Floral Relations of Native Bees in Camas Meadows
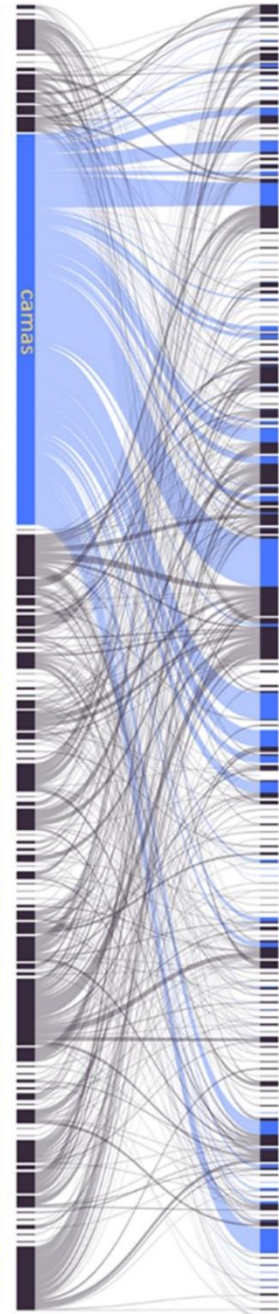
COL-F23-W3673

Executive Summary

Improving the conservation and understanding of culturally important plants and animals has been identified as a high priority action in the Fish and Wildlife Compensation Program (FWCP) Columbia Region Wetland & Riparian Action Plan (FWCP 2019b; COLWRA.CXP.RI.05.01: Culturally important resources). The FWCP Upland and Dryland Action Plan (FWCP 2019a) also supports inventory and monitoring for pollinators to elucidate community structure and act as indicators of ecosystem function (COLUPD.SOI.ME.33.01: Invertebrate monitoring for pollinators).

This project, in its third of five years, presents fundamental empirical data on physical, biological, and ecological components of West Kootenay camas (*Camassia quamash*) meadows necessary to inform future conservation, ecological restoration, and enhancement activities. The Kootenay Native Plant Society (KNPS) is working with the Sinixt Confederacy of the Confederated Tribes of the Colville Reservation to renew people-plant relationships in their traditional territory where most camas meadows have been lost. Documenting plant-pollinator communities in remnant meadows is a critical first step in a process to understand what species, communities, and interactions remain and helps to identify how best to conserve and restore the remaining imperilled West Kootenay camas meadows.

Ten camas meadow sites were selected at low to mid elevations along approximately 60 km of the Kootenay and Columbia River systems, a corridor that has national, biological, ecological, and cultural significance. The sites represent a diversity of habitat types including bedrock seepage meadows, rocky shorelines, and open floodplains. General site attributes and plant community structure were recorded at each site. Native bee species were sampled directly from flowering plants at eight of the sites, and soil was sampled at three sites that were not sampled in 2021. In total, 99 species of flowering plants were surveyed along the research transects and their phenology recorded during multiple visits at eight of the sites.

We detected the COSEWIC listed Western Bumble Bee (*Bombus occidentalis*) at all sites, with over half of the 23 observations involving interactions with camas flowers. In 2022 alone, we observed 156 bee species and morphospecies among eight camas meadow sites. Bumble bees (Apidae: *Bombus*) were the most abundant, followed by mining bees (Andrenidae: *Andrena*), mason bees (Megachilidae: *Osmia*), and sweat bees (Halictidae: *Lasioglossum*). We documented over 200 distinct bee taxa over the previous three years of sampling, which represent more than forty percent of the bee species currently known

from British Columbia. Our results include new provincial records, new national records, and at least two species new to science.

Plant-pollinator networks among the sites clearly demonstrate the critical importance of camas as an early season network hub, or anchor among the communities at these sites. Seventy-two of the 156 bee species and morphospecies interacted with camas during this sampling season, which effectively organized the plant-pollinator communities into an early-season, camas-associated network, and a later season network consisting of similar amounts of bee species but requiring more plant species to support similar quantities of bees. Early season networks tended to have fewer introduced species in contrast to the later season networks.

The measured importance of camas in driving species richness and connectivity in early season communities highlights the high ecological value of this flagship species and its important function as a network hub. Resilient communities rely on multiple network hubs across the season, and our work to develop recommended plant mixes has identified critical plant species in these vernal upland, wetland, and riparian habitats. This information will enable the optimization of native plant community design for ecological restoration resulting in the establishment of resilient networks consisting of hundreds of species of native plants and pollinators.

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1   Introduction

Pollination is a critical ecosystem service and native bees are our most important pollinators. Pollination sustains native ecosystem health and function, yet little is known about the identity, status, habitat use, and pollinator-plant relationships in the West Kootenay ecosystems of the British Columbia (BC) Interior. Baseline data on native bee distribution and abundance are limited in the region (but see Huff et. al. 2021; Best 2018; Best et al. 2022; Westcott and Irvine 2010). Even less is known about the bee diversity and abundance in the meadows of small camas (*Camassia quamash* (Pursh) Greene [Asparagaceae]). Wet meadow communities are known to harbour diverse pollination networks (Moroń et al. 2008), and in one survey of Garry oak and associated meadows in southwestern BC, *C. quamash* was the most frequently visited plant species by the largest diversity of bees (Parachnowitsch and Elle 2005). Additional studies found that despite relatively high visitation, the reproduction of camas plants can be limited by pollen received (Gielens et al. 2014; Neame 2009). The status of camas reproductive capacity in the West Kootenay region is currently unknown.

In our previous work in camas meadows, we have observed and photographed many invertebrate visitors on camas (Huff and Johansson 2012). Lynn Westcott, a bee specialist familiar with local flora and bee fauna has suggested that up to 60 different bee species may rely on camas meadows for their livelihood (L. Westcott, pers. comm., Sept. 30, 2013). Our 2020 and 2021 sampling has confirmed this and more, with 84 distinct bee taxa documented in 2020 trap sampling, and 130 distinct taxa found in 2021 net sampling including 51 species observed visiting camas. A BC Conservation Data Centre (BC CDC) blue-listed bumble bee species, *Bombus occidentalis*, has been observed in camas meadows, with a second less common species, *B. suckleyi*, possibly present, as well. Only bumble bees have been assessed by the BC CDC; the majority of the other 483 bee species known from BC are data deficient and unable to be assessed for conservation status (Canadian Endangered Species Conservation Council 2022; Sheffield and Heron 2018). Even as bee populations face threats, such as rapid land use change, loss of habitat, and increasingly unpredictable weather events, we still have relatively little idea of what we stand to lose.

Camas, known as ʔíʔtxʷăʔ (black camas) in the ṅsəl̓xčiṅ (Interior Salish) language, is a perennial herbaceous species with grass-like leaves, light blue to deep purplish-blue flowers, and an edible bulb. It is native to the Pacific Northwest from California, through Oregon, Washington, Utah, Idaho, Wyoming, Montana to southern BC and Alberta. In BC, it occurs along the Pacific Coast, largely restricted to

southeastern Vancouver Island and the Southern Gulf Islands, as well as in the Canadian Columbia Basin from Trail to Nakusp (Huff and Johansson 2012; Beckwith 2004). In every place where camas occurs across western North America it has played a dominant role in shaping First Nations/Native American economies and identity for millennia (Thoms 2008; Beckwith 2004; Hunn 1981). The bulbs are a significant resource, a "root food" that was—and still is for many Native Americans—a staple component of the traditional diet. Camas was cultivated primarily by women, who maintained bulb quality and quantity (Beckwith 2004), by creating and maintaining extensive meadows that, when in bloom, were described as blue lakes by Lewis and Clark (Stevens et al. 2001). Widely celebrated in story, legend, and ceremony, it has been described as a cultural keystone species (Garibaldi and Turner 2004).

The formerly cultivated camas communities are also ecologically significant, supporting a diversity of other plant, animal, and fungal species/beings. In the Columbia Basin, these communities occur along the Columbia and Kootenay rivers in floodplain meadows, in the upper riparian zone, and in moist seeps in bedrock meadows from Marsden Face, located outside of Nelson, south to the US border (Figure 1). Small populations are known from the Slocan Valley, Pass Creek, and Robson areas. Historically, camas occurred up Lower Arrow Lake to Nakusp and Edgewood in locations now underwater after the construction of the Hugh Keenleyside Dam. Ongoing habitat loss, agricultural conversion, forest in-growth, and invasive plant species have contributed to the decline of these ecologically and culturally significant places and, it is suspected, that changing precipitation patterns with the ongoing climate crisis could further imperil the remnant camas populations. In the BC Interior, it is estimated that camas occupies less than 1% of the original, pre-settler extent (B. Beckwith, KNPS Senior Scientist, pers. comm., October 15, 2019). The loss of these meadows is likely accompanied by a corresponding loss of invertebrate pollinator species abundance and richness in the region.

2 Goals and Objectives

Improving the conservation and understanding of culturally important plants and animals has been identified as a high priority action in the Fish and Wildlife Compensation Program (FWCP) Columbia Region Wetland & Riparian Action Plan (FWCP 2019b):

> COLWRA.CXP.RI.05.01 Culturally important resources. Work with appropriate Indigenous groups and organizations to conduct research and inventory to improve the understanding of culturally important plants and animals. Conservation and increased understanding of culturally important species.

Camas has been identified by our Indigenous colleagues with the Sinixt Confederacy as a high priority for eco-cultural restoration. Through the mapping of meadow vegetation and habitat attributes in the study area, this project will establish a robust baseline from which to measure progress toward the enhancement of and recovery of these culturally significant ecosystems.

The FWCP Upland and Dryland Action Plan (FWCP 2019a) supports inventory and monitoring for pollinators to elucidate community structure and act as an indicator of ecosystem function:

> COLUPD.SOI.ME.33.01 Invertebrate monitoring for pollinators. Support inventory/monitoring of upland terrestrial invertebrate groups to increase knowledge of community structure and act as an indicator of productivity and ecosystem health/function in areas related to FWCP compensation activities.

Pollinator biodiversity data for the West Kootenay is sorely lacking (Jennifer Heron pers. comm., October 21, 2019), and our collection and identification of native bees in the region's camas meadow communities will significantly elevate our understanding of bee distribution across an important heritage landscape.

The goal of this project report is to provide a rigorous understanding of the floral relations currently occurring within camas meadows to inform future conservation, ecological restoration, and enhancement activities in the West Kootenay region. This goal will be addressed through the analysis and integration of site-specific environmental information with data generated from plant community, bee fauna, and plant-pollinator interaction and diversity studies. Documenting floral relations among plants and bees in the region's remnant meadows is a critical step in understanding how the remaining diversity is interacting, and which species are critical to maintaining ecosystem function. The Kootenay Native Plant Society (KNPS) has been working with the Sinixt Confederacy of the Confederated Tribes of the Colville Reservation for nearly a decade to renew people-plant relationships in their unceded traditional and ancestral territory. The results from this work will provide a more comprehensive and robust picture of camas communities of the West Kootenay and will be invaluable in increasing our understanding of how best to conserve and restore a highly sacred plant to the Indigenous Peoples of this region.

Other aspects of the "Floral Relations of Native Bees in Camas Meadows" project have been addressed in Appendix I and in the online Final Report for the project.
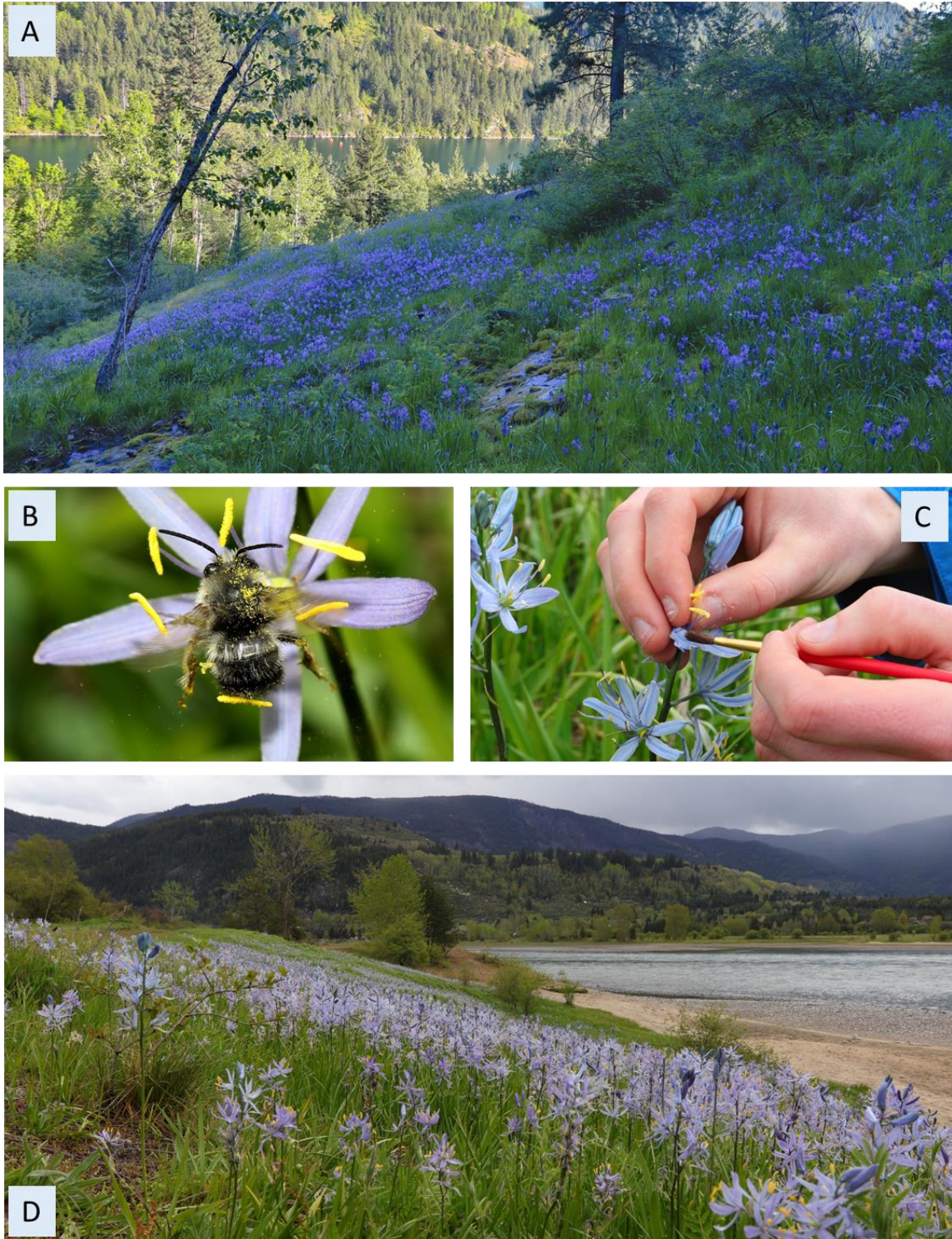
*Figure 1. Photo Plate: A. Bedrock seepage meadow on Mount Sentinel; B. Male Ashy Digger Bee (*Habropoda cineraria)
departing a camas flower in a burst of pollen; C. Hand pollinating camas flowers; D. Riparian floodplain meadow at K̓ṗiⱢⱢs. A, B
& D – Rowan Rampton, C – Lincoln Best

3 Study Area

The camas meadow sites were initially selected as independent study sites, separated by a minimum of 1 km of land or by a body of water (e.g., the Kootenay & Columbia rivers) (Figure 2). These distances were chosen to be beyond typical bee foraging range, with the goal of ensuring bee communities at each site were independent. The sites represent a diversity of habitat types including bedrock seepage meadows (Figure 1A), rocky shorelines, and open floodplains (Figure 1D), none of which fit well within current provincial ecological land classification systems (MacKillop and Ehman 2016; MacKenzie and Moran 2004). Bedrock meadows have recently been described as unique, biodiverse ecosystems that should be incorporated into classification systems (Pätsch et al. 2022).

The selected sites occur over an elevation gradient with each site representing a small patch of unique habitat within a varied landscape dominated by managed forests, reservoirs, urban development, industrial infrastructure, and transportation corridors (Table 1). Hence, the diversity of flowering plants is high relative to adjacent habitat in all our sites. Most sites fall within the Interior Cedar Hemlock - Very Dry Warm (ICHxw) Biogeoclimatic Unit, though the Upper Marsden Conservancy site is transitional with the Interior Cedar Hemlock - Dry Warm Unit (ICHdw1) (MacKillop and Ehman 2016). The climate, in general, includes very hot, very dry summers and mild dry winters (MacKillop and Ehman 2016). The ICHxw subzone contains forests and brushlands with a diverse assemblage of tree and shrub species and a disproportionately large number of wildlife and plant species at risk (MacKillop and Ehman 2016).

