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Effectiveness of pollinator (Anthophila) sampling methods across western Colorado: implications for conserving sensitive bee species

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Abstract.—The global decline of bee species has intensified concern for their conservation and the critical pollination services they provide. Effective monitoring of bee diversity and population trends depends on robust sampling methods, yet the efficiency of these methods varies across regions, habitats, and taxa. Colorado supports over 1000 bee species, but areas west of the Rocky Mountains remain poorly studied compared to the eastern Front Range. To address this gap, we assessed the effectiveness of multiple active and passive sampling techniques for surveying native bee communities and their floral associations across western Colorado. From June to August 2024, we sampled 64 plots across shrubland, grassland, alpine, and forest ecosystems using blue vane traps, 4 colors of pan traps, and 3 active methods: targeted, sweep, and aerial netting. We collected 4872 bees representing 39 genera. Halictidae was the most abundant family (65.7%), followed by Apidae (19.5%) and Megachilidae (6.8%). Blue vane traps captured the highest number of individuals, predominantly Apidae including *Bombus occidentalis*, while targeted netting produced the greatest taxonomic richness (33 genera). Yellow pan traps yielded high bee counts but low diversity, dominated by Halictidae. Although aerial and sweep netting captured fewer bees, they contributed unique genera not represented in other methods. Bees visited 26 flower families, with Asteraceae, Fabaceae, Plantaginaceae, Malvaceae, and Brassicaceae accounting for over 76% of observations. We observed all 5 bee families on *Melilotus officinalis*, *Sphaeralcea coccinea*, and *Cirsium* spp. No single sampling method captured the complete diversity of bees, highlighting the need to combine active and passive approaches. This study provides one of the most comprehensive assessments of bee sampling in western Colorado to date and offers practical guidance to enhance monitoring, improve data comparability, and support bee conservation amid global declines.

Resumen.—El declive global en las poblaciones de abejas ha incrementado la preocupación en torno a su conservación y a los servicios críticos de polinización que proporcionan. Implementar un monitoreo eficaz de su diversidad y tendencias poblacionales depende de métodos de muestreo robustos; no obstante, la eficiencia de dichas metodologías varía entre regiones, hábitats y taxones. El estado de Colorado alberga más de 1000 especies de abejas; sin embargo, las zonas ubicadas al oeste de las Montañas Rocosas han sido escasamente estudiadas en contraste con la región oriental del Front Range. Para abordar esta brecha, evaluamos la eficacia de múltiples técnicas de muestreo activas y pasivas para estudiar las comunidades de abejas nativas y sus asociaciones florales en el oeste de Colorado. Entre junio y agosto de 2024, muestreamos 64 parcelas en ecosistemas de matorral, pastizal, zona alpina y bosque mediante trampas de veleta azul, trampas de plato de cuatro colores y tres métodos activos: colecta dirigida, red de golpeo y red aérea. En total se recolectamos 4872 abejas que representaron 39 géneros. Halictidae constituyó la familia más abundante (65.7%), seguida por Apidae (19.5%) y Megachilidae (6.8%). Las trampas de veleta azul capturaron el mayor número de individuos, principalmente Apidae, incluido *Bombus occidentalis*, mientras que la captura dirigida generó la mayor riqueza taxonómica (33 géneros). Las trampas de plato amarillas atrajeron altas cantidades de abejas, pero baja diversidad, dominadas por Halictidae. Aunque con la red aérea y la red de golpeo se capturaron menos abejas, estas aportaron géneros únicos que no aparecieron en otros métodos. Las abejas visitaron 26 familias de plantas con flor, y Asteraceae, Fabaceae, Plantaginaceae, Malvaceae y Brassicaceae representaron más del 76% de las observaciones. Observamos las cinco familias de abejas en *Melilotus officinalis*, *Sphaeralcea coccinea* y *Cirsium* spp. Ningún método de muestreo registró la diversidad completa de abejas, lo que destaca la necesidad de combinar enfoques activos y pasivos. Este estudio constituye una de las evaluaciones más completas hasta la fecha sobre el muestreo de abejas en el oeste de Colorado y aporta orientación práctica para fortalecer el monitoreo, mejorar la comparabilidad de los datos y apoyar la conservación de estos polinizadores ante su declive global.

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Invertebrates make up approximately 97% of all described animal species on Earth, yet they remain vastly understudied compared to vertebrates (Cardoso et al. 2011). These organisms play crucial roles in ecosystems, contributing to pollination, nutrient cycling, soil formation, pest control, decomposition, and more (Eisenhauer and Hines 2021). Pollination service facilitates reproduction for over 75% of flowering plants and nearly 35% of global food crops (Klein et al. 2007, Ollerton et al. 2011).

Bees are among the most important insect pollinators, with an estimated 65% to 80% of flowering plants relying on them for reproduction (Ollerton et al. 2011). Their unique morphological and behavioral adaptations make them highly efficient pollinators, capable of transferring large quantities of pollen between flowers (Michener 2007). Bees provide critical ecosystem services for human food systems, pollinating flowers of a wide variety of fruits, vegetables, nuts, and oilseeds (Klein et al. 2007). Yet, bee populations are experiencing substantial declines, with many species facing severe threats from habitat fragmentation, climate change, and intensive agricultural practices (Goulson et al. 2015, Potts et al. 2016). Conservation efforts require robust monitoring and research to understand bee diversity, distribution, and ecological interactions, ensuring the protection of these vital pollinators and the ecosystems that depend on them. Various sampling methods differ in effort, cost, ability to capture specific taxonomic and functional groups, logistics, and more (Klaus et al. 2024). Concerns about declines in bee populations have led to increased adoption of standardized sampling protocols to minimize biases in bee research (Roulston et al. 2007, Tronstad 2022, Maffei and USGS Bee Lab 2024). We categorized these commonly used methods into active methods (e.g., targeted, aerial, and sweep netting, which involve direct human actions for capture) and passive methods (e.g., pan traps and vane traps, which collect bees without intervention). While some authors prefer active methods, personal skill and experience can bias this approach (Roulston et al. 2007).

The number and diversity of bees captured by active and passive sampling methods also vary by region. In Germany and the Mediterranean, researchers found pan traps to be most effective at capturing diverse bee species (Westphal et al. 2008, Nielsen et al. 2011, Krahner et al. 2024), particularly for capturing sweat bees (Halictidae; Roulston et al. 2007). Alternatively, in Wyoming's sagebrush-dominated shrubland regions and southwestern Australia, vane traps proved more successful than pan traps (Prendergast et al. 2020, Tronstad et al. 2022) and are known for their ability to sample a wide diversity of bee species (Roulston et al. 2007). Active methods such as netting and transect walks also effectively sample bees on flowers (Prendergast et al. 2020). However, no single method is best overall; each one has strengths and limitations. Combining multiple techniques helps reduce biases, ensuring a more comprehensive assessment of bee populations (Krug and Alves-dos-Santos 2008, Wilson et al. 2008, Klaus et al. 2024). A robust and diverse methodology is essential for accurately assessing bee populations, understanding species ecology, and evaluating conservation efforts (Cane 2001, Cane and Tepedino 2001).

Despite their vital role in ecosystem functioning and crop pollination, most native bees, particularly solitary species, remain poorly documented, with limited information on their abundance, distribution, and population trends (Michener 2007, Danforth et al. 2019). Their small size, solitary habits, cryptic nesting behavior, short activity periods, and specialized floral preferences make them difficult to detect through traditional monitoring approaches (Burkle et al. 2013, Galimberti et al. 2014). Consequently, many regions lack systematic surveys or long-term datasets, leaving major gaps in our understanding of population dynamics and habitat needs (Keller et al. 2015).

Home to over 1000 bee species (Scott et al. personal communication 2025), Colorado hosts an exceptionally rich bee fauna shaped by its varied landscapes, from alpine tundra to arid grasslands. The presence of the Rocky Mountains, which divide the state into east and west halves, creates distinct ecological regions that influence bee distribution and diversity. This geographic and climatic variability makes Colorado a prime setting for studying how different sampling techniques perform across diverse habitats. This study aims to provide essential insights into optimizing methodologies for bee monitoring, improving the accuracy of population and diversity assessments, and guiding conservation strategies in similarly complex ecosystems.

