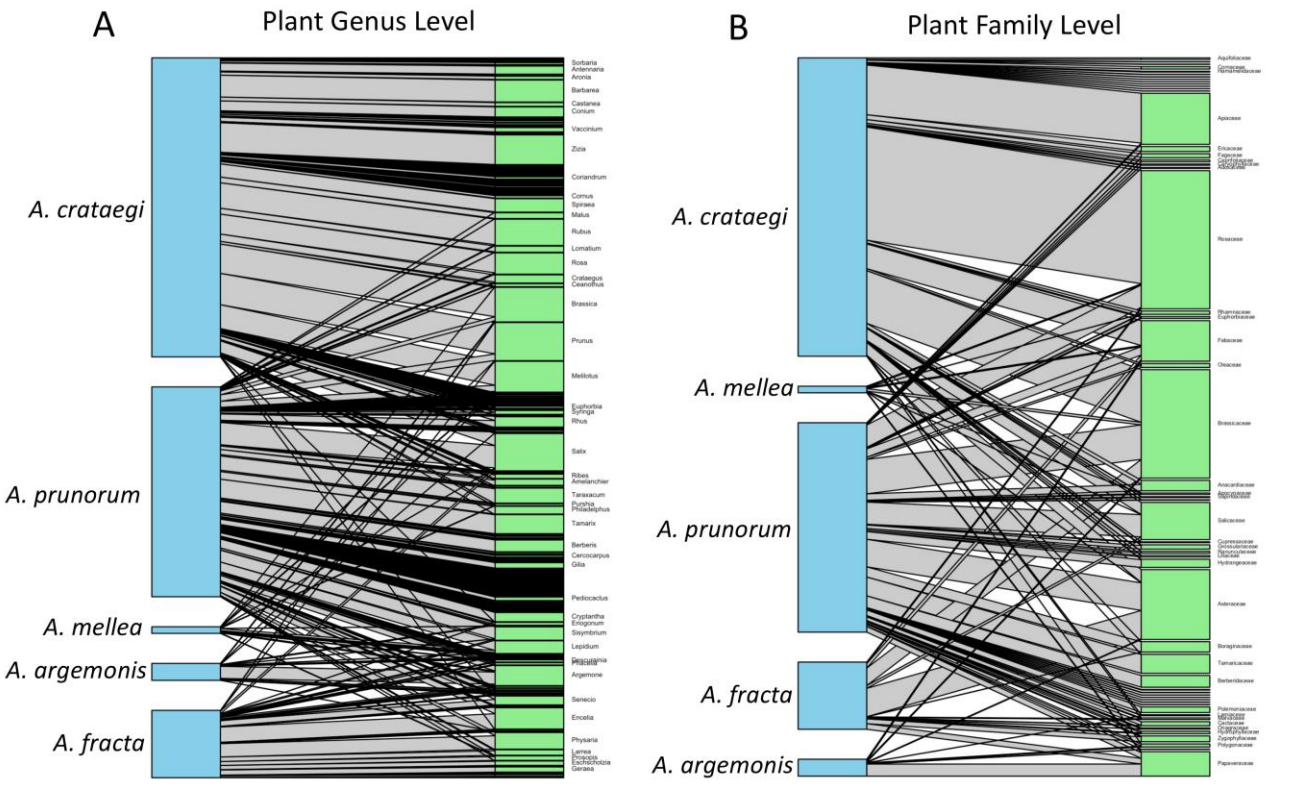

Figure 2. North American *Andrena* subgenus *Plastandrena* bipartite network analysis. Pollinators are depicted in light blue on left side. Flower genus or family is depicted in green on right side. The interactions between bee species and plant species are grey and weighted by frequency, with thicker lines indicating higher frequency. (A) Network analysis with plants at genus level. All plant genera that have less than 10 interactions had label removed to reduce cluttering. (B) Network analysis with plants at family level. All plant families that have less than 4 interactions had label removed to reduce cluttering.