3.1 Site Sampling Overview

Ten camas meadows at various locations and elevations that span the range of camas occurrence in the West Kootenay region were chosen for sampling. The cold, wet spring in 2022 limited pollinator activity and opportunities to sample within these sites, resulting in eight of 10 sites becoming the focus of this year's study. The eight sites were sampled for floral abundance, floral phenology, and interactions between plants and floral visitors. A pollen limitation experiment was also conducted to assess to what degree the reproductive capacity of camas is being fulfilled based on the level of pollination received (Figure 1C).
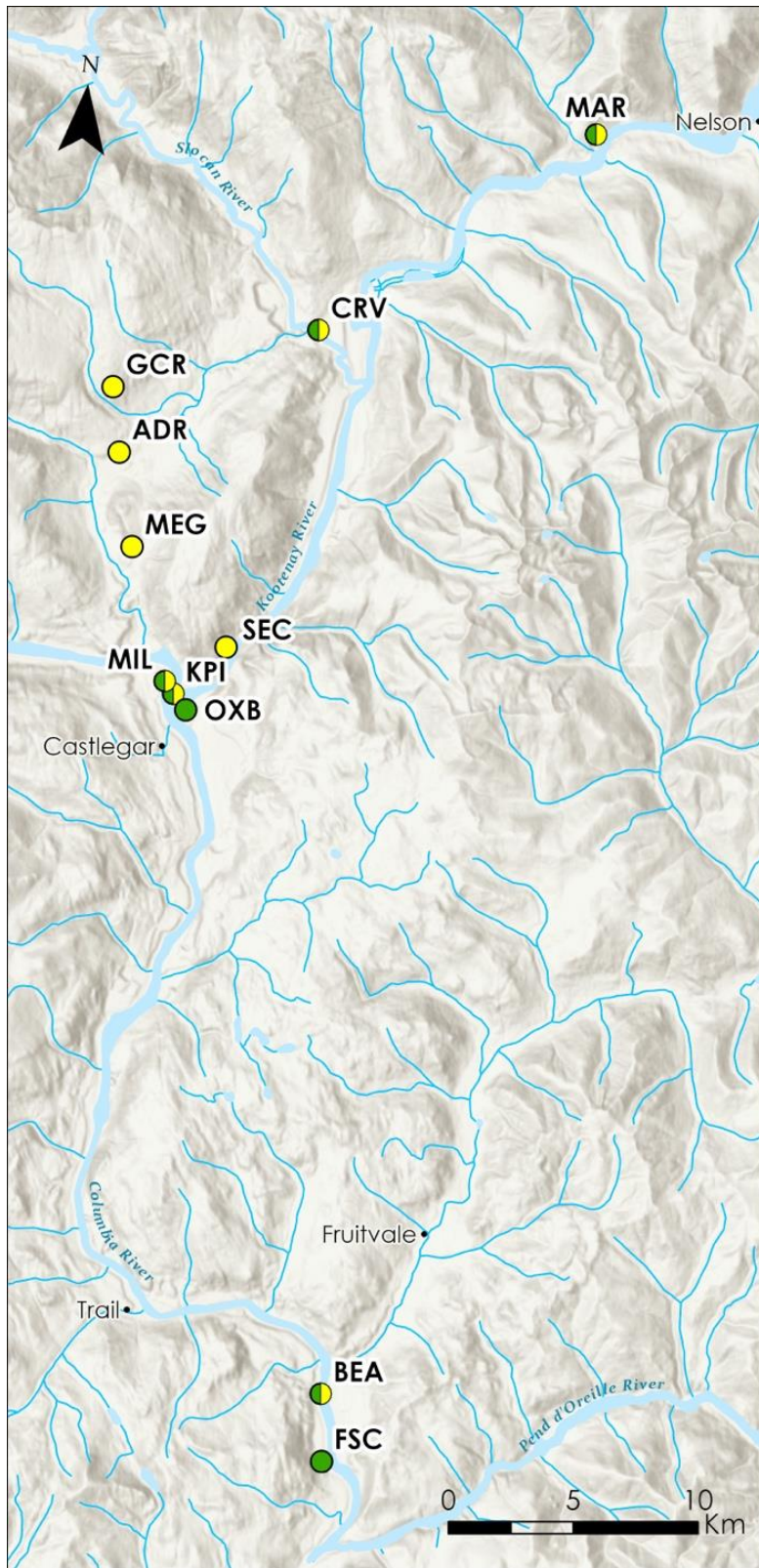
Figure 2. Pollination Pathway Climate Adaptation Initiative sites in the Lower Columbia. Floral interaction research sites are in yellow, ongoing ecological restoration sites are in green.

Table 1. List of floral interaction sampling sites including elevation, sampling year(s), and year, if conducted, of soil assessment.

Site Code	Site Name	Elevation (m)	Sampled 2021	Sampled 2022	Soil Profile
GCR	Goose Creek Meadow	1120	Y	Y	2021
CRV	Crescent Valley	490	Y	Y	2021
KPI	K̓p̓iƛ̓ís (Brilliant)	423	Y	Y	2021
MIL	Millennium Park	425	Y	Y	2022
SEC	Mount Sentinel	520	Y	Y	
MEG	Megan's Meadow	750	Y	N	
ADR	Adrian's Meadow	640	Y	Y	
MAR	Marsden Face	610	Y	Y	2021
BRO	Brilliant Overlook	590	N	N	
BEA	Beaver Creek Provincial Park	410	N	Y	2022

4 Methods

4.1 Site Description & Soils

Eight sites were sampled in 2022 span a 700 m elevation gradient, from the river floodplain at 410 m (Beaver Creek Provincial Park) to a south-facing bedrock meadow at 1120 m (Goose Creek Meadow). Sites occur from Beaver Creek Provincial Park, located south of Trail, north to Marsden Face located west of Nelson. All sites are vernally wet, either from spring snowmelt, seepage, and groundwater or because they are on or near floodplains (including historic pre-damn floodplains).

In 2022, three additional locations were identified for soil pit descriptions and classifications and Audrey Ehman PAg (2023) was contracted to conduct the soil analysis, as she did at other camas sites in 2021. Representative sites within the selected camas meadows were identified for soil analysis based on the surrounding site attributes. Soil pits were dug to 60 cm, where soil depth permitted. Data were collected on BC Ministry of Forest and Range Ecosystem Field Form (FS822) and followed provincial standards and codes (B.C. Ministry of Forests and Range B.C. Ministry of Environment. 2015). All appropriate fields on the site and soils cards were filled in at each site; soil and humus structure were excluded. Field observations impacting site and soil factors were recorded in the notes section.

4.2 Flowering Plant Communities

During the previous field season, transects totalling 100 m in length and 2 m in width were established at each site. Many sites were not 100 m in length; therefore, four 25 m x 2 m transects were established

at these locations, approximately in parallel with the nearest river. Sampling used the same transects as 2021, but since species accumulation curves from 2021 sampling indicated that three 25 m transects were adequate to detect much of the floral diversity, three of the four established transects at each site were sampled in 2022.

All flowering plants within 1 m of the centre of the transect (2 m width total) were identified to species and sampled for abundance. Flowering plants were separated into two types: a) flowers large enough to feasibly count (e.g., *C. quamash*, *Symphoricarpos albus*), and b) plants with tiny flowers too small to feasibly count, which were typically introduced species (e.g., *Valerianella locusta*, *Veronica arvensis*). For the first group, all inflorescences present on the plants within each transect were counted. For the second group, each metre of each transect was evaluated for presence or absence of open flowers. This led to a count out of 25 for each 25 m long transect. Each site was sampled six to eight times throughout the spring and summer, from April 23 to August 6, by which time the meadows had dried out and most plants had finished flowering.

Plant phenology was also recorded during each visit for all flowering plants sufficiently abundant to evaluate. Each of these plants were assigned a number on the extended BBCH scale (Hess et al. 1997) to describe the flowering stage of each species across the transects (Table 2).

4.3   Bee Fauna

In this Bee Fauna section, the general methods of bee identification and the more specific technique of DNA barcoding will be described.

4.3.1   Bee Identification

Bee specimens were identified to species or assigned a sequential morphospecies code at the generic or subgeneric level. Morphological assessment was made using a Nikon SMZ-1 dissecting microscope. Identifications were made using scientific literature, unpublished keys, a private reference collection, and COI DNA barcoding. Morphospecies were identified to genus and/or subgenus, then differentiated using morphological characters and assigned a sequential morphospecies number. The following resources were used in this study to identify bee specimens: Ascher and Pickering (2013), Bouseman and LaBerge (1978), DeSilva (2012), Gibbs (2010), Hurd and Michener (1955), LaBerge (1969; 1973; 1980; 1985; 1986; 1989), LaBerge and Ribble (1975), McGinley (1986), Portman (2023), Roberts (1973a), Roberts (1973b), Sheffield (2020), Sheffield et al. (2011), Stephen (1954). Species occurrence data for

the bee specimens collected will be served to the Global Biodiversity Information Facility (GBIF) via the Canadensys Integrated Publishing Toolkit (IPT).

Table 2. Portion of the BBCH phenology scale (Hess et al. 1997) used to describe the growth stage of forbs that were flowering during the bee sampling period.

Code	Description
Principal growth stage 5: Inflorescence emergence (main shoot)	
51	Inflorescence or flower buds visible
55	First individual flowers visible (still closed)
59	First flower petals visible (in petalled forms)
Principal growth stage 6: Flowering (main shoot)	
60	First flowers open (sporadically)
61	Beginning of flowering: 10% of flowers open
63	30% of flowers open
65	Full flowering: 50% of flowers open, first petals may be fallen
67	Flowering finishing: majority of petals fallen or dry
69	End of flowering: fruit set visible

4.3.2 DNA Barcoding

Sixty-six bee specimens from taxonomically problematic genera were selected for DNA barcoding to aid in their identification. These genera are typically extremely speciose, morphologically indistinct, and in need of both contemporary revision and identification resources. From these specimens a single mid-leg from the left side was removed and placed in individual wells of a 96-well plate. Plates were sent to the Canadian Centre for DNA Barcoding (CCDB), Guelph, Ontario. DNA was extracted using an automated extraction protocol (Ivanova et al. 2006). Cytochrome *c* oxidase subunit 1 region of the mitochondrial DNA was amplified using the LepF1 and LepR1 primers (Hebert et al. 2004) and failed amplifications were rerun using internal primer pairs MLepF1 (Hajibabaei et al. 2006). Details regarding extraction, amplification, primers, and sequencing standard protocols are available at URL: https://ccdb.ca/resources/.

4.4 Plant-Pollinator Floral Relations

Methods for floral interactions and plant-pollinator networks, a pollen limitation experiment, and the generation of a recommended species list are described in this section, Plant-Pollinator Floral Relations.

4.4.1 Floral Interactions and Plant-Pollinator Networks

Hand net sampling and careful observations were used to document the floral interactions occurring in the meadows (Figure 1B). Floral interactions were largely sampled during the same site visits described in section 5.2. In a few cases, weather conditions deteriorated after floral sampling occurred but before bee sampling could begin. In these cases, floral interactions were documented within 1-2 days of floral sampling. A sampling "round" based on the sequential visit was assigned to each sample to account for this and ensure the matching of related samples.

To document floral interactions, all bees observed visiting flowers were collected using hand nets for one person hour at each site visit, with the hour representing only searching time and excluding the time spent catching and processing specimens caught. Sampling attention was divided equally between all floral resources within a site. Each plant-bee interaction was documented, providing a record of both bee presence and the floral resource use associated with that occurrence record. All bees were pinned and labelled for identification and future museum deposition.

Plant-bee data were used to make plant-pollinator networks and species accumulation curves. Bee morphospecies were converted to genera in these analyses, such that all morphospecies of a given genus are assigned to a single taxon, that taxon being the associated genus name. This is a conservative method that ensures full abundance is included but errs on the side of caution regarding the number of species represented by morphospecies. Estimated species totals would likely be higher if morphospecies were included as distinct taxa.

4.4.2 Pollen Limitation Experiment

Twenty pairs of camas plants were selected at each site, with each member of the pair receiving one of two pollination treatments. The first treatment, open pollination, was the natural level of pollination occurring at a site via the pollinators present. During the second treatment, pollen-addition, pollen from nearby camas plants (approximately 20 m away from experimental plants) was gathered from anthers (male part) using a small paintbrush and then transferred to the stigma (female part) of all treatment flowers that were blooming (Figure 1C). Because camas flowers bloom sequentially along the flowering stalk, this process was repeated over 2-3 visits at each site. During each visit, the number of flowers hand pollinated and total flowers per plant were recorded. Plants in the pollen-added treatment were exposed to open pollination before and after hand pollination, meaning that they received both experimentally added pollen and pollen deposited by wild pollinators. This should represent a theoretical maximum level of pollination. An additional treatment that excluded pollinators was also

used on separate plants to confirm that the camas populations studied do require external pollination. This treatment involved placing a fine mesh bag over an inflorescence before any flowers had opened. All treatment plants were marked with flagging tape at the base of the inflorescence and labelled with pair number and treatment.

For all treatments, marked plants were periodically checked after the flowering period and throughout the time of seed production. The inflorescences were collected when the seed pods had reached full size and seeds had produced a black shiny seed coat, but before the seed pods dried out and began to split and disperse seeds. For each collected inflorescence, the number of seed pods and total number of seeds were counted to compare the number of seeds produced by natural pollination (open treatment), to what the plants can produce if pollen was available in abundance, or not limiting (the pollen addition treatment).

Seed counts were analyzed using GAMLSS models to account for both zero inflation (many camas' inflorescences did not produce any seeds) and non-normal count data. The model process and details will be described in detail in future publications, particularly R. Rampton's upcoming MSc Thesis.

4.4.3   Priority Plants for Conservation and Restoration

To develop recommended plant lists based on our plant-bee interaction data in a quantitative manner, a tool developed in M'Gonigle et al. (2017) was used to select mixes of plants that maximize the following parameters of plant-bee interactions: a) bee abundance, b) richness, c) bees supported over time, and d) network robustness. Network robustness is a property of bipartite (e.g., plant-bee) networks that represents the ability of the network to retain its structure as species are lost (Sheykali et al. 2020). Higher robustness means the network is more resistant to collapse. The tool was used to generate priority species for the entire bee dataset from 2021 and 2022, as well as based on subsets of 2022 data which had high enough sampling resolution to separate habitat type and time of season.

4.5   Data Analysis

Analyses were completed in R 4.1.3 (R Core Team 2022). Network metrics were generated using the bipartite package (Dormann et al. 2009) and visualizations were created with the bipartiteD3 package (Terry 2021). Non-metric multidimensional scaling (NMDS) and rarefaction analysis (sampling completeness estimates) were completed using the vegan package (Oksanen et al. 2020), 3-dimensional

NMDS visualisations were done using plotly (Sievert 2020), and other figures were made using ggplot2 (Wickham 2016). R packages mgcv (Wood 2011) and GAMLSS (Rigby and Stasinopoulos 2005) were used to model the relationships described in sections 5.3 and 5.6, respectively.

5 Results and Outcomes

In this Results section, the same structure that was used in the Methods section will be applied, describing the outcomes of the analyses of site and soils, flowering plant communities, bee fauna, and plant-pollinator floral relations.

5.1 Site Description & Soils

Site classifications were unchanged from the previous report, though a different spring resulted in moisture availability persisting at the sites for much longer than seen in 2021. Riparian sites had prolonged flooding occur for much of June and July, particularly at K̓pix̌ʎ̓s, also locally known as Lower Brilliant Terrace (Figure 1D), and Beaver Creek sites, which experienced high water levels that included submersion of camas habitat. The seeps in bedrock meadow communities remained moist three to four weeks later than the summer of 2021.

The results of the soil study by Audrey Ehman (2023) helped us to classify sites as either floodplain (fluvial-derived) or bedrock (shallow-soil) (see Appendix A for details). The floodplain sites had deeper soil than bedrock meadows and were located near the Columbia, Kootenay, and Slocan rivers, whereas bedrock meadows were found on the lower faces of mountains where snowmelt seeps occur (Table 3).

Table 3. Site classification into bedrock and floodplain. Soil depths provided by Ehman (2022).