Our study provides the first comprehensive assessment of bee communities across diverse habitats on public lands in western Colorado, a region recognized for its high, yet underexplored pollinator diversity. Despite being a hotspot for native bees, invertebrates only recently became legally considered wildlife in Colorado in 2024 (74th General Assembly Regular Session House Bill 24-1117 [Colorado 2024]; https://leg.colorado.gov/sites/default/files/2024a_1117_signed.pdf), and many bee species require more information to assess their population status for conservation (Brodhead et al. 2023, Colorado Parks and Wildlife 2025). Information needs include habitats present, estimated populations, resources utilized, and more. Addressing these critical knowledge gaps through standardized sampling, repeated monitoring, and community science engagement is essential for detecting potential declines, guiding effective conservation strategies, and ensuring the long-term persistence of these ecologically vital but understudied pollinators (Richardson et al. 2019, XSIC 2020). Here we focus on 3 key objectives: (1) documenting bee diversity, including conservation-sensitive species such as the western bumble bee (*Bombus occidentalis* Greene, 1858); (2) evaluating and comparing different collection methods to optimize pollinator sampling and minimize biases; and (3) documenting pollinator–flower associations by linking specimens caught by targeted netting to the plant on which we collected it. This multifaceted approach enhances our understanding of bee diversity and sets a baseline for tracking changes in bee communities, detecting population declines, and ensuring the long-term sustainability of pollination services essential for biodiversity and food security (Cane and Tepedino 2001).

Methods

Study Area

We conducted our study on 64 unique plots across lands managed by the U.S. Bureau of Land Management (BLM) in Colorado. We visited plots once each from 3 June to 21 August 2024 (Fig. 1). We selected sampling sites in collaboration with BLM staff to ensure they represented ecosystems of interest, afforded accessibility, aligned with management priorities, and contained floral blooms. Sites included the Northwest, Southwest, Rocky Mountain, and Upper Colorado River BLM districts of Colorado. Each transect measured 50 m^2 with minor modification in shape as needed to accommodate local landscape features, making sure to include blooming vegetation. We sampled primarily between 12:00 and 14:00 to target periods of peak pollinator activity (Pyke et al. 2011), and under favorable weather conditions (temperatures above 15 °C, low wind, and no rain). Colorado's diverse elevation, exposure, and water availability contribute to varied habitats, which affect flora and associated invertebrate populations. To categorize habitats, technicians used a flow chart developed by the Colorado Natural Heritage Foundation using dominant vegetation types (Decker 2020). We simplified these results into 6 broader categories: alpine, forest-woodland, shrublands, grasslands, woodland-savanna, and barren. We utilized definitions for the 2 woodland categories as seen in Decker (2020): forest-woodland habitat (n = 6) as significant tree cover by conifer and/or aspen, and woodland-savanna habitat (n = 11) as having open or scattered tree cover and dominated by other deciduous, pine, pinyon, or juniper trees. These 2 habitats combined account for roughly 27% of sites surveyed, as compared to approximately 35% of public land managed by the BLM in Colorado that the bureau considers deciduous, evergreen, or mixed forest. Shrubland covers over 60% of BLM lands in Colorado and represents an important economic interest for both rangeland and recreation (USDI BLM 2025). Thus, this habitat type composed approximately half of all sites sampled (48%, n = 31). The representation of each habitat type was not exact; grassland habitat was overrepresented (17%, n = 11) compared to BLM designation (3%), and "alpine" was not a category in the latest Public Land Statistics report (USDI BLM 2025). We used these categories to contextualize pollinator diversity, abundance, and collection method performance as we believed they best fit the locations observed. Due to the limited number of "barren" habitat sites (n = 2), these were omitted from habitat comparisons.

Invertebrate Sampling

Each collection site included two 50-m^2 sampling transects (n = 64) spaced a minimum of 200 m apart. To investigate sampling biases, our collection methods combined passive trapping and active collection techniques to capture a wide range of pollinators. Passive methods included blue vane traps and pan traps. We painted the basins of blue vane traps with fluorescent yellow paint (Rustoleum®) to target bees and filled them with a mixture of tap water and dish

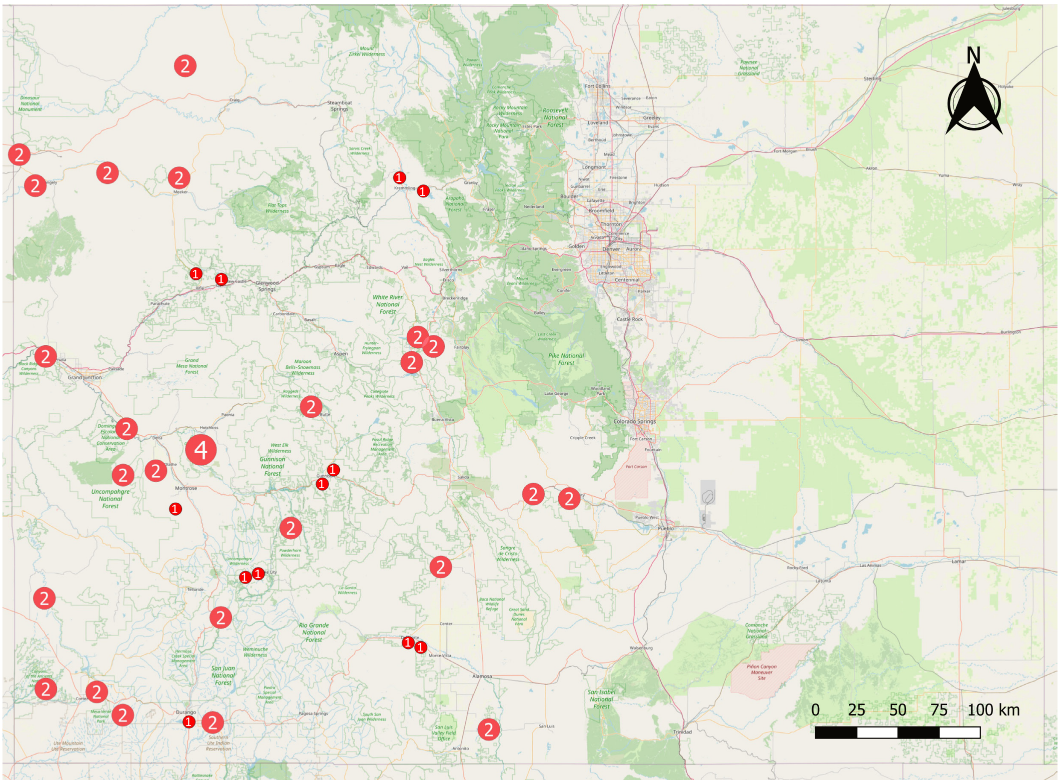

Fig. 1. 2024 Bee collection transects ($n = 64$) across a map of Colorado, USA. Numbers correspond to the number of transects at each location. Map data © OpenStreetMap Contributions (2025) [QGIS 3.38.3; QGIS Development Team 2025].

soap. We suspended these traps no more than 1 m aboveground using a metal post, with 2 traps placed randomly at each site. We used plastic pan traps approximately 15 cm in diameter with a depth of 5 cm (Highmark® Plastic Bowls) colored white, yellow, blue, and red to attract visually oriented flying insects. We deployed 8 pan traps (2 of each color) at ground level within a 1-m radius of the vane traps and filled them with the same soapy water solution. Distance between individual pan traps varied based on terrain to ensure contents were level but did not exceed 1 m. We set out all traps before 12:00 and retrieved them after a minimum of 4 hours. We poured trap contents through a 1000-micron strainer or smaller as needed to collect specimens.

Active collection methods included targeted, sweep, and aerial netting. Targeted netting focused on capturing pollinators actively visiting flowers so that we could establish plant–pollinator relationships. We performed this method for 2 person-hours daily, divided between 2 field technicians in two 30-min sessions: once during trap setup and again at trap retrieval.

We conducted sweep netting along standardized transects, 50 m in length, using 30-cm muslin nets. Technicians sampled transects at a consistent pace for 30 min per transect. Aerial netting involved sweeping the air column above vegetation to capture flying insects not easily caught by standard sweep netting along plant surfaces. We conducted aerial netting along the same transects, staggered to avoid conflict with sweep netting, for a fixed duration of 30 min per transect using 30-cm mesh nets with approximately 24 × 20 holes per square inch. While less commonly employed in bee sampling, aerial netting complements sweep netting by capturing bees in flight, particularly those between forb and arboreal vegetation layers.

We conducted both sweep and aerial netting daily between 10:00 and 17:00 (but primarily between 12:00 and 14:00) and immediately after trap installation to standardize sampling effort across all sites and habitats. We took special care to avoid damaging sensitive vegetation and equipment during collection; sweep nets did not contact cacti.