two peaks one in early to mid-April and a larger peak in mid to late July (Fig. 1D). While these two peaks seem to point towards bivoltinsim, there is evidence that this may be due to geographic variation or sampling bias. The majority of records in the spring peak occur in Mexico, while the majority of late summer peak are in the United States. This geographic variation, however, may be an artifact of sampling, as the majority of specimens in Mexico seem to come from a national project of collection events in Northeastern Mexico and the majority of United States specimens come from Southeastern Arizona and Southwestern New Mexico, which is where the annual BeeCourse Workshop is held in August at the Southwestern research station in Portal Arizona. *Andrena prunorum* ranges from early February to late September with peak in mid to late May (Fig. 1E). Additionally, all species had peak occurrences corresponding to different times of year relative to each other.

Bee-plant relationships

From the results of Table 1 & 2, it is indicated that *A. argemonis* and *A. mellea* should be classified as polylectic species, due to occurring on more than three plant families. *Andrena prunorum A. crataegi*, and *A. fracta* should be classified as broad polylectic due to occurring on more than 10 families and 30 genera. Even at the plant order level it is clear all five species have been collected on different distinct plant lineages. The results of Shannon-Wiener Index and Simpson's diversity index corroborate the polylectic and broad polylectic determinations due to *A. argemonis* and *A. mellea* having lower indices and *A. prunorum A. crataegi*, and *A. fracta* having the highest indices. *Andrena argemonis* had the lowest index levels for Shannon-Wiener Index and Simpson's diversity index, demonstrating a more moderate level of plant genera diversity (Table 1). For example, *A. argemonis* with a 0.48 Simpsons diversity equates to a 48% chance that if randomly collected it would be found on a different plant genus. While *A.*

Table 3. Species specialization (d') values at plant genus and family levels.

Species	Species specialization (d') Plant Genus Level	Species specialization (d') Plant Family Level
Andrena argemonis	0.7725764	0.6000729
Andrena crataegi	0.7389409	0.3992046
Andrena fracta	0.7506115	0.3596342
Andrena mellea	0.4827607	0.1131480
Andrena prunorum	0.5364563	0.2701199

prunorum had the highest index levels for Shannon-Wiener Index with 3.66 and Simpson's diversity index with 0.96, demonstrating a high level of plant genera diversity (Table 1).

Results of the plant-pollinator network analysis demonstrates the degree of specialization (d′) within these species. At both the plant genus and family level, *A. argemonis*, *A. crataegi*, and *A. fracta* have the highest specialization, being more restricted to specific plant genera and families, while *A. mellea* and *A. prunorum* have lower specialization (Table 3). Metrics of connectance, modularity Q, nestedness, and H2 are provided in supplementary results as goals of this paper are not demonstrated through these metrics. Furthermore, the overall network metrics are not proper representations as this data has come from different locations and the species have varying distributions, leading to biases in metric results.

The genus counts data demonstrated: 71.4% of *A. argemonis* records were on *Argemone; Andrena crataegi*: 60.8% of records were on seven genera, (*Brassica*, *Barbarea*, *Melilotus*, *Prunus*, *Rosa*, *Rubus*, and *Zizia*); *Andrena fracta*: 42.7% of records were on (*Encelia* and *Physaria*); *Andrena mellea* 31.7% of records were on *Lepidium*; *Andrena prunorum*: 37.8% of records were on five genera, (*Berberis, Salix, Sisymbrium, Tamarix,* and *Taraxacum*). At the family level, 71.4% of *A. argemonis* records were on Papaveraceae, the family *Argemone* is in. For *A. crataegi*, 80.6% of records were represented by four families, (Apiaceae, Brassicaceae, Rosaceae, and Fabaceae), the highest in the family Rosaceae, which comprised 37.9% of records. *Andrena fracta* had 68.3% of records on Asteraceae and Brassicaceae. *Andrena mellea* had 39% of records represented by the family Brassicaceae. *Andrena prunorum* had 60% of records spread across five families (Asteraceae, Brassicaceae, Rosaceae, Salicaceae, and Tamaricaceae). These results are depicted visually in Fig. 2, displaying which genera and families each species was collected on most frequently.