Site Code	Site Name	Site Type	Soil Depth (cm)
GCR	Goose Creek Meadow	Bedrock	9
CRV	Crescent Valley	Floodplain	>100
KPI	K̓pix̌ʎ̓s (Brilliant)	Floodplain	>100
MIL	Millennium Park	Floodplain	>100
SEC	Mount Sentinel	Bedrock	--
MEG	Megan's Meadow	Bedrock	--
ADR	Adrian's Meadow	Bedrock	--
MAR	Marsden Face	Bedrock	18
BRO	Brilliant Overlook	Bedrock	--
BEA	Beaver Creek Provincial Park	Floodplain	>100

5.2 Flowering Plant Communities

In 2022, a total of 99 flowering plant species were documented during transect surveys, with more than 110,000 inflorescences counted across all species. In both years of sampling, 116 species were documented across the 10 meadows visited, representing 93 genera and 35 families (see Appendix B for full lists). Among the flowering plants documented, there were several notable records for the West Kootenay. For example, *Erythranthe breweri*, *Hemizonella minima,* and *Myosotis verna* are only known from two to three other publicly available records in the region and, in the case of the latter, the most recent record was in 1946 (GBIF 2023a).

Non-Metric Multi-Dimensional Scaling (NMDS) was used to visualize the floral resource communities observed during each floral transect sample. Floral community is a subset of the true plant community but is representative of the resources available to bees, and examining patterns among samples related to site factors and time of season will have relevance to the community of bees supported. Across the entire season, the factor that best explained variation in floral community was timing of sampling over the field season, with a clear progression in floral community through the eight sampling rounds of the season (Figure 3). Rounds 1 to 4 contain peak camas bloom (at some sites peak bloom occurred during rounds 1-3, at others during rounds 2-4).

Due to the seasonal gradient of floral composition seen in Figure 3, the sites were split into early season and late season, with approximately equal sampling rounds in each part of the season at each site. Due to the summer dormancy of camas meadows, 'early season' is the early-mid spring season, and 'late season' is the late spring to early summer season. Sampling round does not represent an *a priori* phenology stage, so the exact round that defined the split between early and late season differed for each site depending on actual visit dates and elevation. Each "split" round was chosen such that early and late season represent similar phenological stages across sites (see Appendix C). Appendix D, Model 1, shows the results of the choices made and supports their effectiveness at dividing the season into the two portions, early and late.

After splitting the data into early and late season, variables of interest included the following factors. The first investigation was site type - whether a site was a bedrock seepage meadow or a rocky shoreline/floodplain meadow. Gradient related trends in floral composition were also investigated, including both elevation and sampling round (within early or late season). Finally, site clustering was investigated to look for patterns unexplained by the previous variables.
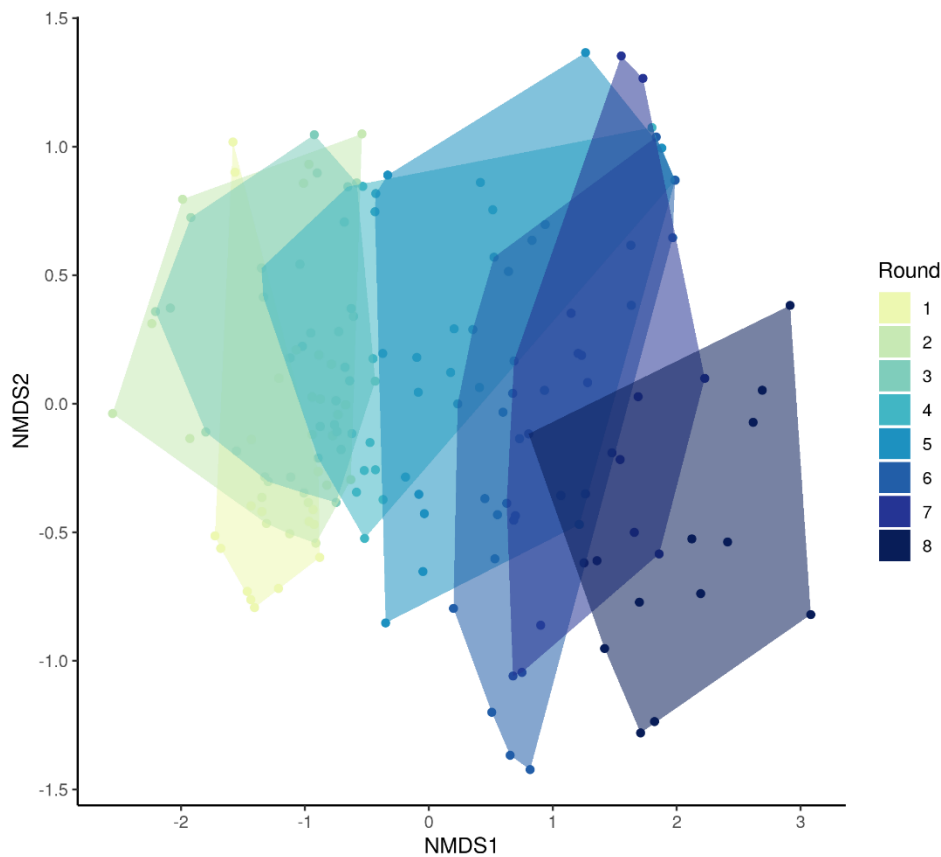
Figure 3. Changes in community composition depicted over time using NMDS caption. K = 2, Stress = 0.109. Each point represents the community composition of a floral transect sample at a certain site on a certain date. Round 1 represents the first visit to a site and higher round numbers are progressively later visits. The coloured polygons contain all the points associated with each round.

Within the two halves of the season, site type most clearly explained variation in floral resource composition, with the two site types mostly clustering into distinct groups (see Appendix D, Models 2, 3). For round and elevation, the communities at the extremes of the scales (e.g., high and low elevation, earliest and latest round) are slightly distinct, with intermediate values forming a central cluster of higher overlap (see Appendix D, Model 4). This tendency can also be seen by looking at the early season site chart (Figure 4 below), where several sites (BEA, GCR, KPI) cluster into unique groups, with the remaining sites appearing broadly overlapping.
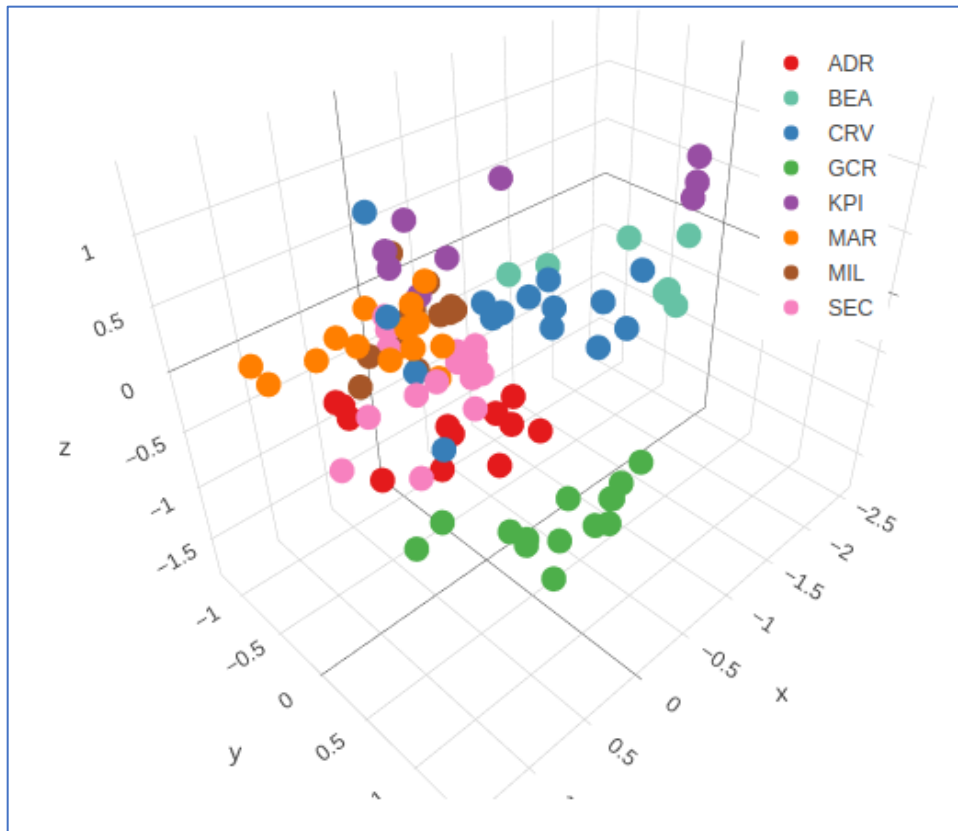
Figure 44. The results of early season floral community NMDS, displayed in three dimensions, with x, y, and z corresponding to NMDS axes 1, 2, and 3. Stress = 0.072, k = 3, indicating minimal loss of information when displayed in three dimensions. Each dot shows floral community composition on a given day at a given site.

The initial ordination result, displayed in Figure 3, shows that time of season most clearly explains variation in floral resource composition. Because of the time dependence of floral resources, further investigations of their patterns across time were completed. At most sites, available floral resources peaked during camas bloom in early to mid-May, and then generally declined after that point as the season progressed and the local weather became drier and warmer. This is typical in vernally wet systems, as water sources (i.e., snowmelt runoff) dry up and many plants enter dormancy to survive summer aridity (Patsch *et al.* 2022).

Disruptions in phenological timing were observed at some sites due to mass bloom of introduced plant species during mid-summer, as seen in the peaks of plant inflorescence abundance of introduced species in July, particularly at the KPI (KṗiẊİs) and SEC (Mount Sentinel) sites (Figure 1A, D; Figure 5). Introduced plant species were a significant part of late season floral communities, with abundance and

species richness values generally increasing through time. At sites with lower introduced species abundance, native inflorescence abundance tended to decline less sharply later in the season (see Goose Creek Road, Adrian Meadow, Marsden Face in Figure 5), whereas abundance of native inflorescences declined through the season at sites with higher abundance of introduced plant species (see Millennium Park and Mount Sentinel in Figure 5). These differences are likely driven by competition with robust introduced plant species such as *Vicia villosa, Potentilla recta*, *Hypericum perforatum*, and *Centaurea stoebe*.
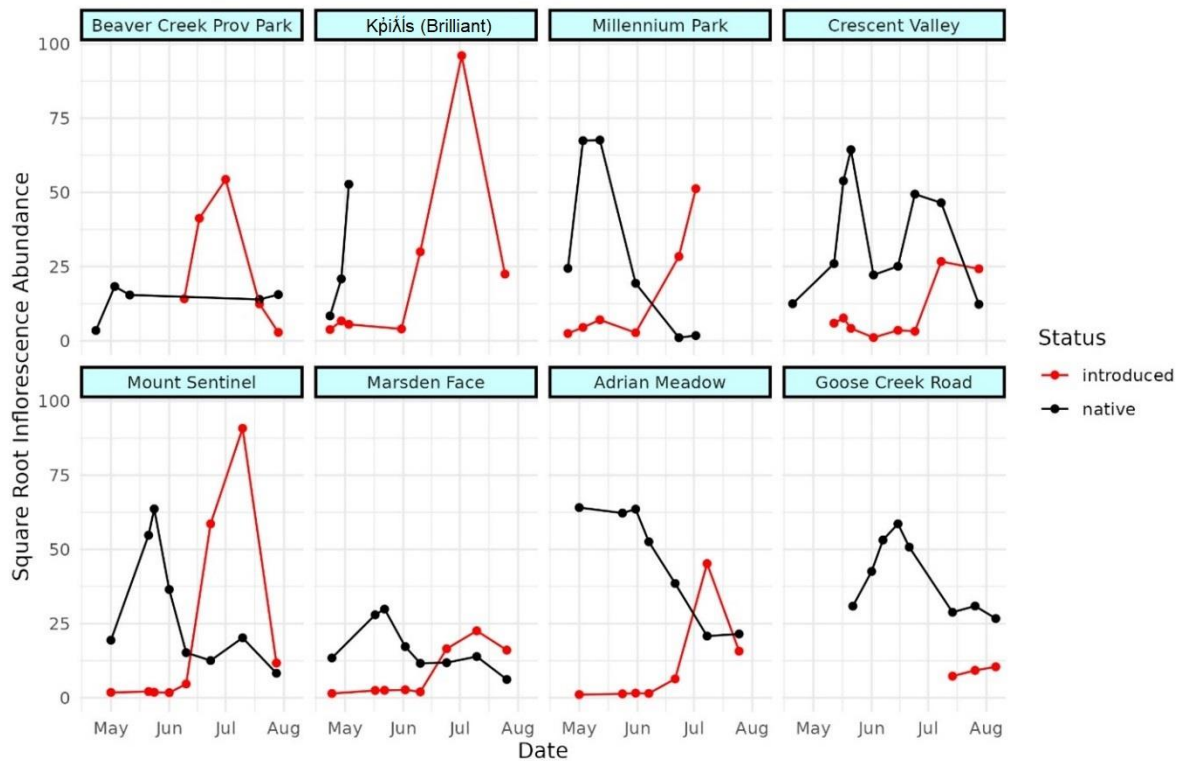
Figure 55. Comparison of plant inflorescence abundance of native or introduced plants over time. Points represent the square root of the total floral abundance of inflorescences. Sites are ordered from lowest elevation in the top left (Beaver Creek) to highest elevation at the bottom right (Goose Creek).

Most species flower between May and early July, with relatively few species present in April and after early July (Figure 6). Introduced species were present throughout the season, though the abundance plots (Figure 5) show their abundance is relatively low until mid to late season.
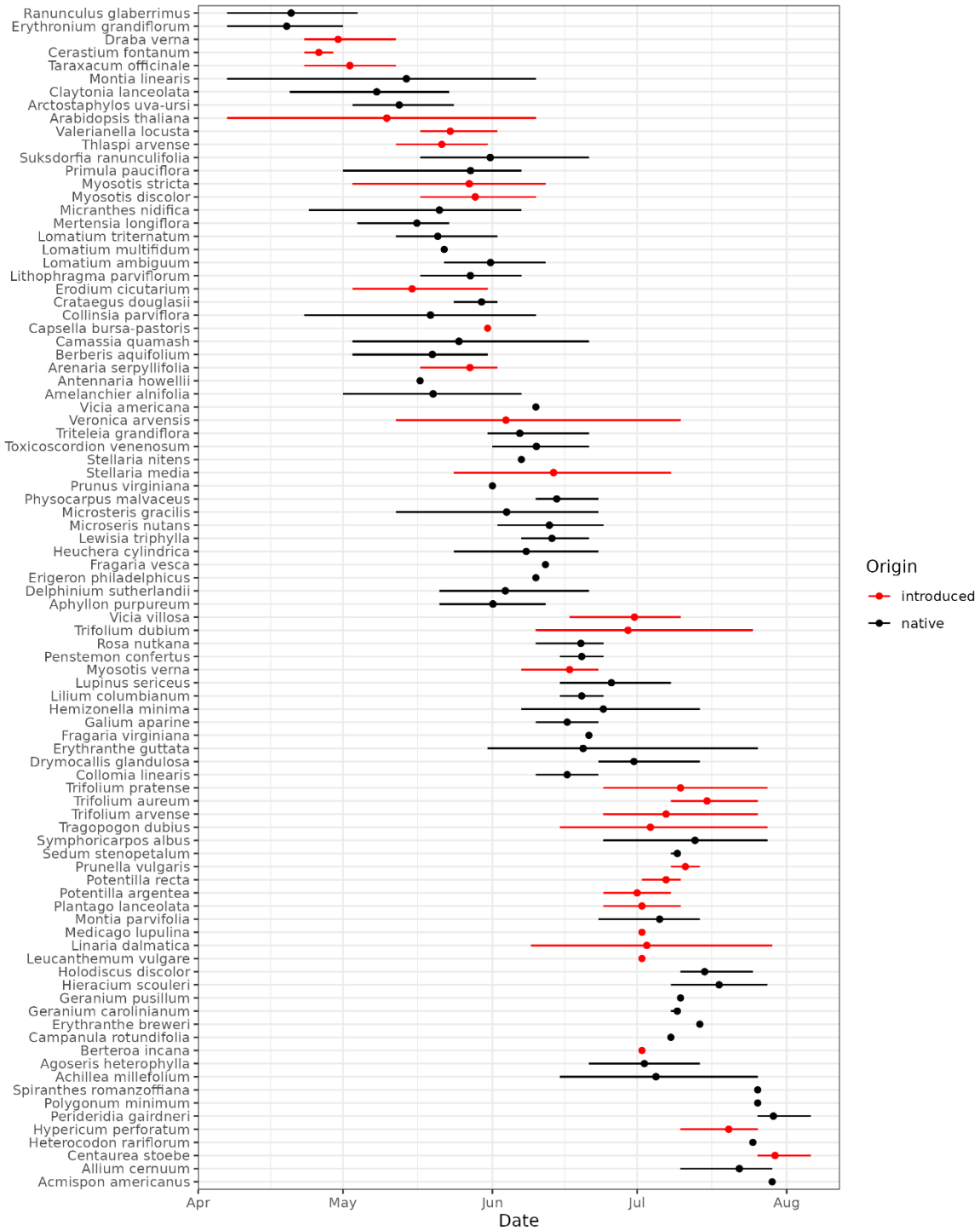
Figure 66. Flowering time of plants recorded from April to August 2022. Points represent peak bloom (stage 65) and the bars represent the duration of the flowering period for that species (stages 60 to 67).