We included opportunistically collected "miscellaneous" bees near established transects not obtained through standardized methods to provide a more complete picture of site diversity. However, we excluded "miscellaneous" bees from comparisons of sampling methodologies to maintain consistency in the data analysis. Although our methods targeted midday-active species, they may have excluded taxa active during dawn or dusk (Roulston et al. 2007).

Preparation and Identification

We preserved all collected specimens for identification. We stunned and euthanized insects using laboratory-grade ethyl acetate or acetone in airtight containers and stored them on ice in the field before freezing them immediately upon returning from the field and within 12 hours of collection. We pinned and stored larger specimens in Cornell drawers and preserved smaller or soft-bodied specimens in ≥90% ethanol or 70% isopropanol for long-term storage. We identified specimens to genus using standard taxonomic resources, a complete list of which we provide in Supplementary Material 1. We elected not to identify specimens to species level unless genera were (1) largely resolved with accessible keys; (2) morphologically distinct enough for high confidence in identification by nonexperts; or (3) immediately relevant to conservation concern (e.g., *Bombus* spp.). To confirm identification to genus or species level for specimens of interest, we consulted Virginia Scott at the University of Colorado Museum of Natural History. Dr. Lisa Overall provided identification training for staff, additional keys, and reference collections. We used specimens identified by Ms. Scott and Dr. Overall as a reference collection for further identification. At the time of this report, all specimens are stored at Butterfly Pavilion offices, with plans for long-term storage at the C.P. Gillette Museum of Arthropod Diversity at Colorado State University.

We identified flowers associated with pollinators collected by target netting using photographs taken during collection. Images captured the bloom, leaves, and stalk of the plant. While we could only identify some plants to family level due to image quality, we identified most using field guides and dichotomous keys listed in Supplementary Material 1. We also consulted with Butterfly Pavilion in-house horticultural staff member Ashley White to confirm identifications made via photos. We did not collect any plant specimens.

We limited set trap duration and frequency to mitigate potential risks to populations. While we primarily collected bees, researchers have not evaluated the potential for population decline due to lethal sampling in other pollinators like butterflies, flies, and beetles (McCravy 2018). Performing short, infrequent sampling and removing blue vane traps after several hours, as opposed to days or even weeks in some studies, likely reduces the risk of oversampling and negatively impacting populations (Prendergast et al. 2020). We made the complete dataset, including observed floral hosts, accessible online at Ecdysis.org as a public database titled "Bees of Western Colorado: 2024 Survey by Butterfly Pavilion" (public access dataset ID: 41; https://ecdysis.org/collections/datasets/public.php?datasetid=41).

Data Analysis

To analyze pollinator diversity and abundance, we present the Shannon diversity, Simpson diversity, Simpson evenness, and McIntosh evenness indices calculated for each sampling plot at genus level using Species Diversity and Richness software (Seaby and Henderson 2006, version 4.1.2, PISCES Conservation Ltd.). We present these multiple, commonly used indices for ease of comparison to other studies and to provide a more complete understanding of bee communities, given the differences between each index. To compare collection methods, we conducted randomization tests using methods described by Solow (1993) based on 10,000 random partitions of the data. We tested data for normal distribution using the Shapiro–Wilk test. To evaluate different habitats, we conducted Kruskal–Wallis and Dunn's pairwise tests of indices means using the '*stats*' package in R (R Core Team 2024), ensuring that the data conformed to the assumptions of each test. We also used the '*stats*' package to conduct Pearson correlation analyses and linear regressions. We used the packages '*ggplot2*' (Wickham 2016) and '*ggpubr*' (Kassambara 2025) for data visualization (version 2024.4.2 .764, R version 4.4.1). We used a significance threshold of $\alpha = 0.05$ for all tests.

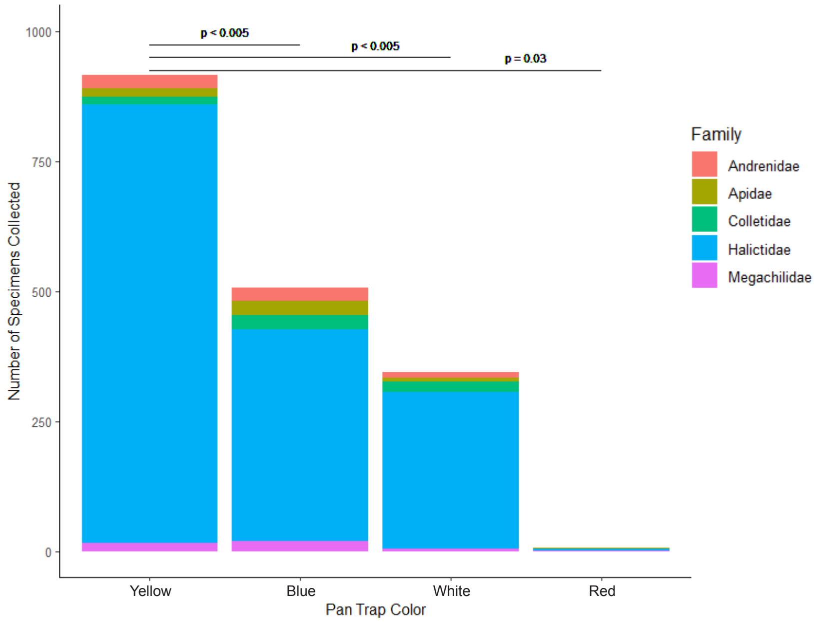

Fig. 2. Total collections of bees (n = 1776) by family at differently colored pan traps in Colorado, USA, in 2024. Bars indicate significant pairwise post hoc Dunn's test adjusted P values using Bonferroni corrections. Insignificant comparisons were omitted for clarity.

RESULTS

Sampled Bee Diversity

We identified 4872 bees representing 39 genera (note that *Pseudopanurgus* and *Protandrena* are currently undergoing taxonomic revisions). We collected specimens from each of the 5 families of bees found in Colorado west of the Rocky Mountains: Andrenidae (193 bees, 7 genera), Apidae (951 bees, 13 genera), Colletidae (196 bees, 2 genera), Halictidae (3203 bees, 7 genera), and Megachilidae (329 bees, 10 genera).

Two genera of small sweat bees (Halictidae) together made up over half of all specimens: *Halictus* (1700 bees, 35%) and *Lasioglossum* (1251 bees, 26%), followed by *Melissodes* (486 bees, 10%), *Bombus* (218 bees, 4.6%), and *Agapostemon* (221 bees, 4.5%). Within Megachilidae, *Osmia* was the most abundant (84 bees). In family Colletidae, we collected *Colletes* (104 bees) and *Hylaeus* (92 bees) in similar abundance. *Perdita* (145 bees) was the most common of the andrenids. We found only 33 honey bees (*Apis mellifera* Linnaeus, 1758) at 7 sites over the course of this survey, composing <1% of the specimens collected.

Most bees collected belong to genera known to exhibit ground-nesting behaviors, making up approximately 90% of our collected specimens. Roughly 11% of bees belong to genera known to exhibit cavity-nesting, with overlap between nesting types within genera. Eight genera we found contained kleptoparasites (Scott et al. 2011). Thirty-six genera we observed contained solitary species, including kleptoparasites. Social bees consisted of *Bombus* spp. and *Apis mellifera*, with future identification of social *Halictus* and *Lasioglossum* species likely.

We focused on 4 bee species of conservation concern, given their documented declines in the western United States. We captured 6 *Bombus occidentalis* using a combination of target netting, vane traps, aerial netting, sweep netting, and miscellaneous methods. Similarly, we collected 6 *B. pensylvanicus* (De Geer, 1773), mostly with vane traps and a single individual via target netting. We found a single *B. morrisoni* (Cresson, 1878) using a vane trap. Notably, we observed no *B. suckleyi*.