In addition, *A. argemonis* and *A. mellea* are much rarer species, together only accounting for 146 of 3,713 floral records and 746 of 10,733 seasonal occurrence data. *Andrena mellea* only had 41 flower association records, which was the lowest out of all the species. This low number of records could lead to biases and or changes in the determinations found here for this species. The low records could be the reason for *A. mellea* having the lowest specialization levels seen from the network analysis. Overall, for both *A. argemonis* and *A. mellea* fewer records may limit the interpretations of their flower visitations. *Andrena prunorum* and *A. crataegi* are demonstrated to be highly polylectic species, especially *A. prunorum,* potentially due to the commonality of collection and distributions of these two species. Future research should focus on the importance of these two species' pollination habits for native ecosystems and crops, as they may be contributing greatly to pollination services.

The limitations of this study are largely rooted in the use of label data from museum specimens and are therefore reliant upon the correct identification of the plant species by the collector, sampling bias of collection event, not discerning between males and females, and not documenting the direct pollen loads to determine if the specimen was actively collecting pollen from the plant. These limitations could alter the results of this study as if the identification of the plant species the bee specimens were collected on is incorrect, this would result in an incorrect visitation record. Additionally, if there is bias in the collecting event, such as being near a road or other more easily accessible area, this may bias results toward plant

species that are commonly found in such areas and may not reflect the same visitation the bee species may partake in a more nature environment. Not discerning between sexes may include a broader flower visitation interpretation as male bees are not actively collecting pollen but are nectar feeding. The best modern approaches for verifying pollen obtained by the bee specimen include DNA metabarcoding and melissopalynology. However, utilizing this museum specimens approach may be an important way to utilize the vast amount of floral association data within natural history museums in a much faster and cheaper way compared to DNA metabarcoding or melissopalynology to quantify the spectrum of pollination habits of bee species. This approach may allow quicker identification of keystone species across ecosystems, and what plant species they are important for, whether they are important narrow oligolectic species ensuring the survival of a single or few plant species or broad polylectic species providing larger pollination to ecosystems. Future studies on these five species should aim at direct pollination observation across their ranges, assessing foraging behaviour of females, and conducting pollen analysis to further refine the understanding of their pollination habits. In addition, future work should study the true impacts these species have on the ecosystems they inhabit and what, if any, important agricultural crops they could be contributing to pollinating.

Notes on unusual foraging behaviours

It is also worth noting that one specimen of *A. crataegi* was labeled as being collected on *Juniperus communis*, four specimens of *A. prunorum* had label data that they were collected on *Juniperus scopulorum,* and two specimens of *A. prunorum* had label data as being collected on *Pinus edulis*. There have been very few records documenting bee species visiting/taking pollen from gymnosperms (Saunders 2018; Yang et al. 2021) and none that I could find specifically in the genus *Juniperus,* or any of *Andrena* performing this behaviour. Due to the nature of this data, as discussed above, it does not fully indicate if the bees were truly trying to feed on these gymnosperms or simply were resting on the plant. This leaves room open for interpretation, but the data was left within this study and indicated here as something for future researchers to look for as potential interesting incidence of *Andrena* trying to feed on gymnosperms.

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Disclosure statement

There is no conflict of interest.

Generative AI disclosure statement

AI was not used in the construction of this manuscript.

Data availability statement

All data, including original GBIF downloads, cleaned monthly occurrences, cleaned floral records, and counts data are available via Zenodo. https://doi.org/10.5281/zenodo.18613611

Appendices

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

Table S1: Metrics from network analysis.

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