5.3   Bee Fauna

In 2022, sampling of bee fauna generated more than 1600 specimens representing five bee families and many additional bee species, further highlighting the wealth of bee diversity in the region. DNA barcoding clarified previously unresolvable taxonomic relationships of some of the bee fauna.

5.3.1   Bee Identification

In 2022, a total of 157 species were detected including 43 morphospecies unable to be identified to species level. Across 2021 and 2022, a total of 207 bee species were detected, including 47 morphospecies that were unable to be identified to the species level. Four additional species were detected in 2020 blue vane trapping (Best et al. 2022, also see Appendix E checklists). Twenty-two genera of bees were recorded in 2022 and 27 genera, in total, for both 2021 and 2022. Overall, more than 40% of the 483 bee species, and 66% of the 41 bee genera known from BC, were recorded in camas meadows during the three seasons of sampling (GBIF 2023b).

Five of the six families known from BC were detected in 2022 (Figure 7). Apidae, which includes the bumble bees, digger bees, carpenter bees, long horned bees, and nomad bees, was the most abundant (Figure 1B). Andrenidae, the mining bees, and Megachilidae, the leaf-cutting bees, contained the most species richness, followed by the Halictidae, which includes sweat bees and short-faced bees, then finally by the Colletidae, represented by plasterer bees and masked bees. The sixth bee family, the Melittidae, or oil bees, were observed in 2021, but not 2022, primarily because the plant they gather floral oils from, *Lysimachia ciliata,* was underwater for much of the spring and summer, and had not bloomed by the end of sampling. This may not represent the loss of the bee or *L. ciliata,* as both are floodplain adapted species, and may have been present in late summer. The inability to detect the bee on a plant known to occur in riparian camas meadows does show that if preferred floral resources are not present, certain bees will be absent as well.

Several of the species detected are new to BC, Canada, or are otherwise poorly known in western Canada. These include *Andrena semipunctata, Andrena ceanothi, Andrena chromotricha, Andrena quintilis, Andrena wilkella, C. inaequalis, Lasioglossum paraforbesii, Lasioglossum perpunctatum, Lasioglossum semicaeruleum, Lasioglossum versans*, *Melissodes robustior, Osmia iridis, and Osmia caraformis* (GBIF 2023b).
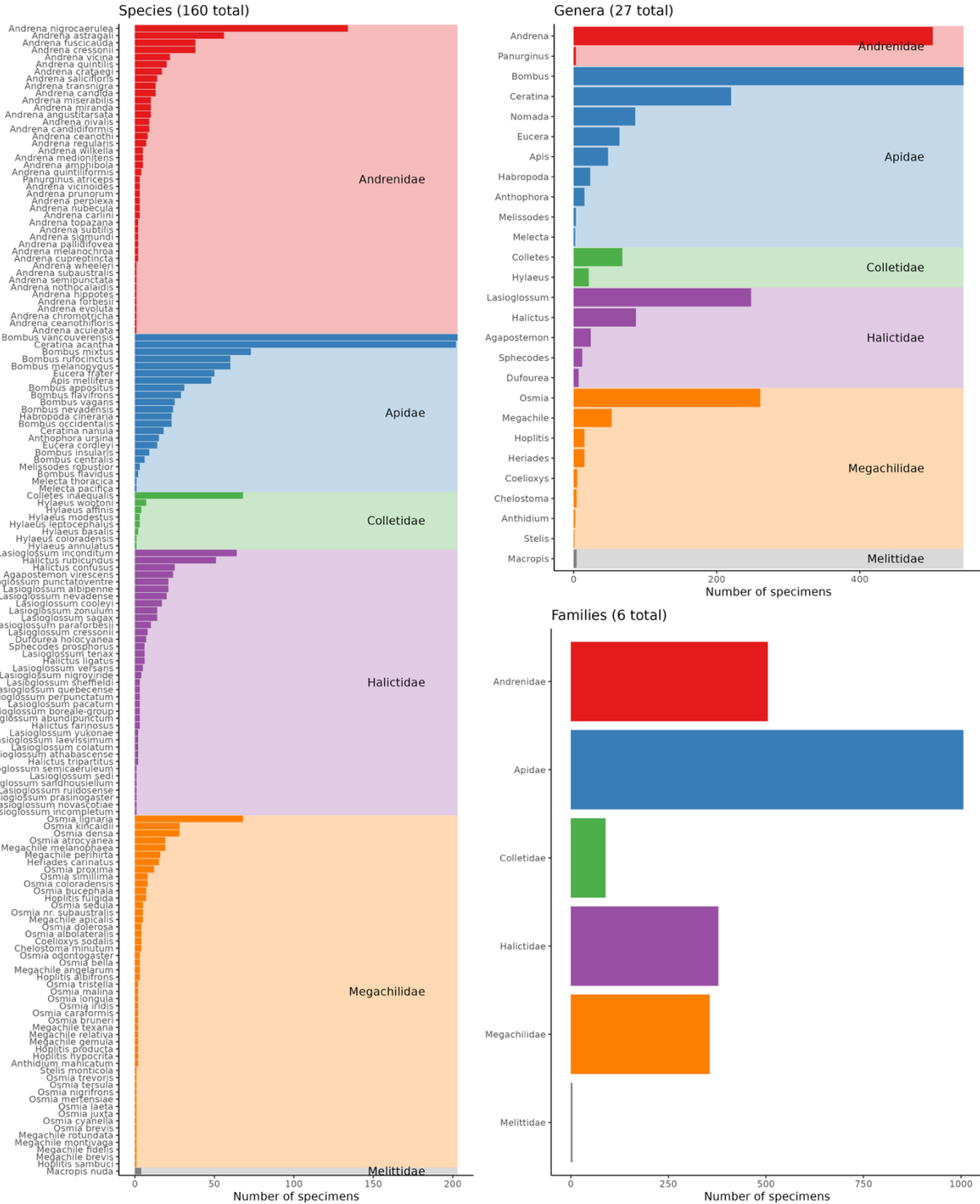
Figure 77. The abundances of species, genera, and families of bees observed across both seasons, with morphospecies counted in genus and family totals, but not added as species.

A few key genera documented in this study are notable. A large proportion of species richness was found within the genus *Andrena,* or mining bees. *Andrena* is an incredibly rich genus with many subgenera and species active in the spring including many floral specialists, and a few subgenera and species active in the summer. The latter of these are almost all specialists of *Asteraceae*. We documented 52 species and morphospecies of *Andrena*, nearly 50% of the 107 total species known from BC, and more than the 50 species found in the better studied Okanagan. Our study also more than doubles the 23 species currently known from the Kootenays (GBIF 2023b). Among these 52 species of mining bees were 10 morphospecies, some of which represent undescribed and additional species.

We detected 39 species of mason bees in the genus *Osmia* in our study. Among these are an undescribed species, and several unidentifiable morphospecies. The species we found make up 40% of those known from British Columbia and doubles the species known from the Kootenays (GBIF 2023b).

There were also many taxa that were unable to be identified to the species level due to a lack of available taxonomic resources and modern revisions. The genus *Nomada* is representative of this problem. These bees are primarily kleptoparasites of the species rich genus *Andrena* in the Nearctic region. Our sampling produced 16 morphospecies, none of which can be reliably identified to species. This taxonomic uncertainty is not limited to the three genera mentioned above. We found that 6% of the total number of bee specimens and 20% of total bee species could not be reliably identified to species.

Colletes inaequalis is one of the bee species newly documented for BC. In contrast to the other new records which were represented by one or a few specimens, *C. inaequalis* was abundant with large and extensive nesting aggregations at low elevation riparian sites from Beaver Creek Provincial Park to Crescent Valley. For example, we observed nesting aggregations in sandy soil greater than 400 m^2 near the camas population at Beaver Creek. Additional large populations were associated with camas at Millennium Park and at sites outside the study sites along the Columbia River. The fact that this abundant, large bee could go unnoticed until now again highlights the importance of pollinator monitoring, and how little is known about the bees of the West Kootenay region.
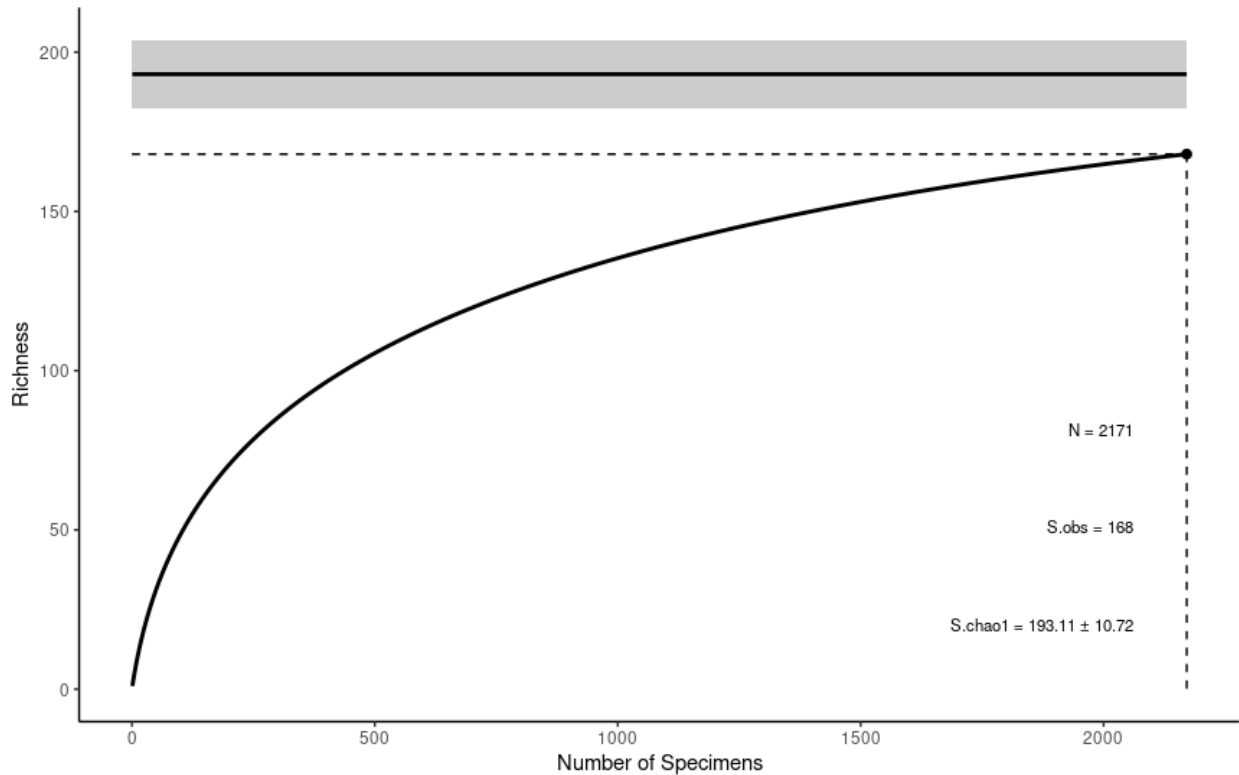
Figure 88. Species accumulation curve across all sites and for both seasons (2021, 2022). N is the number of individuals, S.obs is the number of taxa observed (note that these numbers include morphospecies lumped into genera as described in Sect. 4.3), and S.chao1 is the estimate for species richness.

Increased sampling in 2022 (more sampling rounds that started earlier in the season) resulted in a species accumulation curve that came closer to plateauing than the curve for 2021 (see Appendix F). The species accumulation curve in 2022, overall, began to flatten but did not approach a horizontal asymptote, even when both years are combined (Figure 8). This indicates that many bee species in the community have not been detected. This result is not unexpected, as the effort (in this case specimens collected) required to detect the final few species rises sharply as accumulation curves plateau (Thomson and Withers 2003). At the individual site level, our sampling was less complete, with species accumulation curves not approaching horizontal asymptotes, and the estimates of richness indicating many additional species are expected with additional sampling. Overall, despite imperfect site level resolution, our sampling appears to have captured much of the considerable bee diversity present and provides a baseline for future studies.
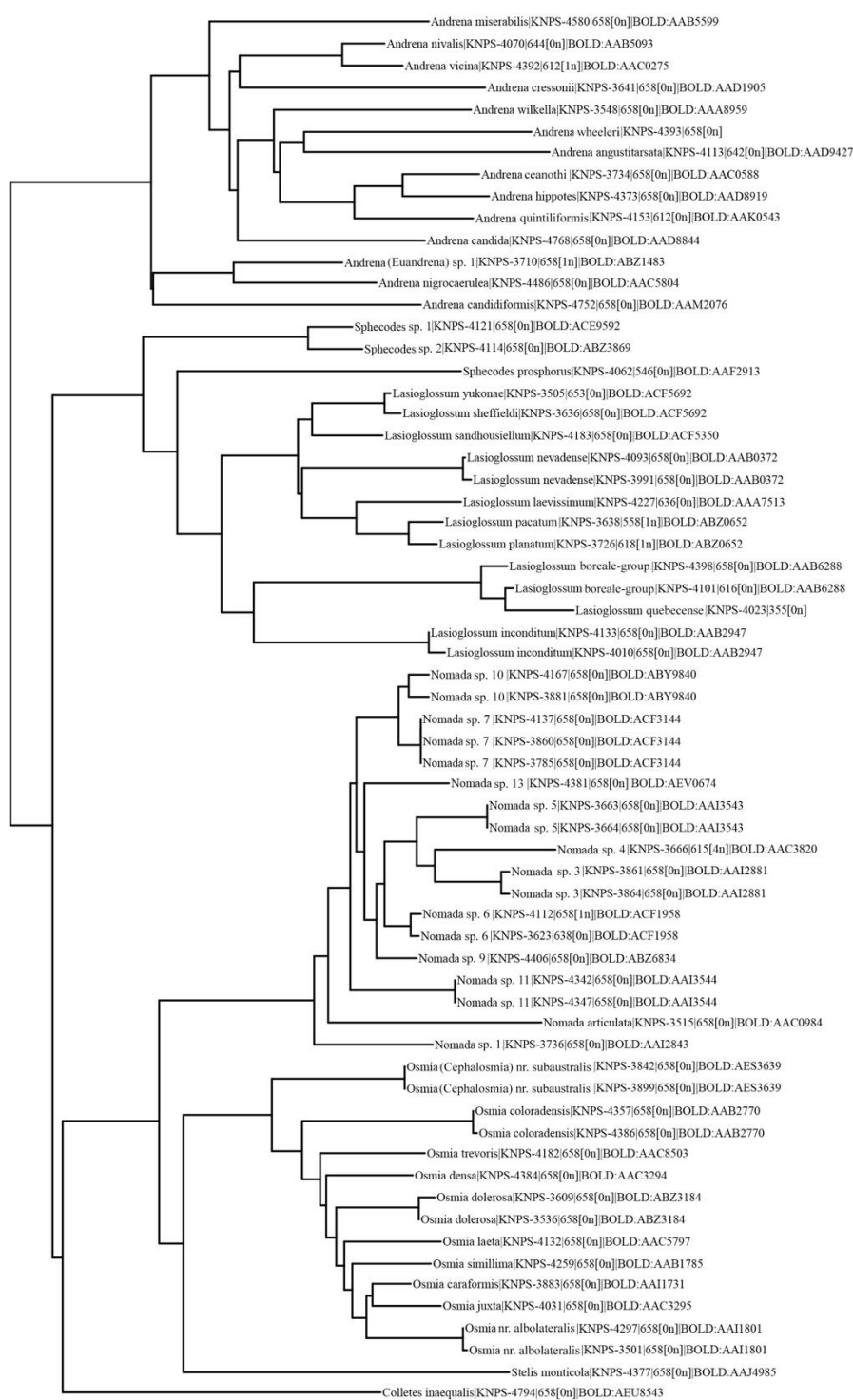
Figure 99. A neighbour-joining tree using the Kimura 2 parameter of 64 COI sequences aligned using the BOLD aligner. Branches longer than approx. 1.5% represent likely species groups. Branch ends are labeled with 1) taxon, 2) SpecimenID, 3) sequence length, and 4) Barcode Index Number (BIN).