Comparison of Collection Methods

The total number of specimens collected varied significantly by collection method ($\chi^2_{\text{Kruskal–Wallis}} = 52.15$, df = 7, $P < 0.01$). Vane traps caught the most bees (n = 1235) and 24 of 39 genera, followed by targeted netting (n = 1147),

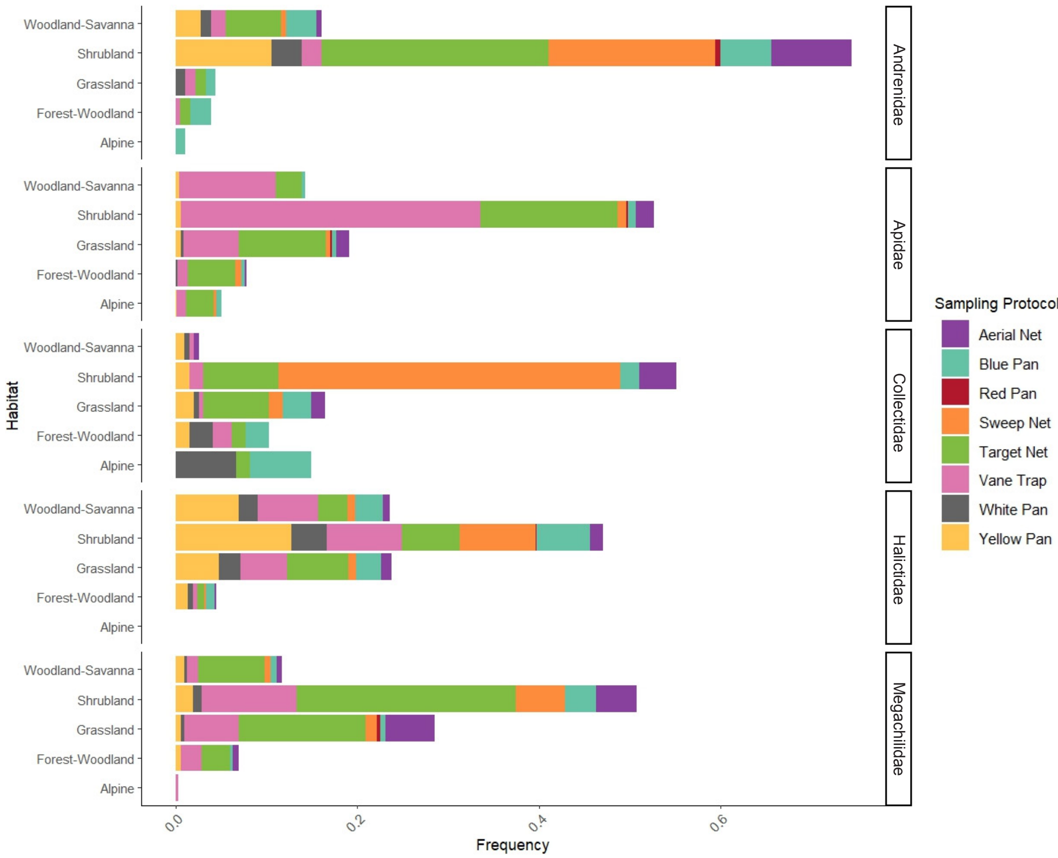

Fig. 3. Frequency (%) of bee specimens collected by trap type and family across habitats in Colorado, USA, in 2024. Total sample sizes for each sampling method include aerial netting (n = 215), sweep net (n = 478), target net (n = 1147), blue vane traps (n = 1235), yellow pan (n = 916), white pan (n = 345), blue pan (n = 507), and red pan (n = 8). Total sample sizes for each bee family are the following: Andrenidae (n = 192), Apidae (n = 944), Colletidae (n = 195), Halictidae (n = 3192), and Megachilidae (n = 328).

which garnered 36 genera. Aerial and sweep netting each yielded 21 genera (n = 215 and n = 478 individuals, respectively). Pan traps collectively caught 1776 bees across 30 genera, with significant variation in abundance between colors ($\chi^2_{\text{Kruskal–Wallis}} = 18.5$, df = 3, $P < 0.005$) (Figs. 2, 3, Supplementary Material 2). Yellow pan traps collected the greatest number of bees (n = 916), followed by blue (n = 507) and white (n = 345); we caught only 8 bees in red pan traps (Fig. 2). The yellow pan traps collected primarily sweat bees, with 92% belonging to the family Halictidae. Apidae comprised 40% of collections by blue vane traps, including 75% of all *Melissodes* individuals and 18% of all *Bombus* individuals (Fig. 3).

Pairwise randomization testing revealed that blue vane traps outperformed pan traps of all colors in terms of diversity found (Supplementary Material 2). The yellow pan traps yielded lower diversity compared to other pan traps, despite higher overall abundance. Among active netting methods, targeted netting samples were more diverse than sweep netting samples, using both Shannon ($|\Delta| = 0.81$, $P < 0.001$) and Simpson ($|\Delta| = 4.4$, $P < 0.001$) indices, but not more diverse than aerial netting with either Shannon ($|\Delta| = 0.16$, $P = 0.13$) or Simpson ($|\Delta| = 1$, $P = 0.28$) indices (Supplementary Material 2). Target and aerial netting yielded higher diversity than passive collection methods (Fig. 4).

Habitat Differences

Total abundance of bees did not vary significantly by habitat type ($\chi^2_{\text{Kruskal–Wallis}} = 4.58$, df = 4, $P = 0.33$). However, diversity scores by

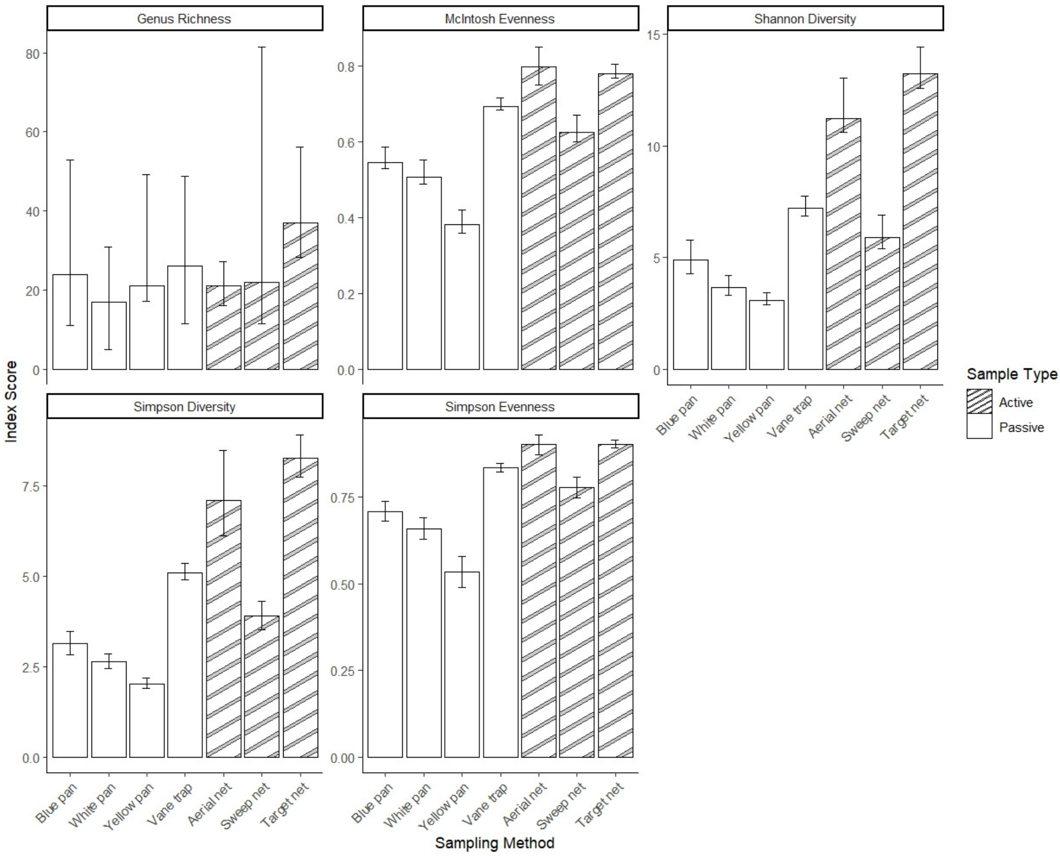

Fig. 4. Abundance, diversity, and evenness indices of bee genera by collection method used for surveys across western Colorado, USA, in 2024. Error bars represent standard error.

habitat varied significantly using both Shannon ($\chi^2_{\text{Kruskal–Wallis}} = 11.97$, df = 4, P = 0.018) and Simpson ($\chi^2_{\text{Kruskal–Wallis}} = 12.08$, df = 4, P = 0.017) indices. Simpson evenness scores did not vary significantly across habitats ($\chi^2_{\text{Kruskal–Wallis}} = 0.79$, df = 4, $P = 0.94$), nor did McIntosh evenness ($\chi^2_{\text{Kruskal–Wallis}} = 7.82$, df = 4, $P > 0.09$). Shrubland habitats demonstrated the greatest bee diversity, followed by forest-woodland. Alpine habitat was the least diverse (Fig. 5). Across all locations, bee genus diversity was inversely correlated to altitude for both the Shannon ($t = -4.4$, $r = -0.48$, df = 63, $P < 0.001$) and Simpson ($t = -3.55$, $r = -0.41$, df = 63, $P < 0.001$) indices (Supplementary Material 3). This remains true for Shannon diversity when looking at shrubland alone ($t = -2.81$, $r = -0.46$, df = 30, $P < 0.01$), suggesting that elevation plays an important role in biodiversity of similar habitats in western Colorado.

We found *Hoplitis* and *Halictus* across all habitat types and found *Bombus* and *Hylaeus* in all but barren habitats. Despite their general high abundance, *Lasioglossum* bees were notably absent in alpine habitats. We collected 5 out of 6 *B. occidentalis* at elevations above 2730 m, as well as 5 of 6 *B. pensylvanicus* specimens and a single *B. morrisoni* at elevations above 2100 m.

Associated Flower Taxa

Approximately 23% of collected specimens (n = 1131) provided associated flower data. Of 26 plant families identified, we collected most bees from Asteraceae (n = 418), followed by Fabaceae (n = 263). The 5 plant families with the greatest number of bees collected—Asteraceae, Fabaceae, Plantaginaceae, Malvaceae, and Brassicaceae—together account for 79% of observations (n = 896). We found Brassicaceae, Boraginaceae, Malvaceae, Asteraceae, and Polemoniaceae with the greatest diversity of bees

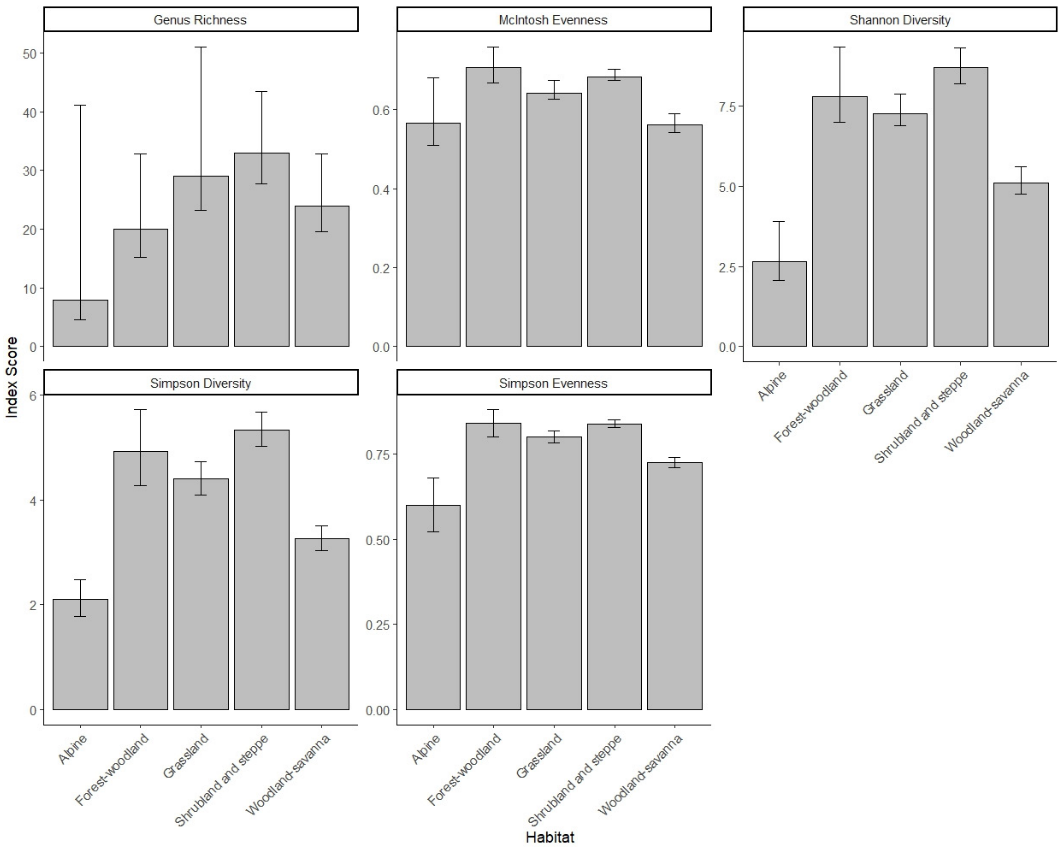

Fig. 5. Abundance, diversity, and evenness indices of bee genera across habitats surveyed in Colorado, USA, in 2024. Total number of sites include alpine (n = 3), forest-woodland (n = 6), grassland (n = 11), shrubland (n = 31), and woodland-savanna (n = 11). Kruskal–Wallis testing and post hoc pairwise Wilcoxon tests were used to compare habitat means. We found no significant differences after Bonferroni correction of P values. Error bars show the 95% confidence interval.

(Supplementary Material 4). We found all 5 bee families on yellow sweet clover (*Melilotus officinalis* [L.] Lam.) (n = 244), scarlet globemallow (*Sphaeralcea coccinea* [Nutt.] Rydb.) (n = 73), and thistles in the genus *Cirsium* (n = 44).

Bombus (n = 97), *Lasioglossum* (n = 68), and *Halictus* (n = 61) represented the most frequent visitors to flowers in the family Asteraceae. Thistles (*Carduus* sp., n = 35; *Cirsium* sp., n = 44), daisy-like forbs (*Tetraneuris* sp., n = 32; *Heterotheca* sp., n = 47; *Erigeron* sp., n = 49), and rabbitbush (*Ericameria* sp., n = 41) constituted the most observed groups in this plant family.

Yellow sweet clover dominated Fabaceae observations (n = 243). The introduced *M. officinalis* commonly occurs in the western part of the state, and we found flowers at 11 sites across 9 different counties. We observed 17 different bee genera on yellow sweet clover, most commonly *Lasioglossum* (n = 104), *Halictus* (n = 43), *Agapostemon* (n = 20), and *Melissodes* (n = 19). *Melilotus* was 1 of only 4 plant genera on which we observed *Apis mellifera* (n = 10). Others included *Convolvulus* (Convolvulaceae, n = 12), *Centaurea* (Asteraceae, n = 5), and *Cirsium* (Asteraceae, n = 1).

Within Malvaceae, we found only scarlet globemallow, which occurred with 11 different bee genera, including *Perdita beatula* Timberlake, 1960 (n = 19). Other common bee genera at this flower included *Diadasia* (n = 21) and *Melissodes* (n = 11).

We found a single *Bombus occidentalis* specimen on toadflax (Plantaginaceae: *Linaria* sp.) and 3 others in association with various Asteraceae. We collected a single *B. pensylvanicus* on locoweed (Fabaceae: *Oxytropis* sp.). We collected the majority of target-net *Bombus*

(65%, $n = 91$) on Asteraceae, followed by Plantaginaceae (15%, $n = 21$), largely on *Penstemon* spp. (11%, $n = 15$).

Discussion

Documenting Bee Diversity

Among the 4872 bees identified to genus, many require further work to identify to the species level, especially those within genera such as *Lasioglossum*, which contains over 200 species in the western United States alone (Carril and Wilson 2023). We will likely find a more complex pollinator network relationship as identification reveals additional species.

The western United States represents a biodiversity hotspot for bees, with Colorado supporting over 1000 species (Scott V. personal communication 2025), which is around 25% of all species identified in the United States (Michener 2007, Scott et al. 2011). In this study, our samples accounted for more than half of the 66 bee genera known in Colorado (Scott et al. 2011). Although Apidae is the most diverse bee family in Colorado, with 289 species reported statewide (Scott et al. 2011), it was not the most common family in our samples. Instead, Halictidae, which includes at least 139 known species in Colorado (Scott et al. 2011), was more frequently represented among our collected specimens.

Several kleptoparasitic and solitary species account for some of the diversity within western Apidae (Scott et al. 2011, XSIC 2018). Many Apidae kleptoparasites target nonhalictid hosts, potentially making them more difficult to observe when sampling in small areas dominated by halictid aggregations. In addition, we conducted sampling only during June through August due to logistical constraints related to study timing, budget, and staff availability. While this period (June to August) generally coincides with peak pollinator activity (Colorado State University Extension [no date]), we acknowledge that we may have missed some species that are active earlier or later in the season. We expect that the mid- to late-season sampling at least partially explains the high number of Halictidae and that numbers may underrepresent the presence of parasitic and other solitary bees (Goldstein and Scott 2015). We recommend further study to examine diversity measures across the entire field season in understudied areas of western Colorado.