5.3.2   DNA Barcoding

Sixty-six specimens were submitted for DNA barcoding resulting in 64 sequences ranging from 355-658 base pairs (bp) long. Sixty-one of these are very high-quality sequences greater than 600 bp in length. A neighbour-joining tree (Figure 9) illustrates the divergence between these sequences with the horizontal branch length where branches greater than approximately 1.5% long are a generalized indication of species' boundaries. Closely clustered groups represent multiple individuals of a single species. Using an iterative method incorporating morphological characters, identification resources, and assessment of nearest neighbour analysis among molecular voucher material, 49 species and morpho-species were identified and sexually dimorphic males and females for some species were associated. This enabled the recognition of species known to science, some new species, and aided in the delineation of species boundaries for some very poorly known species and species groups.

Significantly, one species of *Andrena* from our study, *Andrena (Euandrena) sp. 1* (KNPS-3710) represents a new species of mining bee. The genus *Andrena* has recently been revised (Pisanty et al. 2022) and the subgenus *Euandrena* has been synonymized with *Ptilandrena.* This unknown species is consequently a *Ptilandrena.* Additionally, a new species of mason bee, *Osmia (Cephalosmia) nr. subaustralis* (KNPS-3842; KNPS-3899) fits the diagnosis for the subgenus *Cephalosmia* but does not match any of the known species. COI data supports a closer relationship to *O.subaustralis* than other species in the subgenus.

5.4   Plant-Pollinator Floral Relations

Continued sampling in 2022 resulted in increasing the number of floral interactions recorded, identifying novel plant-bee interactions not previously known, gaining a better understanding of the relationships among the abundances of plant flower inflorescences and bees and pollen limitation in camas, and generating a list of priority plants for bee conservation.

5.4.1   Floral Interactions and Plant-Pollinator Networks

The 2022 plant-bee network involved 1610 documented interactions, consisting of 518 unique plant-bee combinations, involving 71 plant species and 156 bee species and morphospecies. Across both years, there were a total of 2302 interactions documented, consisting of 738 unique plant-bee combinations involving 81 plant species and 207 bee species and morphospecies. Bipartite network metrics describing the structure of networks are known to be correlated to network size, making comparisons and interpretation between years, sites, and seasons difficult without null modeling. Such modelling is

beyond the scope of this report and will be presented in R. Rampton's upcoming MSc Thesis, and likely in future scientific journal publications as well.

As can be seen in Figure 10 below, and in additional interactive networks developed by R. Rampton (see Appendix G for online links), camas was a key member of the network, supporting members of all five bee families detected in 2022, as well as 14 genera, 57 species, and 15 morphospecies. We also documented visits to camas by the threatened bumble bee, *Bombus occidentalis*, with half of the records involving interactions with camas.

Many floral interactions are poorly documented, and our dataset contains many novel combinations. For example, *Chelostoma minutum* is only known in BC from publicly available records in the Okanagan (GBIF 2023b). Through our work we can now expand its range to the West Kootenay and confirm a floral interaction between *C. minutum* and *Sedum stenopetalum,* that was previously suggested based on studies of nest pollen provisions (Parker 1988), but not documented in Canada. We also found contradictory results to research by Cane (2018) on the pollination of *Toxicoscordion venenosum*. In the paper, the author describes *T. venenosum* as being visited nearly exclusively by *Andrena astragali,* with only occasional visits by other *Andrena*. Cane (2018) suggests this is a rare case of mutual specialization in which a pollinator visits only one type of plant and the plant is only pollinated by that single pollinator. Our data confirmed that *Andrena astragali* is specialized on *T. venenosum,* but we found five other species of *Andrena* visiting *T. venenosum,* including evidence of pollen collection, indicating visits were more than simply incidental.

Another floral interaction we found contradictory evidence for was visitation of camas by the introduced European Honeybee, *Apis mellifera*. Parachnowitsch and Elle (2005) found honeybees to be a frequent visitor of camas flowers in Garry oak and camas meadows on the BC coast. In contrast, we found a total of two honeybees visiting camas across both years. The frequency of beekeeping and resulting honeybee abundance is likely lower in the West Kootenay, but there may also be temperature limitations, where temperatures are not adequate for honeybees to forage vigorously, or forage far from hives during camas bloom in this region. Most honeybees (47 of 48 individuals) were observed during June and July largely foraging on introduced plants, such as *Potentilla recta*, *Centaurea stoebe*, and *Vicia villosa,* but also on the native shrub *Symphoricarpos albus*.
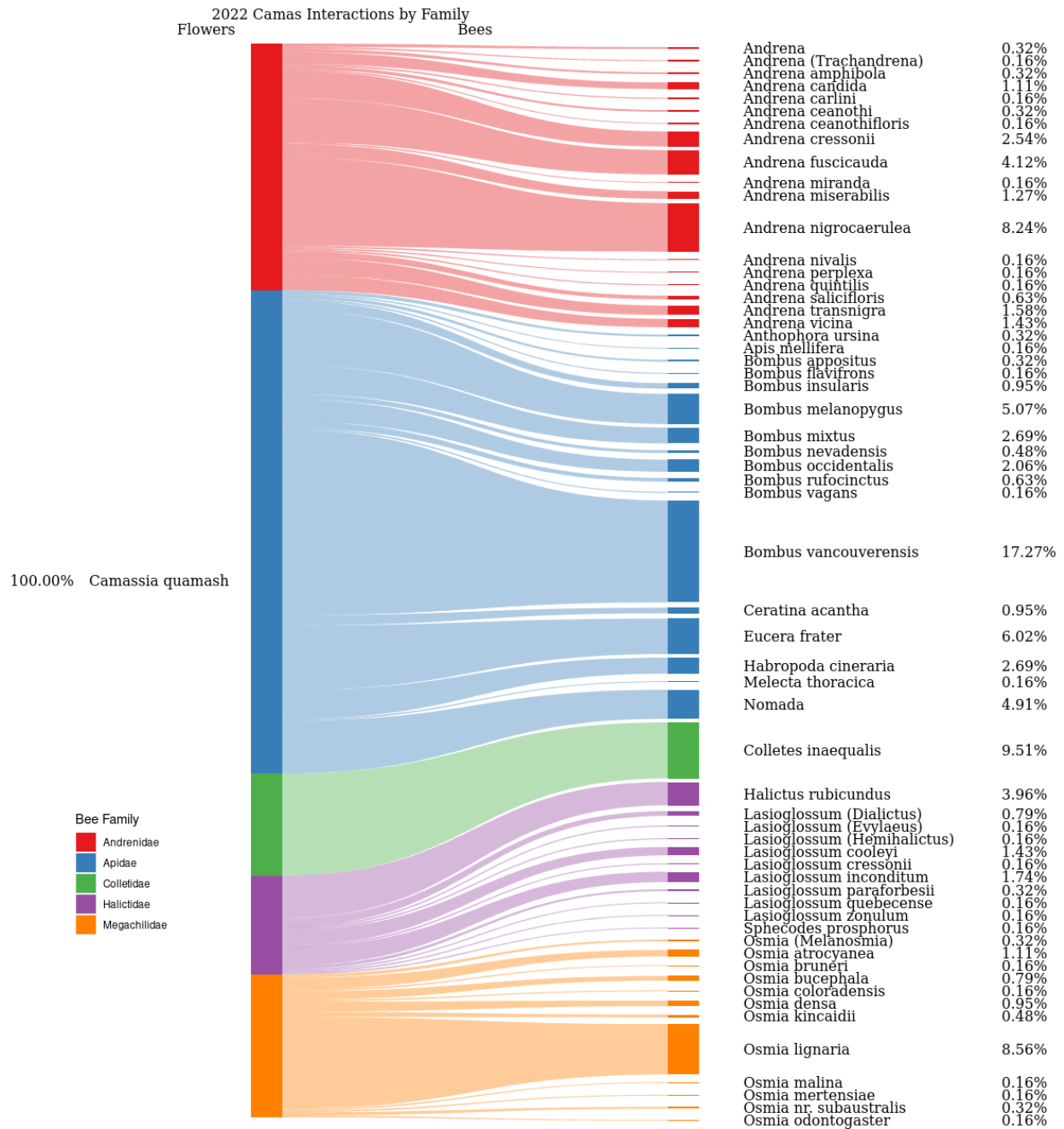
Figure 1010. Interaction network of Camassia quamash *and bees, coloured by family group. Percentages represent the frequency at which each interaction occurred out of the total interactions recorded over the field season 2022.*

The relationship between plant and bee abundance was investigated through the season. Figure 11 below shows similar trends between the two across sampling rounds. In general, when floral resources are abundant, bees are abundant. This relationship was formally modeled for the 2022 data using

Generalized Additive Models (GAMs) that allow for non-linear relationships and can account for relationships over time (including autocorrelation between observations similar in time). The model that explained the most variation in bee abundance involved native plant inflorescence abundance and day of year. The same model was also best at explaining variation in bee species richness. There was a positive relationship between native plant inflorescences and bee abundance, after controlling for changes in abundance over the season (see Appendix H). One criticism of net sampling is that because flowers are attractive to bees, the abundance of net sampled bees will to some degree be intrinsically linked with floral abundance, and not necessarily related to true bee abundance. However, recent mark-recapture studies have shown that among typical bee sampling methods, netting is the most related to true abundance (Briggs et al. 2022).

Several of the most abundant bee taxa in the meadows (e.g., *Bombus vancouverensis* & *Osmia lignaria)* rely on camas for a significant portion of their floral interactions, and vice versa, camas relies on many of the most abundant bee taxa (many of which are bumble bees but see Figure 7). Despite the abundance of visits and reliance on camas, the networks provided via online links in Appendix G show us that camas does not support all pollinators by itself. Instead, floral resources are required through the season, which can be demonstrated by the most abundant bumblebee, *B. vancouverensis.* It visits 16 other flowering plants, many of which flower at different times to camas. *Allium cernuum* is one example, flowering from late June to late July, as well as *Berberis aquifolium,* which flowers 2-3 weeks after camas, in mid-May to mid-June depending on elevation. With floral interaction data, it is possible to identify plants that ensure bees are provided with local resources across the season. Not needing to disperse to other areas to find food increases the likelihood that bees will be able to make use of camas meadows as stable, high-quality habitat. This in turn contributes to stable pollination services for camas and other flowering plants, and ultimately leads to a functional, self-sustaining ecosystem.
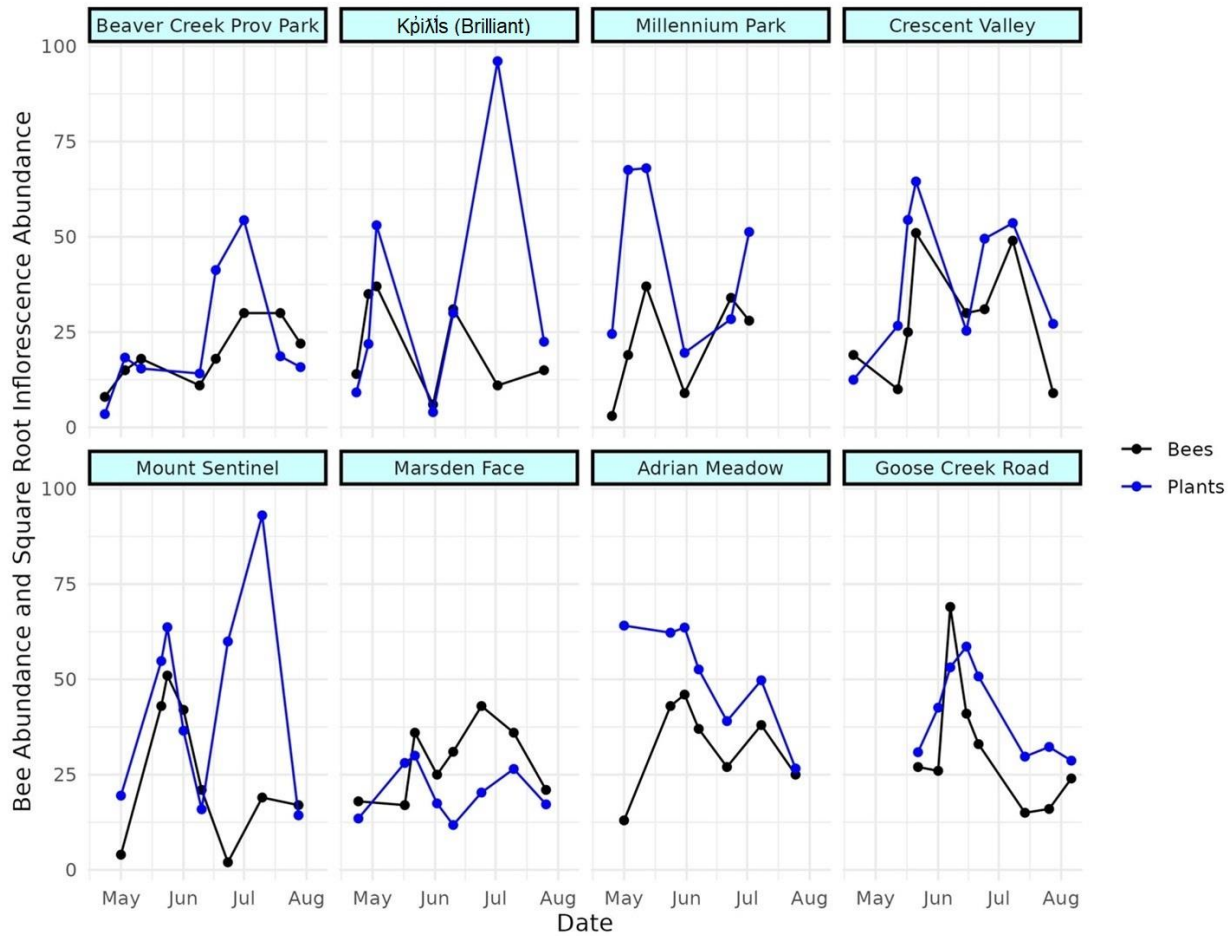
Figure 1111. Comparison of bee abundance and plant inflorescence abundance over time. Plant points represent the square root of the total floral abundance of inflorescences. Sites are ordered from lowest elevation in the top left (Beaver Creek) to highest elevation at the bottom right (Goose Creek).