Significant variation within diversity indices across habitats suggests that the sampled ecosystems provide dissimilar resources for bees, resulting in unique community compositions. Shrublands make up most public lands in western Colorado (USDI BLM 2025), and we therefore disproportionately sampled them in this survey compared to other habitat types. To better understand the differences in bee diversity among western Colorado habitats, we recommend increasing the number of sites sampled across nonshrubland habitat types. Other studies in heterogeneous landscapes found similar results, (i.e., where diversity often varies significantly across habitats) (Carril et al. 2018, Escobedo-Kenefic et al. 2020, Twerd and Sobieraj-Betlińska 2020, Diacon-Bolli et al. 2012). Declines in bee diversity and richness as elevation increases followed documented trends in North America and worldwide as pollinator communities shift toward greater numbers of Diptera at higher altitudes, likely due to their greater cold tolerance and ability to remain active under cooler, windier conditions (Dillon and Frazier 2006, McCabe and Cobb 2021).

Comparing Collection Methods

We employed multiple methods to ensure comprehensive data collection and compensate for sampling biases, enabling us to identify patterns in bee diversity and abundance. Our findings align with existing literature describing variation in effectiveness for different methods, such as pan traps, transect walks, sweep netting, and other traps (Westphal et al. 2008, Prendergast et al. 2020). For instance, pan traps often underrepresent large-bodied bees, whereas targeted netting favors conspicuous floral visitors (Roulston et al. 2007, Westphal et al. 2008, Prendergast et al. 2020). We found that blue vane traps functioned as the single most effective method of capturing specimens for abundance and the best passive method for measuring diversity. Blue vane traps were particularly effective for Apidae. Other researchers obtained similar findings (Prendergast et al. 2020, Tronstad et al. 2022). However, vane traps may require a larger number of samples to detect changes in species richness because of their bias toward larger, visually oriented bees like Apidae while undersampling smaller or less visually responsive taxa (Wilson et al. 2008). Stationary traps may also miss species active near the ground, in dense vegetation, or outside peak activity times (Roulston et al. 2007). Increasing sample numbers improves the likelihood of detecting rare species and provides a more representative view of the bee community (Westphal et al. 2008).

Pan traps showed clear color-specific differences, with yellow pans being especially effective at capturing Halictidae. Despite their high abundance numbers, yellow pan traps yielded the lowest diversity and evenness indices. This result contrasts with earlier studies suggesting that yellow traps attract a wide range of bee species by mimicking floral cues (Leong and Thorp 1999), and instead supports recent discussions that pan traps, particularly yellow ones, tend to attract a large number of halictids in bee diversity studies (Portman et al. 2020).

Red pan traps collected only 7 bees, likely because bees' photoreceptors lack discrimination for red wavelengths (Chittka and Menzel 1992). Future research should explore additional trap colors, such as pink and violet, and the use of UV in diurnal insect collection methodologies. Based on preferences observed in other studies, there may be potential to further enhance species capture or target specific taxa using trap color (Moreira et al. 2016). Overall, pan traps are widely used for bee monitoring but have significant limitations such as their bias toward certain bee families and inability to accurately detect changes in abundance or diversity. To improve bee monitoring and better detect population declines, it is important to test alternative approaches that reduce sampling bias (Gollan et al. 2011, Prendergast et al. 2020).

Targeted netting proved particularly effective, yielding the greatest diversity and complementing traps by sampling taxa not represented in passive methods. Sweep netting demonstrated effectiveness for capturing Colletidae that we may have otherwise missed or undercounted in shrubland habitat. Active methods like these can prove effective; however, they require skilled collectors and are labor intensive.

This study highlights the importance of using multiple complementary methods (blue vane traps, 4 colors of pan traps, and 3 active methods: targeted, sweep, and aerial netting) to capture representative data on pollinator diversity and abundance, as no single method detected all 39 genera. Our results align with regional surveys, including pan traps in Utah's West Desert (27 genera) (Toler et al. 2005); targeted netting in Albany County, Wyoming (40 genera) (Tepedino and Stanton 1981), and sagebrush-dominated shrubland habitats in Mesa County, Colorado (34 genera) (Thapa-Magar et al. 2023); and combined pan traps and targeted netting in Boulder County, Colorado (39 genera) (Kearns and Oliveras 2009). Sampling methods vary in efficiency and the taxa they detect. For instance, pan traps often underrepresent large-bodied bees, whereas targeted netting favors conspicuous floral visitors (Roulston et al. 2007, Westphal et al. 2008, Prendergast et al. 2020). No single method captures the full community, so combining active and passive approaches is essential to reduce bias, strengthen ecological inferences, and provide a robust assessment of pollinator diversity and abundance (Wilson et al. 2008, Prendergast et al. 2020).

Implications for Monitoring Sensitive Species

Our findings of species of conservation concern such as the western bumble bee (*B. occidentalis*), American bumble bee (*B. pensylvanicus*), and Morrison's bumble bee (*B. morrisoni*) contribute valuable new data that contributes to our understanding of the bees' distribution, ecology, and conservation status.

Monitoring sensitive bumble bee species in Colorado such as *B. occidentalis, B. pensylvanicus*, *B. morrisoni*, and *B. suckleyi* is critical given their rapid population declines over recent decades, largely attributed to habitat loss and pathogen spillover, especially from *Nosema* parasites (Colla et al. 2006, Cameron et al. 2011). The IUCN lists these species as vulnerable (Koch et al. 2015, MacPhail 2019, IUCN 2025), and the Bureau of Land Management lists them as species of conservation concern (Brodhead et al. 2023). Our findings, including observations of *B. occidentalis* at high elevations (2700–3350 m) suggest that these habitats may serve as refuges or support potential remnant populations. Given the kleptoparasitic relationship of *B. suckleyi* with *B. occidentalis*, declines in host populations likely impact parasite persistence (Dolan personal communication 2025). Due to the potential negative impact of passive trapping methods such as blue vane traps on vulnerable species and their limitations (taxonomic bias, oversampling, etc.) in accurately reflecting population trends, we recommend noninvasive targeted approaches such as timed visual surveys, nest searches, and floral resource sampling for broader and effective monitoring in the future (Prendergast et al. 2020, Colla et al. 2006).

Nonlethal monitoring methods generally prove more feasible for bumble bees, whose larger size, conspicuous coloration, and social behavior facilitate detection (Goulson 2010). In contrast, solitary bees, which represent most native bee diversity, pose greater monitoring challenges due to their small size, cryptic nesting habits, brief activity periods, and specialized floral associations (Michener 2007, Danforth et al. 2019). Records of purportedly abundant bees such as some species of *Perdita* remain limited in southwestern Colorado, highlighting the underexplored pollinator diversity of this region. The scarcity of data on solitary bee population trends and habitat requirements, despite their critical ecological roles, calls for focused studies employing both traditional surveys, population density studies, and emerging molecular techniques like DNA metabarcoding and network analyses (Burkle et al. 2013, Galimberti et al. 2014, Keller et al. 2015). Community science initiatives, exemplified by the Bumble Bee Atlas, provide important frameworks to expand data collection, improve species detection, and engage the public and should be adapted to better include solitary taxa to inform comprehensive conservation strategies (Richardson et al. 2019, XSIC 2020).

Floral Resources

Flowering community turnover rates vary by habitat, and species may rarely bloom reliably at the same time every year, especially in extreme environments (Wright et al. 2015). These data provide a snapshot of mid- to late-season bee activity with associated flowers for comparison with future studies or historical records, providing data to support land management practices and monitoring.

Visitation by all 5 observed families of bees supports existing literature identifying *Melilotus* and *Cirsium* flowers as highly utilized resources in shrubland habitats despite their nonnative status (Thapa-Magar et al. 2023). These plants play a significant role in sustaining bee populations; however, such frequent visitation may also enhance the reproductive success of invasive plants, potentially facilitating their spread and altering native plant–pollinator interactions (Stout and Tiedeken 2017, Bueno et al. 2023).

Bees often visited yellow sweet clover (*M. officinalis*) and scarlet globemallow (*S. coccinea*) in our study. These plants represent important livestock forage. They flower as late as October (Tollefson 2006, Gucker 2009) and provide important pollen and nectar resources in midsummer and in disturbed areas with few other flowers in bloom (Tepedino et al. 2008). Many thistles may also bloom into early fall, and control efforts directed at *Melilotus* and *Cirsium* should carefully regard availability of other forbs blooming during mid- to late-season to best support pollinator populations.

Conclusions

Our findings highlight the critical role of targeted netting, combined with additional methods, to best assess bee diversity and reduce taxonomic biases. This study provides one of the first comprehensive inventories of bee species and their floral associations on public lands in western Colorado, establishing a valuable baseline for monitoring changes, detecting population declines of critical pollinators, and supporting long-term biodiversity conservation. While social bumble bees are relatively easy to detect in the field, most solitary bees remain underrepresented because of their small size and cryptic behavior, leading to substantial knowledge gaps. To address these gaps, sampling efforts should explicitly target solitary bees to generate representative data, which in turn would strengthen conservation strategies for the full diversity of native pollinators.

SUPPLEMENTARY MATERIAL

Five online-only supplementary files accompany this article (https://scholarsarchive.byu.edu/wnan/vol86/iss2/5).

SUPPLEMENTARY MATERIAL 1. List of keys used to identify specimens collected from western Colorado, 2024.

SUPPLEMENTARY MATERIAL 2. Results of a pairwise randomization test described by Solow (1993) using 10,000 partitions to compare diversity indices of collection methods.

SUPPLEMENTARY MATERIAL 3. Bee genera diversity index scores (Simpson and Shannon diversity indices) across 64 sites in Colorado, USA, by elevation.

SUPPLEMENTARY MATERIAL 4. Abundance, diversity, and evenness of bee families by associated flower family at time of collection in Colorado, USA, 2024.

SUPPLEMENTARY MATERIAL 5. List of taxa collected in western Colorado, 2024, presented to the lowest level identified with accompanying habitat and floral genus. This list is available by request to the corresponding author.

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Literature Cited

Brodhead, K., C. Dawson, T. Fresques, P. Krening, and R. Sell. 2023. BLM Colorado Sensitive Species List. Colorado State Office, Bureau of Land Management, U.S. Department of the Interior. https://www.blm.gov/sites/default/files/docs/2023-09/BLM%20CO%20Sensitive%20Species%20List_2023.pdf

Bueno, F.G.B., L. Kendall, D.A. Alves, M.L. Tamara, T. Heard, T. Latty, and R. Gloag. 2023. Stingless bee floral visitation in the global tropics and subtropics. Global Ecology and Conservation 43:e02454.

Burkle, L.A., J.C. Marlin, and T.M. Knight. 2013. Plant–pollinator interactions over 120 years: loss of species, co-occurrence, and function. Science 339: 1611–1615.

Cameron, S.A., J.D. Lozier, J.P. Strange, J.B. Koch, N. Cordes, L.F. Solter, and T.L. Griswold. 2011. Patterns of widespread decline in North American bumble bees. Proceedings of the National Academy of Sciences 108:662–667.

Cane, J.H. 2001. Habitat fragmentation and native bees: a premature verdict? Conservation Ecology 5:3.

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.

Cardoso, P., P.A.V. Borges, K.A. Triantis, M.A. Ferrández, and J.L. Martín. 2011. Adapting the IUCN Red List criteria for invertebrates. Biological Conservation 144:2432–2440.

Carril, O.M., T. Griswold, J. Haefner, and J.S. Wilson. 2018. Wild bees of Grand Staircase–Escalante National Monument: richness, abundance, and spatio-temporal beta-diversity. PeerJ 6:e5867.

Carril, O.M., and J.S. Wilson. 2023. Common bees of western North America. Princeton University Press, Princeton, NJ. 416 pp.

Chittka, L., and R. Menzel. 1992. The evolutionary adaptation of flower colors and the insect pollinators' color vision. Journal of Comparative Physiology A 171:171–181.

Colla, S.R., M.C. Otterstatter, R.J. Gegear, and J.D. Thomson. 2006. Plight of the bumble bee: pathogen spillover from commercial to wild populations. Biological Conservation 129:461–467.

Colorado Parks and Wildlife. 2025. Colorado's 2025 State Wildlife Action Plan invertebrates rankings dashboard. https://lookerstudio.google.com/embed/reporting/590a929e-cd66-4d95-9fc4-3bdac550f416/page/p_xwfesf15sd

Colorado State University Extension. No date. Native bee watch. Colorado State University. [Accessed October 2025]. https://arapahoe.extension.colostate.edu/nbw/

Danforth, B.N., R.L. Minckley, and J.L. Neff. 2019. The solitary bees: biology, evolution, conservation. Princeton University Press, Princeton, NJ. 488 pp.

Decker, K. 2020. Ecological systems of Colorado. Colorado Natural Heritage Program. https://cnhp.colostate.edu/projects/ecological-systems-of-colorado/

Diacon-Bolli, J., T. Dalang, R. Holderegger, and M. Bürgi. 2012. Heterogeneity fosters biodiversity: linking history and ecology of dry calcareous grasslands. Basic and Applied Ecology 13:641–653.

Dillon, M.E., and M.R. Frazier. 2006. *Drosophila melanogaster* locomotion in cold thin air. Journal of Experimental Biology 209:364–371.

Eisenhauer, N., and J. Hines. 2021. Invertebrate biodiversity and conservation. Current Biology 31:R1214–R1218.

Escobedo-Kenefic, N., P. Landaverde-González, P. Theodorou, E. Cardona, M.J. Dardón, O. Martínez, and C.A. Domínguez. 2020. Disentangling the effects of local resources, landscape heterogeneity and climatic seasonality on bee diversity and plant–pollinator networks in tropical highlands. Oecologia 194:333–344.

Galimberti, A., F. De Mattia, I. Bruni, D. Scaccabarozzi, A. Sandionigi, M. Barbuto, M. Casiraghi, and M. Labra. 2014. A DNA barcoding approach to characterize pollen collected by honeybees. PLOS ONE 9:e109363.

Goldstein, P.Z., and V.L. Scott. 2015. Taxonomic and behavioral components of faunal comparisons over time: the bees (Hymenoptera: Anthophila) of Boulder County, Colorado, past and present. Proceedings of the Entomological Society of Washington 117: 290–346.

Gollan, J.R., M.B. Ashcroft, and M. Batley. 2011. Comparison of yellow and white pan traps in surveys of bee fauna in New South Wales, Australia (Hymenoptera: Apoidea: Anthophila). Australian Journal of Entomology 50:174–178.

Goulson, D. 2010. Bumblebees: behaviour, ecology, and conservation. Oxford University Press, Oxford, England. 336 pp.

Goulson, D., E. Nicholls, C. Botías, and E.L. Rotheray. 2015. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. Science 347:1255957.

Gucker, C.L. 2009. *Melilotus alba*, *M. officinalis*. Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. https://www.fs.usda.gov/database/feis/plants/forb/melspp/all.html

[IUCN] INTERNATIONAL UNION FOR CONSERVATION OF NATURE. 2025. The IUCN Red List of Threatened Species. Version 2025-1. ISSN 2307-8235. https://www.iucnredlist.org

KASSAMBARA, A. 2025. ggpubr: 'ggplot2'-based publication-ready plots. R package version 0.6.1. https://rpkgs.datanovia.com/ggpubr/

KEARNS, C.A., AND D.M. OLIVERAS. 2009. Boulder County bees revisited: a resampling of Boulder Colorado bees a century later. Journal of Insect Conservation 13: 603–613.

KELLER, A., N. DANNER, G. GRIMMER, M. ANKENBRAND, K. VON DER OHE, W. VON DER OHE, S. ROST, S. HÄRTEL, AND I. STEFFAN-DEWENTER. 2015. Evaluating multiplexed next-generation sequencing as a method in palynology for mixed pollen samples. Plant Biology 17:558–566.

KLAUS, F., M. AYASSE, A. CLASSEN, J. DAUBER, T. DIEKÖTTER, J. EVERAARS, F. FORNOFF, H. GREIL, H.P. HENDRIKSMA, T. JÜTTE, ET AL. 2024. Improving wild bee monitoring, sampling methods, and conservation. Basic and Applied Ecology 75:2–11.

KLEIN, A.-M., B.E. VAISSIÈRE, J.H. CANE, I. STEFFAN-DEWENTER, S.A. CUNNINGHAM, C. KREMEN, AND T. TSCHARNTKE. 2007. Importance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society B, Biological Sciences 274:303–313.