5.4.2   Pollen Limitation Experiment

A pollen limitation experiment was completed to measure an outcome of floral relations: plant reproduction (Figure 12). All sites began with 20 plants each in the open and pollen added treatments, with the Goose Creek Road site beginning with 40 per treatment, as herbivory was observed to be high before beginning sampling. There were losses in sample size due to herbivory at several sites, from submersion due to high water levels in riparian sites, as well as to overgrowth by invasive vegetation. There was a relatively high fruit set failure rate within the inflorescences that reached seed production, with almost 30% failing to produce any seeds. This is a case of zero-inflation, which violates the normality assumptions of typical statistical models. In addition to zero inflation, the data are also

counts, and so require a generalized modeling approach to account for the non-normal distribution of count data. A zero inflated, negative binomial (ZINBI) model can accept this type of data, and was used to fit the subsequent models, via the R package GAMLSS (Rigby and Stasinopoulos 2005).
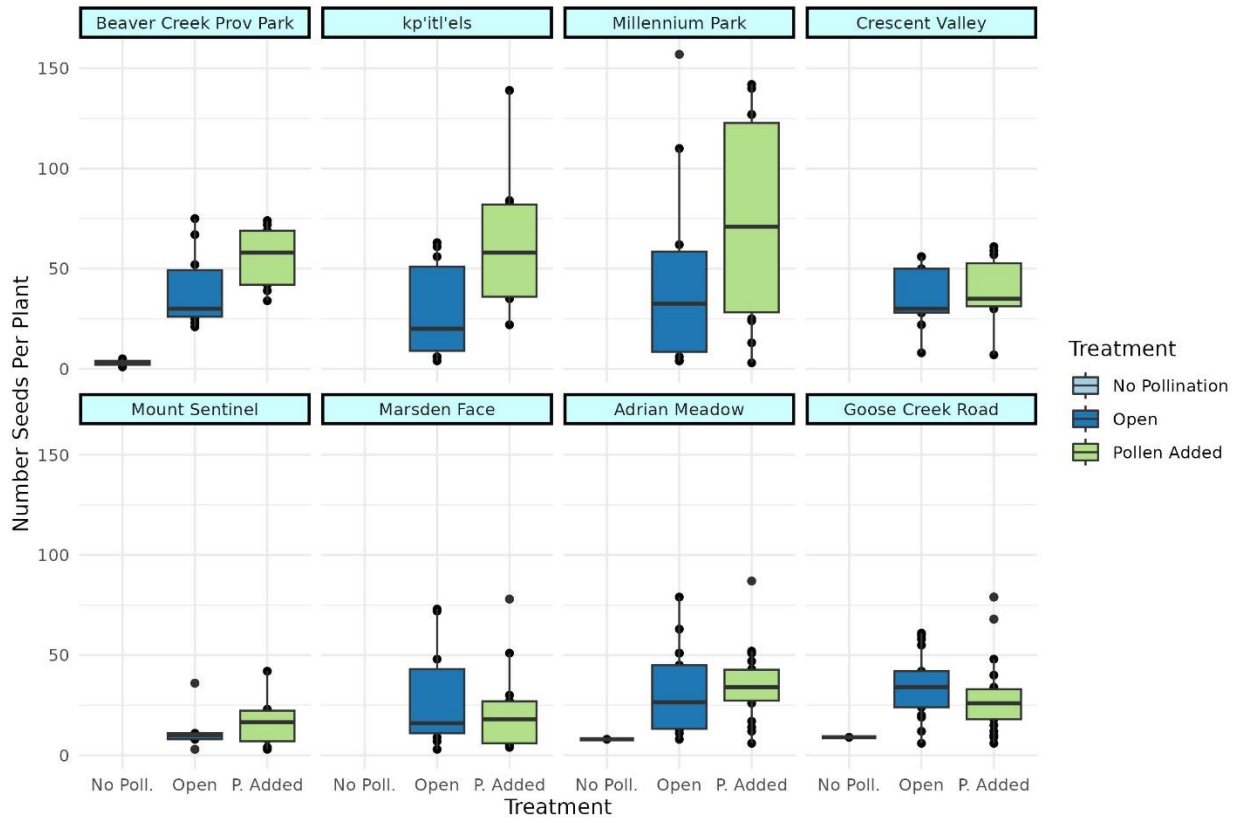
Figure 1212. Mean number of seeds produced per plant for each pollination treatment: none, open, and pollen-added at all sites.

The goal was to compare seed production between treatments; any increase in seed production of the hand pollinated treatment relative to the open pollinated treatment indicates that reproduction is not at maximum capacity (i.e., reproduction is pollen limited). The ZINBI model used allows seed set success/failure to be modeled separately from quantity of seeds produced.

First, the factors relating to seed set success or failure were explored, *i.e.*, whether an inflorescence produced more than zero seeds or zero seeds, respectively. The variable that explained the most variation in seed set was amount of precipitation during bloom; though in the reverse of the expected direction, with more precipitation relating to a higher likelihood of successfully producing seeds. In

separate models, elevation, and abundance of introduced inflorescences were each significantly, but negatively, related to seed set success, though these models explained less variation than the model with precipitation as the variable explaining success.

Increased precipitation had a counterintuitive positive relationship with probability of seed set success. One possibility is that camas is limited by precipitation during bloom, and more rain results in greater contribution to reproductive effort. More likely, is that the precipitation data was based on an average of nearby Nelson and Castlegar weather stations (ECCC 2023), which do not represent the true level of local precipitation at each site. Elevation and quantity of introduced plant inflorescences were also significantly negatively related to probability of seed set success. Unfortunately, the three variables were correlated, limiting our ability to untangle the influence of each on seed set success. It is also possible that the variables above are correlated with an unmeasured variable that drives seed set success.

Second, factors relating to number of seeds produced were modeled. The best model indicated that number of seeds produced depends on number of flowers per plant, elevation, and precipitation (number of rainy days during bloom). The variables elevation, number of flowers, and number of rainy days during bloom were all significant, while pollination treatment was marginally significant. Elevation was negatively related to number of seeds produced, while number of flowers and number of rainy days were both positively related to number of seeds produced. Being a member of the open pollinated group was associated with a decrease in seeds produced, however, this was less than a one seed decrease in seed production on average.

The negative relationship between seed production and elevation suggests that conditions are harsher for camas at higher elevation, making seed production more difficult as a result. Number of flowers was positively related to seed production, which is expected, as number of flowers per plant is a proxy for plant size and resource availability (Gielens et al. 2014), both of which relate to greater seed production capacity. This is mainly important to control for when modelling but also suggests that larger plants are important in terms of their ability to contribute offspring to populations. Rainy days were positively associated with number of seeds produced, with the potential explanations like those described for seed set success, where local weather stations may not have been local enough, and the variable representing rainy days may be correlated with another unmeasured variable. Finally, there was

marginal significance of the hand pollination treatment, indicating that after controlling for the previous factors, there was pollen limitation detected, albeit at very low levels.

Flowers in the pollinator exclusion treatment failed to produce seeds in almost all cases, confirming previous results from Garry oak and camas meadows (Neame 2009), indicating that sexual reproduction in camas requires pollination.

In summary, there was a marginally significant, small effect of pollen limitation treatment detected, but other factors mattered more for seed production, including elevation, plant size, and weather.

5.4.3   Priority Plants for Conservation and Restoration

The plant mix selection tool developed by M'Gonigle et al. (2017) was adapted to include the ability to choose a mix of plants that maximizes plant-pollinator network robustness in addition to its included functions that maximize bee abundance, species richness, and phenological coverage.

After removing invasive plant species from the input data, plant mixes were generated for all sites combined, as well as for each site type (bedrock and riparian), which were split into early and late season as defined in Section 5.2. The results can be seen in Table 4 below. There were distinct groups of plants represented in each site-season combination, showing the necessity of creating distinct mixes for the distinct combinations. Plants that appear in both site types as well as the overall list are likely to be safe choices for all sites, while those that appear in only one site type are likely to be specific to that type. Some mid-season species appear in both the early and late subsets of a season. Site specific characteristics should still be considered when making planting decisions, but these plant mixes provide a starting point for restoration and represent priority plants for supporting the bees of camas meadows in the West Kootenay.

Table 4. Priority native plant list for ecological restoration. 'All Sites' indicate plant species that are highly recommended for both bedrock and riparian camas communities. 'Early' and 'late' refer to timing of peak camas bloom of plant community. 'Value Level' indicates the total number of instances that the plant species is recommended across all camas communities. Shrub species are in bold.

Plant Species	Both Sites	Bedrock Early	Bedrock Late	Riparian Early	Riparian Late	Value Level
Achillea millefolium				X		1
Allium cernuum	X		X		X	3
Arctostaphylos uva-ursi	X			X		2
Berberis aquifolium		X		X		2

Camassia quamash	X	X		X		3
Claytonia lanceolata	X	X		X		3
Collinsia parviflora	X	X		X		3
Crataegus douglasii				X		1
Delphinium sutherlandii	X	X				2
Drymocallis glandulosa	X		X			2
Erythranthe guttata	X	X	X			3
Hieracium scouleri					X	1
Holodiscus discolor	X		X			2
Lomatium ambiguum	X	X				2
Lomatium triternatum				X		1
Lupinus sericeus	X			X	X	3
Microseris nutans	X		X			2
Microsteris gracilis				X		1
Montia linearis		X				1
Montia parvifolia	X					1
Penstemon confertus				X		1
Perideridia gairdneri	X		X			2
Physocarpus malvaceus	X	X				2
Prunus virginiana	X	X				2
Ranunculus glaberrimus				X		1
Rosa nutkana	X				X	2
Sedum stenopetalum	X		X			2
Symphoricarpos albus	X		X		X	3
Toxicoscordion venenosum	X	X	X			3
Triteleia grandiflora		X				1
Vicia americana			X			1

6   Discussion

Our investigations of floral relations of bees in camas meadows provide robust baselines of plant diversity, bee fauna, and the interactions of bees and flowers in plant-pollinator networks. Our studies have increased knowledge of community structure in upland camas meadows in the West Kootenay (FWCP 2019a See Priority Action COLUPD.SOI.ME.33.01 in FWCP [2019a]). Documenting these plant-pollinator networks has provided us with a robust, though incomplete, baseline of plant, bee, and interaction data between the two. Our networks act as a baseline indicator of ecosystem health and function in these meadows and provide guidance for conservation and restoration.

Floral transect data provides additional information about forb diversity in these meadows, the availability of floral resources throughout the growing season, and the structure of the floral resource

community. This is useful for developing goals for restoration that include abundant, diverse floral resources, as well as evaluating restoration success and changes under climate change.

The phenology data establishes baseline information on the timing of bloom for many of the flowering plants found in camas meadows, including how they differ across elevation. This will allow optimization of the timing of management decisions, as well as future evaluation of the impacts of climate change on the timing of floral resources in camas meadows.

The bees documented in camas meadows represent more than 40% of bee species known to be present in BC, as well as two thirds of bee genera, and all six families (Sheffield and Heron 2018). This richness was found within eight small and fragmented habitat patches, collectively representing no more than two square kilometers. The surrounding landscape is undoubtedly also important in maintaining such diverse bee communities, but by protecting these meadows, a significant portion of the bee fauna of BC and Canada can be provided with critical habitat.

Species accumulation curves showed that while many of the bee species present were detected, there are still many bee species that went undetected. Additionally, within the collected specimens, there are many taxa that cannot be identified to species due to a lack of taxonomic revisions in Northwestern North America.

The number of new national and provincial bee records, as well as undescribed species present among the samples demonstrates the importance of conducting pollinator surveys, monitoring, and ecological assessment. The baseline data established by the current study represents a small portion of what needs to be done to understand the distribution, phenology, and foraging behaviour of this ecologically important, species diverse, and threatened group. Most bee species in the West Kootenays are data deficient.

Plant-pollinator interaction networks describe not only the species present, but also the patterns of their linkages. These linkages can range from very simple, to complex and interconnected, with camas meadow linkages decidedly the latter. This complexity can also be seen as a measure of ecosystem resilience. Complex networks of plants and pollinators are less impacted by disturbance and can maintain ecosystem services and function in contrast to simple networks with fewer species and interactions.

Floral-relation data from camas meadows produce a network containing hundreds of unique plant-bee interactions. Several of these interactions are novel to science, and fill knowledge gaps, especially at the local level. Sampling the entire community of plant-pollinator networks is even more difficult than detecting bee species, and the floral relations data is almost certainly missing interactions, particularly those involving rare species which can only be detecting with more sampling. Understanding regional floral interactions is necessary to better understand local habitats and identify the plants necessary in ecological restorations to maximize network complexity, stability, and ability to provide the crucial ecosystem service of pollination.

As we have shown, West Kootenay camas meadows are ecologically unique. They occur on sensitive soil types and in complex with many rare and at-risk ecosystems. They do not currently fit within BC's provincial classification system, though it is clear they need to be recognized for their ecological uniqueness and prioritized for conservation, enhancement, and restoration.

Landscape scale conservation should prioritize maintaining the ecological integrity of the plant community, which in turn supports bee biodiversity. Meadows need to be protected from further loss, through development, tree and shrub encroachment, and invasion by non-native species.

Plant-bee networks among the sites clearly demonstrate the critical importance of camas as an early season network hub, or anchor among the communities at these sites. Seventy-two of the 156 bee species and morphospecies interacted with camas during this sample season which effectively organized the plant-pollinator communities into an early-season, camas-associated network, and a later season network consisting of similar amounts of bee species but requiring more plant species to support similar quantities of pollinators. The measured importance of camas in driving species richness and connectivity in early season communities highlights the high ecological value of this flagship species, so sustaining camas communities wherever they occur is essential to supporting bee-plant networks which, in turn, sustain pollination.

Little is known about the pollination status of most plants in our system. The result of our investigation into camas pollination indicates that camas received nearly enough pollen to reach its maximum capacity of seed production, suggesting that its reproduction is currently not limited by a lack of pollinators. About 30% of plants failed to produce any seeds, and there are likely many other factors that influence pollination success including extreme weather events, fluctuating spring temperatures, grazing, and trampling. It may in fact be that camas is acting as a pollinator magnet, attracting a diversity

of pollinators, and facilitating pollination of other flowers in the network. Repeated experiments on pollen limitation in co-flowering species are required before we can draw any conclusions about the stability of pollination in these meadows.

Resilient communities rely on multiple network hubs across the season. Equally important are the specialist interactions identified in our networks. Loss of the plant species that a specialist bee depends on can cause the extirpation of the specialist. It takes a diverse plant community to support such a diverse pollinator community. In analyzing the network, we identified thirty essential plant species in these habitats. Future monitoring, conservation efforts and habitat restoration can focus on maintaining and enhancing populations of these plants to support the greatest abundance and diversity of bees.

Broadening and challenging our perspectives of plant-bee interactions, our understanding of people's relationships to the land and its beings, and our approaches to doing ecological research will help keep our work open, relevant, place-based, and adaptive. The "ʔíʔtxʷǎʔ (Camas) and təptəpqiɬ (Bees)" workshop in May 2022 (see Appendix I) contributes greatly to community and capacity building.

7   Recommendations

Our research results represent an in-depth and comprehensive understanding of the unique, biodiverse, and culturally valuable plant and bee communities in West Kootenay camas meadows. These data will directly contribute to empirically derived conservation actions and nurture more fully realized eco-cultural restoration efforts. However, to support and drive better and more informed conservation decisions in the West Kootenay region and beyond, as well as in other plant communities, more research is necessary. Based on our work, we provide the following recommendations.

7.1   Research

At a regional level there is much more that remains to be discovered about plant-pollinator communities and their floral relations. We recommend extending the geographic and ecological scope of these data collection efforts to include the greater Columbia River watershed. Furthermore, an increase in the scale of data collection efforts could help reconcile the challenge of detecting rare and threatened bee species.

7.2   Eco-cultural Restoration

Conserving camas meadows has been identified as a priority by the Sinixt Confederacy, as well as regional First Nations. Camas shares pollinators with several other traditional food plants present in and around these meadows, including *Allium cernuum* (nodding onion)*, Perideridia gairdneri* (yampah), and *Amelanchier alnifolia* (saskatoon). Pollination is fundamental to, and inherent in, the interconnected nature of ecosystems; the importance of this vital system in the maintenance of populations of plants, mammals, and other organisms that people rely upon for sustenance and culture should not be overlooked. We recommend greater support for continued collaboration and reciprocity with First Nations Elders and knowledge keepers, and communities, together working toward fostering stronger relationships, respectful sharing of knowledge, and measurable land management approaches that serve and honour both ecological and cultural objectives (eco-cultural restoration).

7.3   Conservation and Restoration Actions

Camas meadows support high levels of bee and plant diversity, as well as robust networks that demonstrate high ecosystem function despite continued habitat loss and degradation, as well as the high abundance of introduced plant species. We recommend that conservation of existing habitat be prioritized to ensure the retention of this nationally and provincially significant bee fauna and plant communities.

Additionally, it is necessary to inventory and conserve camas populations that were not part of this project, including but limited to the Columbia River between Castlegar and Trail and the Pass Creek valley, as well as the many camas containing seeps that are visibly blue for a few weeks each spring along Highway 3A between Thrums and Brilliant and up the face of Mount Sentinel.

Within existing sites, there is room for improvement. All sites we studied contained invasive plant species and large quantities were documented at K̓p̓iƛ̓ls (Brilliant) and Mount Sentinel. We recommend that all sites are enhanced by removing the invasive plants and replacing them with the native plant equivalents that fill the same or similar floral resource niches. Our priority plant list has been developed to support bee abundance, species richness, and plant-bee network stability in camas meadows. These plants should be amplified in abundance when already present and used as the building blocks in local ecological restoration efforts.

8   Conclusions

Pollination is a key ecosystem process that supports the foundation of ecosystem productivity, stability, and resilience. Plant-pollinator networks, such as those documented in this study, provide powerful empirical insights into the mutualistic interactions between bees and plants. In this era of biodiversity loss – which includes serious declines in bee abundance and biodiversity – we are in danger of losing species and interactions before they have even been described.