KOCH, J., J. LOZIER, J. STRANGE, H. IKERD, T. GRISWOLD, N. CORDES, L. SOLTER, I. STEWART, AND S. CAMERON. 2015. U.S. *Bombus*, a database of contemporary survey data for North American bumble bees (Hymenoptera, Apidae, *Bombus*) distributed in the United States. Biodiversity Data Journal 3:e6833.

KRAHNER, A., A.C. DIETZSCH, T. JÜTTE, J. PISTORIUS, AND J. EVERAARS. 2024. Standardising bee sampling: a systematic review of pan trapping and associated floral surveys. Ecology and Evolution 14:e11157.

KRUG, C., AND I. ALVES-DOS-SANTOS. 2008. O uso de diferentes métodos para amostragem da fauna de abelhas (Hymenoptera: Apoidea), um estudo em floresta ombrófila mista em Santa Catarina. Neotropical Entomology 37:265–278.

LEONG, J.M., AND R.W. THORP. 1999. Colour-coded sampling: the distribution of bees in yellow, blue, and white pan traps. Journal of Insect Conservation 3:241–245.

MACPHAIL, V.J., L.L. RICHARDSON, AND S.R. COLLA. 2019. Incorporating citizen science, museum specimens, and field work into the assessment of extinction risk of the American bumble bee (*Bombus pensylvanicus* De Geer 1773) in Canada. Journal of Insect Conservation 23:597–611.

MAFFEI, C., AND USGS BEE LAB (BIML). 2024. The very handy bee manual. Version 2.0. Zenodo. 74 pp. https://zenodo.org/records/12812755

MCCABE, L.M., AND N.S. COBB. 2021. From bees to flies: global shift in pollinator communities along elevation gradients. Frontiers in Ecology and Evolution 8: 626124.

MCCRAVY, K. 2018. A review of sampling and monitoring methods for beneficial arthropods in agroecosystems. Insects 9:170.

MICHENER, C.D. 2007. The bees of the world. 2nd edition. Johns Hopkins University Press, Baltimore, MD. 992 pp.

MOREIRA, E.F., R.L.D.S. SANTOS, U.L. PENNA, C. ANGEL-COCA, F.F. DE OLIVEIRA, AND B.F. VIANA. 2016. Are pan traps colors complementary to sample community of potential pollinator insects? Journal of Insect Conservation 20:583–596.

NIELSEN, A., I. STEFFAN-DEWENTER, C. WESTPHAL, O. MESSINGER, S.G. POTTS, S.P. ROBERTS, J. SETTELE, H. SZENTGYÖRGYI, B.E. VAISSIÈRE, M. VAITIS, M. WOYCIECHOWSKI, ET AL. 2011. Assessing bee species richness in two Mediterranean communities: importance of habitat type and sampling techniques. Ecological Research 26:969–983.

OLLERTON, J., R. WINFREE, AND S. TARRANT. 2011. How many flowering plants are pollinated by animals? Oikos 120:321–326.

OPENSTREETMAP CONTRIBUTIONS. 2025. OpenStreetMap: provides map data. Cambridge, England. https://www.openstreetmap.org

PORTMAN, Z.M., B. BRUNINGA-SOCOLAR, AND D.P. CARIVEAU. 2020. The state of bee monitoring in the United States: a call to refocus away from bowl traps and towards more effective methods. Annals of the Entomological Society of America 113:337–342.

POTTS, S.G., V. IMPERATRIZ-FONSECA, H.T. NGO, M.A. AIZEN, J.C. BIESMEIJER, T.D. BREEZE, L.V. DICKS, L.A. GARBALDI, R. HILL, J. SETTELE, ET AL. 2016. Safeguarding pollinators and their values to human well-being. Nature 540:220–229.

PRENDERGAST, K.S., M.H.M. MENZ, K.W. DIXON, AND P.W. BATEMAN. 2020. The relative performance of sampling methods for native bees: an empirical test and review of the literature. Ecosphere 11:e03076.

PYKE, G.H., D.W. INOUYE, AND J.D. THOMSON. 2011. Activity and abundance of bumble bees near Crested Butte, Colorado: diel, seasonal, and elevation effects. Ecological Entomology 36:511–521.

QGIS DEVELOPMENT TEAM. 2025. QGIS Geographic Information System: open source geospatial foundation project. Grüt, Switzerland. http://qgis.osgeo.org

R CORE TEAM. 2024. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

RICHARDSON, L.L., M.D. BOWERS, AND R.E. IRWIN. 2019. Citizen scientists documenting pollinator declines. Biological Conservation 238:108217.

ROULSTON, H.T., S.A. SMITH, AND A.L. BREWSTER. 2007. A comparison of pan trap and intensive net sampling techniques for documenting a bee (Hymenoptera: Apiformes) fauna. Journal of the Kansas Entomological Society 80:179–181.

SCOTT, V.L., J.S. ASCHER, T. GRISWOLD, C.R. NUFIO, AND NATURAL HISTORY INVENTORY OF COLORADO. 2011. The bees of Colorado (Hymenoptera: Apoidea: Anthophila). Natural History Inventory of Colorado 23:1–100. https://www.colorado.edu/cumuseum/sites/default/files/attached-files/the_bees_of_colorado.pdf

SEABY, R.M., AND P.A. HENDERSON. 2006. Species diversity & richness, version 4 [software]. Pisces Conservation Ltd., Lymington, England.

SOLOW, A.R. 1993. A simple test for change in community structure. Journal of Animal Ecology 62:191–193.

STOUT, J.C., AND E.J. TIEDEKEN. 2017. Direct interactions between invasive plants and native pollinators: evidence, impacts and approaches. Functional Ecology 31:38–46.

TEPEDINO, V.J., B.A. BRADLEY, AND T.L. GRISWOLD. 2008. Might flowers of invasive plants increase native bee carrying capacity? Intimation from Capitol Reef National Park, Utah. Natural Areas Journal 28:44–50.

Tepedino, V.J., and N.L. Stanton. 1981. Diversity and competition in bee-plant communities on short-grass prairie. Oikos 36:35–44.

Thapa-Magar, K.B., T.S. Davis, S.M. Galbraith, and M. Grant-Hoffman. 2023. Effects of sage-grouse habitat restoration efforts on pollination networks in an arid ecosystem. Rangeland Ecology and Management 91:95–104.

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

Tollefson, J.E. 2006. *Sphaeralcea coccinea*. Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. https://www.fs.usda.gov/database/feis/plants/forb/sphcoc/all.html

Tronstad, L., C. Bell, and M. Crawford. 2022. Choosing collection methods and sample sizes for monitoring bees. Agricultural and Forest Entomology 24:531–539.

Twerd, L., and A. Sobieraj-Betlińska. 2020. Wild bee (Apiformes) communities in contrasting habitats within agricultural and wooded landscapes: implications for conservation management. Agricultural and Forest Entomology 22:358–372.

[USDI BLM] United States Department of the Interior, Bureau of Land Management. 2025. Public land statistics 2024. Volume 209:44–45. Table 2-5: Types of wildlife habitat on public lands in the conterminous 48 states, fiscal year 2024. https://www.blm.gov/sites/default/files/docs/2025-07/BLM-Public-Land-Statistics-2024.pdf

Westphal, C., R. Bommarco, G. Carré, E. Lamborn, N. Morison, T. Petanidou, S.G. Potts, S.P. Roberts, H. Szentgyörgyi, T. Tscheulin, et al. 2008. Measuring bee diversity in different European habitats and biogeographical regions. Ecological Monographs 78: 653–671.

Wickham, H. 2016. ggplot2: elegant graphics for data analysis. Springer-Verlag, Cham, Switzerland. 260 pp.

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 81:288–300.

Wright, K.W., K.L. Vanderbilt, D.W. Inouye, C.D. Bertelsen, and T.M. Crimmins. 2015. Turnover and reliability of flower communities in extreme environments: insights from long-term phenology data sets. Journal of Arid Environments 115:27–34.

[XSIC] Xerces Society for Invertebrate Conservation. 2018. Appendix C: Native bee genera lists by ecoregion and U.S. Forest Service region with floral and nest plant associations. Page 124 *in* Best Management Practices for Pollinators on Western Rangelands. Xerces Society for Invertebrate Conservation, Portland, OR.

[XSIC] Xerces Society for Invertebrate Conservation. 2020. What is the Bumble Bee Atlas? https://www.bumblebeeatlas.org/pages/about

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