Plant-pollinator networks can be used to describe baseline species abundance and diversity. As shown in this study, bee species richness is little known in the region and far more diverse than previously recognized. There are still dozens of bee species that are unable to be identified using available taxonomic resources. DNA barcoding and integrative taxonomy can reveal some of this hidden diversity and enhance our taxonomic resolution. In addition to providing baseline species diversity, plant-pollinator networks can be analyzed to detect which plants support the greatest diversity of bees and contribute to network integrity. They can reveal specialist mutual interactions between plants and bees, such as *Macropis nuda* that only visits *Lysimachia ciliata*, or the snowberry bee, *Dufourea holocyanea* which only visits *Symphoricarpos albus.* Specialized interactions are the most vulnerable to extinction from ongoing habitat loss though land use conversion, non-native plant invasion, and climate disruption. The effects of non-native plant and bee invasion can be inferred from these networks to develop an understanding of the resilience of communities to invasion. Repeat surveys may be able to detect changes to network structure and serve as an early warning system for the disruption of pollination because of non-native plants and bees, or to the disruptive effects of climate change.

Our efforts to inventory species and their interactions has informed us about these amazing communities, and their community structure. Through our analyses, we have described the key drivers of these community structures, and have identified priority plant species for protection, conservation, and restoration of these unique ecological interactions and evolutionary pathways in these precious camas meadows.

9   Acknowledgements

We are thankful for our community of passionate individuals who see the value of these places, their function, their networks, and their seemingly endless diversity of species. We are inspired to protect and understand these places and to share our passion and knowledge about them to our greater community. Local initiatives are nearly always the product of remarkable individuals, and we thank Eva Johansson and Lynn Westcott for their early vision, engagement, and support towards knowing, conserving, and enhancing these places and ecological communities.

And, of course, we thank the plants and the bees.

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Appendix A. "Meadow Soil Description and Classifications: Amended January 2023;" technical report by Audrey Ehman PAg, January 25, 2023.

Introduction and Methods

In the fall of 2021 and 2022, nine locations from the Kootenay Camas Project were sampled for soil pit descriptions and classifications. Representative sites within the selected Camas Meadows were identified for soil pit description based on the surrounding site attributes. In total, twelve soil pits were dug and described. Soil pits were dug to 60cm, where soil depth permitted. Data were collected on BC Ministry of Forest and Range Ecosystem Field Form (FS822) and followed provincial standards and codes (BCMOFR 2015). All appropriate fields on the site and soils cards were filled in at each site; soil and humus structure were excluded. Field observations impacting site and soil factors were recorded in the notes section at each location.

Field data cards were scanned and are contained in Digital Appendix I (KNPS_Soils_2021.PDF). These data were entered into VPro, BC's provincial ecosystem software, and exported to Excel for ease of summary (Digital Appendix II: KNPS_soils_2021.xlsx).

Results

Table 1 summarizes the site characteristics for each plot. Of the twelve plots, four occurred in the Very Dry Warm Interior Cedar-Hemlock - warm phase (ICHxwa), seven occurred within the Very Dry Warm Interior Cedar-Hemlock (ICHxw) and one occurred within the West Kootenay Dry Warm Interior Cedar-Hemlock (ICHdw1) (MacKillop and Ehman 2016). Elevation, slope, aspect, and meso slope position varied with site. Locations are contained within the Digital Appendices (I and II).

Table 1: Key site features of Kootenay Camas Meadow sites sampled. Fall 2021 and 2022.

Plot Number	Field Location	BEC Subzone	Elevation (m)	Slope (%)	Aspect (Degrees)	Meso Slope Position
01KNP21	Marsden	ICHxw	608	27	164	Mid-slope
02KNP21	Goose Creek	ICHdw1	1129	20	180	Mid-slope
03KNP21	Kṗiƛ̓ls (Brilliant)	ICHxw	423	16	199	Toe
04KNP21	Kṗiƛ̓ls (Brilliant)	ICHxw	424	3	999	Depression
05KNP21	Playmor	ICHxw	479	0	999	Level
06KNP21	Oxbow Island	ICHxw	420	0	999	Level
12-6380	Millenium Park	ICHxw	429	0	999	Level
14-2117	Millenium Park	ICHxw	435	0	999	Level
14-2118	Beaver Creek	ICHxwa	409	0	999	Level
01-14435	Beaver Creek	ICHxwa	406	6	280	Lower
01-14436	Fort Shepherd	ICHxwa	404	15	78	Lower (Toe)
01-14438	Fort Shepherd	ICHxwa	410	12	78	Lower

Soil moisture regimes (SMR) varied from xeric (SMR 1) to subhygric (SMR 5) (Table 2; BCMOFR 2020). Soil nutrient regimes ranges from Medium (C) to Rich (D). Sites occurred on shallow, weathered-bedrock soils with Orthic Humic Regosols (O.HR) or on deep, fluvial-derived soils with a variety of Brunisolic soils deepening on pH, Humic enriched A-layer, and the presence or absence of mottling/gleying. Humic enriched A-layer horizons (Ah) of variable depths were found at all locations. Additional site and soil data are contained in Digital Appendices I and II.

Table 2: Key soil features at the Kootenay Camas Meadow sites. Fall 2021 and 2022.

Plot Number	SMR	SNR	Dominant Soil Texture	Overall Soil Depth (cm)	Ah Depth (cm)	Parent Material	Soil Classification[a]
01KNP21	1	C	SL	19	18	Weathered bedrock	O.HR
02KNP21	1	C	SL	9	9	Weathered bedrock	O.HR
03KNP21	5	D	SL	>100	5	Fluvial	GL.MB
04KNP21	4	C	SL	>100	7	Fluvial	O.MB
05KNP21	3	C	SL	>100	15	Fluvial	O.MB
06KNP21	5	C	SL	>100	15	Fluvial	GL.MB
12-6380	4	C	LS	>100	N/A	Fluvial	GL.EB
14-2117	4	C	SL	>100	N/A	Fluvial	O.EB
14-2118	4	C	LS	>100	10	Fluvial	O.SB
01-14435	4 (5)	C	LS	>100	15	Fluvial	O.MB
01-14436	5	C	LS	>100	11	Fluvial	GL.MB
01-14438	5	C	SL	>100	12	Fluvial	GL.MB

[a]Diagnostic soil classifications can be found in LMH 25 (BCMOFR 2015). Abbreviations used for ease of display. Orthic Humic Regosol (O.HR), Orthic Melanic Brunisol (O.MB), Gleyed Melanic Brunisol (GL.MB), Orthic Eutric Brunisol (O.EB), Gleyed Eutric Brunisol (GL.EB), and Orthic Sombric Brunisol (O.SB).

Discussion

Sites sampled occur on two unique types: shallow soils over bedrock and fluvial-derived soils. Sites are summarized in these groups.

Shallow-Soil Sites

Field locations Marsden (01KNP21) and Goose Creek (02KNP21) occur on shallow soils over bedrock (Table 2). Rich Ah-layers and high pH measurements contribute to high nutrients content within the limited soil profile of these meadows. Although these soils dry out quickly due to their shallow depth, moisture during spring and after rain events is held in the rooting area and highly available to plants

when present (E McKenzie, pers. comm. 2022). Water was observed and noted on the rock surface at the Goose Creek site (Digital Appendix I: KNPS_Soils.PDF).

The shallow soils of the Marsden and Goose Creek sites, make these areas highly sensitive. Erosion-causing activities can be challenging to reverse where soil is already limited. Trail construction, as noted at Goose Creek will likely be difficult to rehabilitate (Digital Appendices I and II). Although vegetation data was not collected, these sites were noted as being non-forested. Lack of shade in these areas may increase the risk of invasive species, where soil depth permits.

Both Marsden Face and Goose Creek Camas Meadows occur in complex with other rare and at-risk ecosystems. Areas of Marsden Face are classified as a non-forested brushland (Gb): Gb03 Ninebark – Oceanspray – Blue bunch wheatgrass (MacKillop and Ehman 2016). This site association is currently in the process of being ranked by the Ministry of Environment Conservation Data Centre (CDC) and will likely be red listed very soon (E. Cameron, pers. comm, 2022). Portions of the Goose Creek site can also be classified as a non-forest rock-outcrop: Ro09.2 (*Rock outcrop*) Saskatoon – Poverty oatgrass – Rock-moss – Clad lichen (MacKillop and Ehman 2016). Although this site association is not listed or ranked with the CDC currently, it is a sensitive ecosystem with numerous rare and at-risk plants and animals associated with its habitat features.

Fluvial-Derived Sites

Sites occurring at ḲṗiȾI̓s (Brilliant), Playmor, Oxbow Island, Fort Shepherd, Millennium Park, and Beaver Creek Provincial Park occur on rich, fluvial- or glacial fluvial-derived soils (Table 2). Five of these plots (02KNP21, 06KNP21, 01-14436, 01-14438, 12-6380) have mottles and gleying within the top 60cm of the soil profile; the other plots on these landforms, likely have mottles deeper in the soil profile. These soils are generally rich in nature with high pH and variable depths of Ah-horizons. Plots 12-6380 and 14-2117 lack Ah horizons.

Soils found in these parent materials are also sensitive to erosion due to their saturation in the spring or at high water times. Level, floodplain areas such as ḲṗiȾI̓s (Brilliant), which was previously accessible to motorized vehicles, shows long term effects of rutting (personal observation, spring 2021). Sites at Millennial, Fort Shepherd, and Beaver Creek Park are all adjacent to recreational hiking trails.

Camas Meadows found on these sites also occur in complex with rare and at-risk ecosystems (MacKillop and Ehman 2016). Of note, the Fm01 (*Middle-bench floodplain*) Cottonwood – Snowberry – Rose is considered a red-listed ecosystem in BC (CDC 2022). Other non-forested and related ecosystem occurring in complex with these floodplain sites could include wetland ecosystems, low bench floodplain (Fl) and active channel floodplains (Fa).

Conclusions and Recommendations

All Camas Meadow sites sampled occur on sensitive soil types and in complex with rare at at-risk ecosystems. Although Camas Meadows do not currently fit within the BC's provincial classification system, it is clear they need to be recognized for their ecological uniqueness and sensitivity. Pairing

existing soils data with completed vegetation sampling following government standards may help initiate the recognition of these important ecosystems.

Sites sampled along the lower Columbia (Fort Shepherd and Beaver Creek) may contain residual smelter impacts. This soils data collection focused on soil moisture and nutrient regimes as well as soil classification, which does not include data around metal concentrations or soil biota. It is recommended that soil chemistry samples be collected and analyzed by a soils lab at these sites to aid in restoration efforts.

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Appendix B. Plant species in 2021 and 2022 transect sampling, separated by type of sampling.

Group 1. Plant Species that were sampled by counting inflorescences.

BC Spp. Code	Common Name	Status	Scientific Name
ACHIMIL	yarrow	native	*Achillea millefolium* L.
ACMIAME	Spanish clover	native	*Acmispon americanus* (Nutt.) Rydb.
ALLICER	nodding onion	native	*Allium cernuum* Roth
AMELALN	saskatoon	native	*Amelanchier alnifolia* (Nutt.) Nutt.
ANTEHOW	Howell's pussytoes	native	*Antennaria howellii* Greene
ANTELUZ	silvery-brown pussytoes	native	*Antennaria luzuloides* Torr. & A.Gray
ANTEROS	rosy pussytoes	native	*Antennaria rosea* Greene
APHYPUR	one flower broomrape	native	*Aphyllon purpureum* (A.Heller) Holub
ARCTUVA	kinnikinnick	native	*Arctostaphylos uva-ursi* (L.) Spreng.
BERBAQU	Oregon grape	native	*Berberis aquifolium* Pursh
BERTINC	hoary alyssum	introduced	*Berteroa incana* (L.) DC.
CAMAQUA	small camas	native	*Camassia quamash* (Pursh) Greene
CAMPROT	common harebell	native	*Campanula rotundifolia* L.
CASTHIS	harsh paintbrush	native	*Castilleja hispida* Benth.
CEANSAN	red-stemmed ceanothus	native	*Ceanothus sanguineus* Pursh
CENTSTO	spotted knapweed	introduced	*Centaurea stoebe* L.
CLAYLAN	lanceleaf claytonia	native	*Claytonia lanceolata* Pursh
COLLLIN	linear-leaved collomia	native	*Collomia linearis* Nutt.
COLLPAR	small-flowered blue-eyed Mary	native	*Collinsia parviflora* Douglas ex Lindl.
CRATDOU	black hawthorn	native	*Crataegus douglasii* Lindl.
DELPSUT	Sutherland's larkspur	native	*Delphinium sutherlandii* M.J.Warnock
DRYMGLA	sticky cinquefoil	native	*Drymocallis glandulosa* (Lindl.) Rydb.
EPILFOL	leafy willowherb	native	*Epilobium foliosum* (Torr. & Gray) Suksd.
ERODCIC	stork's bill	introduced	*Erodium cicutarium* (L.) L'Hér.
ERYTBRE	Brewer's monkeyflower	native	*Erythranthe breweri* (Greene) G.L.Nesom & N.S.Fraga
ERYTGRA	yellow glacier lily	native	*Erythronium grandiflorum* Pursh
ERYTGUT	seep monkeyflower	native	*Erythranthe guttata* (DC.) G.L. Nesom
FRAGVES	wild strawberry	native	*Fragaria vesca* L.
FRAGVIR	strawberry	native	*Fragaria virginiana* Duchesne
HETERAR	heterocodon	native	*Heterocodon rariflorum* Nutt.
HEUCCYL	roundleaf alumroot	native	*Heuchera cylindrica* Douglas
HIERPIL	hawkweed	introduced	*Hieracium piloselloides* Wallr., 1822
HIERSCO	Scouler's hawkweed	native	*Hieracium scouleri* Hook.
HOLODIS	oceanspray	native	*Holodiscus discolor* (Pursh) Maxim.
HYPEPER	St. john's wort	introduced	*Hypericum perforatum* L.
LAMIAMP	henbit deadnettle	introduced	*Lamium amplexicaule* L.
LAMIPUR	red deadnettle	introduced	*Lamium purpureum* L.

LEUCVUL	oxeye daisy	introduced	*Leucanthemum vulgare* Lam.
LEWITRI	three leaf lewisia	native	*Lewisia triphylla* (S.Watson) B.L.Rob.
LILICOL	Columbia lily	native	*Lilium columbianum* Leichtlin
LINADAL	dalmatian toadflax	introduced	*Linaria dalmatica* (L.) Mill.
LITHPAR	small-flowered woodland-star	native	*Lithophragma parviflorum* (Hook.) Nutt. ex Torr. & A.Gray
LOMAAMB	Wyeth biscuitroot	native	*Lomatium ambiguum* (Nutt.) J.M.Coult. & Rose
LOMAMUL	fern-leaved desert-parsley	native	*Lomatium multifidum* (Nutt.) R.P.McNeill & Darrach
LOMATRI	ternate desert-parsley	native	*Lomatium triternatum* (Pursh) J.M.Coult. & Rose
LUPISER	silky lupine	native	*Lupinus sericeus* Pursh
LYSICIL	fringed loosestrife	native	*Lysimachia ciliata* L.
MAIASTE	star-flowered false Solomon's seal	native	*Maianthemum stellatum* (L.) Link
MELIALB	white sweet-clover	introduced	*Melilotus albus* Medik.
MICRNID	peak saxifrage	native	*Micranthes nidifica* (Greene) Small
MICRNUT	nodding/smooth microseris	native	*Microseris nutans* (Hook.) Sch.Bip.
MONTLIN	narrowleaf miner's lettuce	native	*Montia linearis* (Douglas ex Hook.) Greene
MONTPAR	small-leaved montia	native	*Montia parvifolia* (Moc. ex DC.) Greene
MYOSSCO	water forget-me-not	introduced	*Myosotis scorpioides* L.
PACKPAU	balsam ragwort	native	*Packera paupercula* (Michx.) Á.Löve & D.Löve
PENSCON	yellow penstemon	native	*Penstemon confertus* Douglas
PERIGAI	Gairdner's yampah	native	*Perideridia gairdneri* (Hook. & Arn.) Mathias
PHILLEW	mock-orange	native	*Philadelphus lewisii* Pursh
PHYSMAL	mallow-leaved ninebark	native	*Physocarpus malvaceus* (Greene) Kuntze
PILOCAE	meadow hawkweed	introduced	*Pilosella caespitosa* (Dumort.) P.D.Sell & C.West
POLYMIN	broadleaf knotweed	native	*Polygonum minimum* S.Watson
POTEREC	sulphur cinquefoil	introduced	*Potentilla recta* L.
PRIMPAU	dark-throated shooting star	native	*Primula pauciflora* (Durand) A.R.Mast & Reveal
PRUNVIR	choke cherry	native	*Prunus virginiana* L.
PRUNVUL	self-heal	introduced	*Prunella vulgaris* L.
RANUGLA	sagebrush buttercup	native	*Ranunculus glaberrimus* Hook.
ROSANUT	Nootka rose	native	*Rosa nutkana* C.Presl
SEDUSTE	wormleaf stonecrop	native	*Sedum stenopetalum* Pursh
SPIRROM	spiranthes	native	*Spiranthes romanzoffiana* Cham.
SUKSRAN	buttercup-leaf suksdorfia	native	*Suksdorfia ranunculifolia* (Hook.) Engl.
SYMPALB	common snowberry	native	*Symphoricarpos albus* (L.) K.Koch
SYMPLAN	western willow aster	native	*Symphyotrichum lanceolatum* (Willd.) G.L.Nesom
TARAOFF	common dandelion	introduced	*Taraxacum officinale* Weber ex Wiggins

| TOXIRYD | poison ivy | native | *Toxicodendron rydbergii* (Small ex Rydb.) Greene |
TOXIVEN	meadow death camas	native	*Toxicoscordion venenosum* (S.Watson) Rydb.
TRAGDUB	yellow salsify	introduced	*Tragopogon dubius* Scop.
TRIFPRA	red clover	introduced	*Trifolium pratense* L.
TRITGRA	large-flowered triteleia	native	*Triteleia grandiflora* Lindl.
VICIVIL	hairy vetch	introduced	*Vicia villosa* Roth
VIOLARV	European field pansy	introduced	*Viola arvensis* Murray

Group 2. Plant species with flowers sampled based on presence-absence

BC Spp. Code	Common Name	Status	Scientific Name
AGOSHET	annual agoseris	native	*Agoseris heterophylla* (Nutt.) Greene
ARABTHA	mouse-ear cress	introduced	*Arabidopsis thaliana* (L.) Heynh.
ARENSER	thyme-leaved sandwort	introduced	*Arenaria serpyllifolia* L.
CAPSBUR	shepherd's purse	introduced	*Capsella bursa-pastoris* (L.) Medik.
CERAFON	mouse ear chickweed	introduced	*Cerastium fontanum* Baumg.
DRABVER	whitlowgrass	introduced	*Draba verna* L.
GALIAPA	cleavers	native	*Galium aparine* L.
GALIPAL	marsh galium	native	*Galium palustre* L.
GERACAR	Carolina geranium	native	*Geranium carolinianum* L.
GERAPUS	small-flowered cranesbill	native	*Geranium pusillum* L.
HEMIMIN	opposite-leaved tarweed	native	*Hemizonella minima* (A.Gray) A.Gray
LEPICAM	field peppergrass	introduced	*Lepidium campestre* (L.) W.T.Aiton
MADIEXI	little tarweed	native	*Madia exigua* (Sm.) Greene
MADIGRA	slender tarweed	native	*Madia gracilis* (Sm.) D.D.Keck & J.C.Clausen ex Applegate
MEDILUP	black medic	introduced	*Medicago lupulina* L.
MICRGRA	slender phlox	native	*Microsteris gracilis* (Hook.) Greene
MYOSARV	field forget-me-not	introduced	*Myosotis arvensis* (L.) Hill
MYOSDIS	changing forget-me-not	introduced	*Myosotis discolor* Pers.
MYOSSTR	strict forget-me-not	introduced	*Myosotis stricta* Link ex Roem. & Schult.
MYOSVER	early forget-me-not	introduced	*Myosotis verna* Nutt.
PLANLAN	ribwort plantain	introduced	*Plantago lanceolata* L.
POTEARG	silvery cinquefoil	introduced	*Potentilla argentea* L.
RUMEACT	sheep sorrel	introduced	*Rumex acetosella* L.
RUMECRI	curled dock	introduced	*Rumex crispus* L.
SCLEANN	German knotgrass	introduced	*Scleranthus annuus* L.
SILEANT	sleepy catchfly	native	*Silene antirrhina* L.
SISYALT	tumble mustard	introduced	*Sisymbrium altissimum* L.
STELMED	common chickweed	introduced	*Stellaria media* (L.) Vill.
STELNIT	shiny chickweed	native	*Stellaria nitens* Nutt.
THLAARV	field penny cress	introduced	*Thlaspi arvense* L.
TRIFARV	rabbitfoot clover	introduced	*Trifolium arvense* L.
TRIFAUR	golden clover	introduced	*Trifolium aureum* Pollich
TRIFDUB	lesser hop-trefoil	introduced	*Trifolium dubium* Sibth.
VALELOC	common cornsalad	introduced	*Valerianella locusta* (L.) Laterr.
VEROARV	corn speedwell	introduced	*Veronica arvensis* L.
VEROOFF	heath speedwell	introduced	*Veronica officinalis* L.

Appendix C. Site names and codes and the sampling round that represented the end of the early season.

Site Name	Site Code	Sampling Round
Adrian's Meadow	ADR	4
Beaver Creek Prov. Park	BEA	3
Crescent Valley	CRV	5
Goose Creek Meadow	GCR	5
K̓ṗiƛ̓ls (Brilliant)	KPI	4
Marsden Face	MAR	5
Millennium Park	MIL	4
Mount Sentinel	SEC	5

Appendix D. Results of NMDS models.
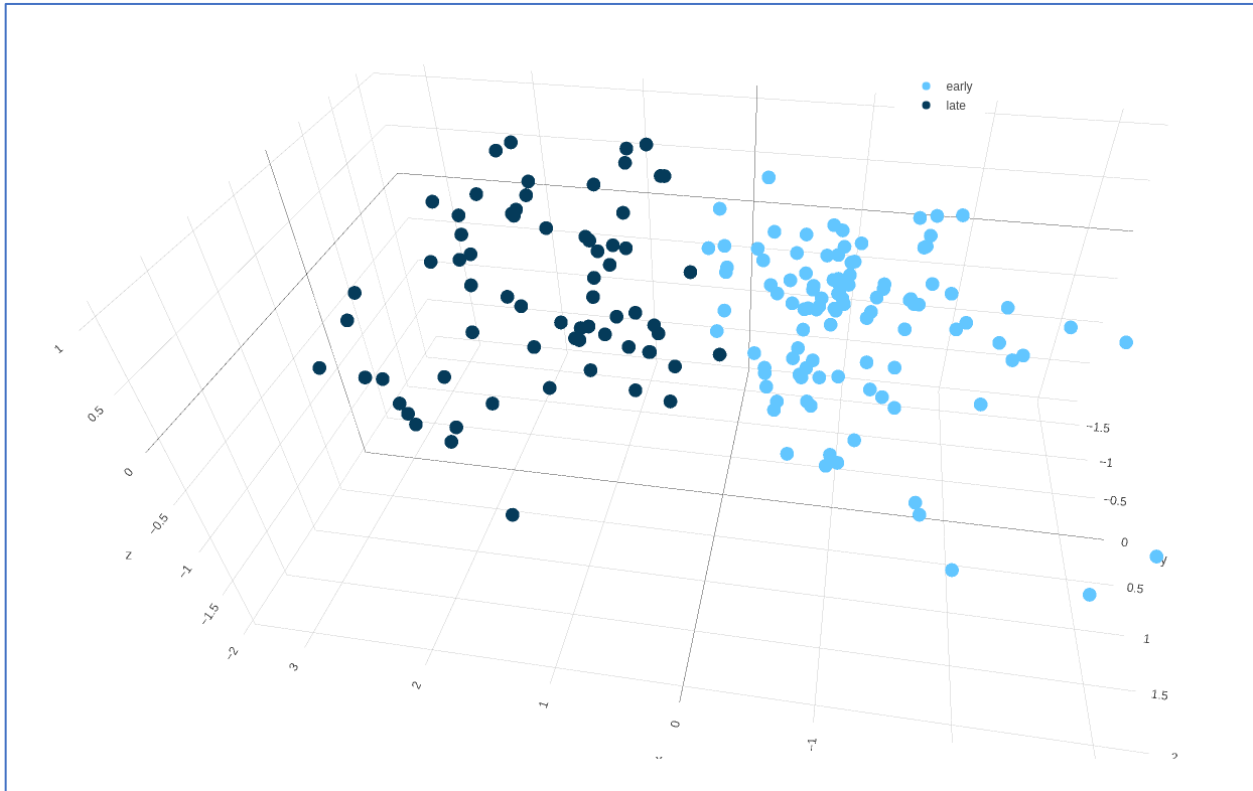
Model 1. The results of NMDS, displayed in 3 dimensions, with x, y, and z corresponding to NMDS axes 1, 2, and 3. Stress = 0.072, k = 3, indicating minimal loss of information when displayed in 3 dimensions. Each sphere shows floral community composition on a given day at a given site. The points are coloured by whether that community was sampled during the early season or the late season.
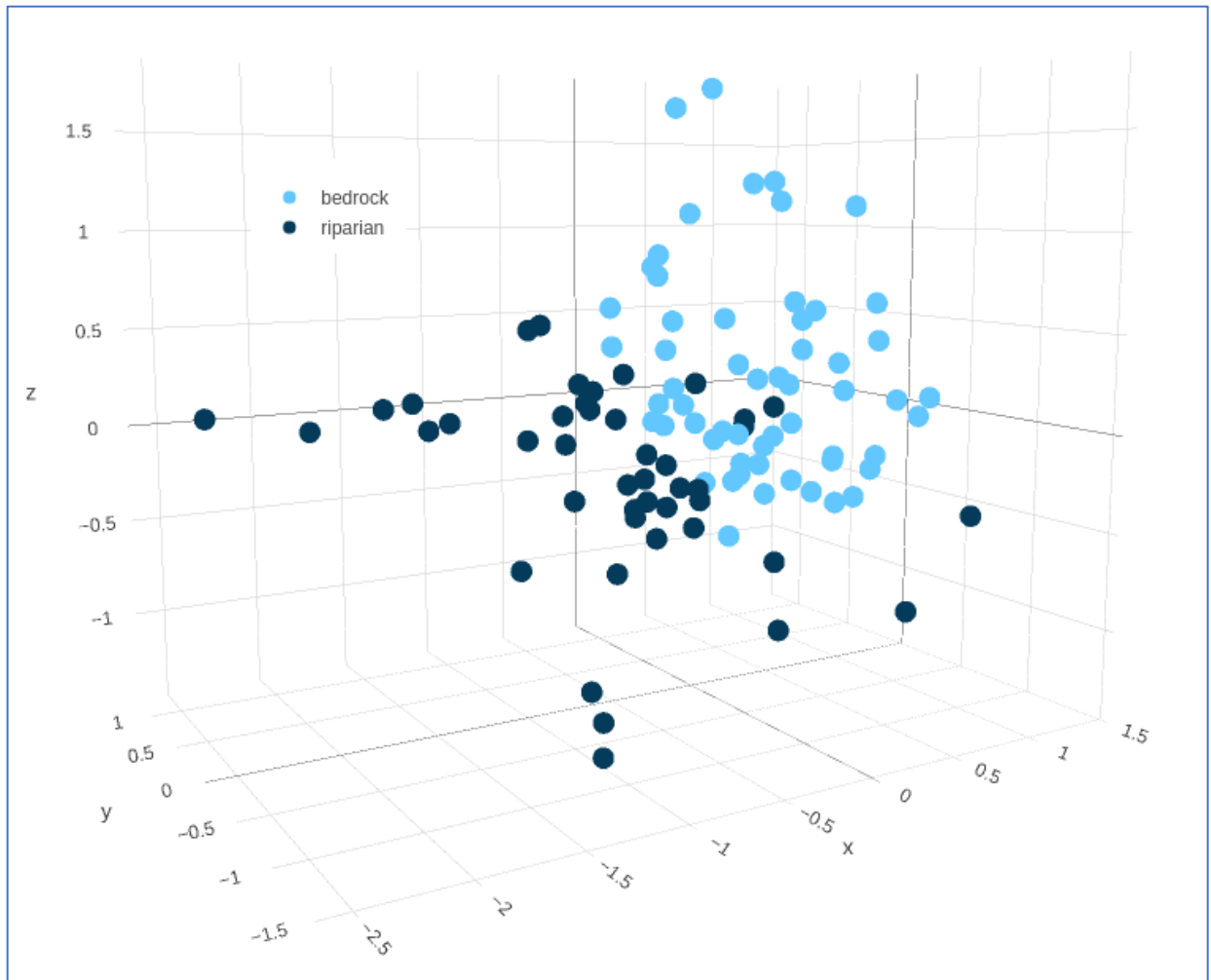
Model 2. Early season floral community NMDS, displayed in 3 dimensions, with x, y, and z corresponding to NMDS axes 1, 2, and 3. Stress = 0.12, k = 3, indicating some, but acceptable loss of information when displayed in 3 dimensions. Each point is coloured by whether it was a sample from a bedrock meadow or a riparian meadow.
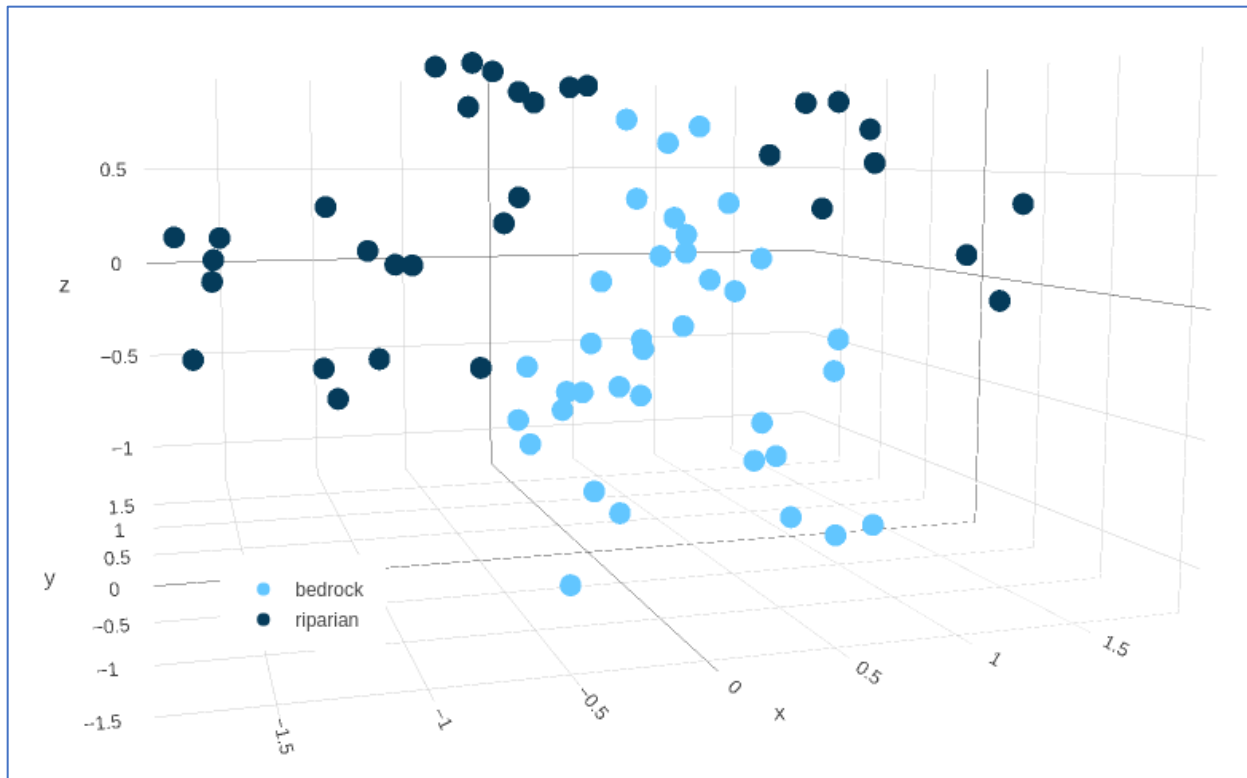
Model 3. Late season floral community NMDS, displayed in 3 dimensions, with x, y, and z corresponding to NMDS axes 1, 2, and 3. Stress = 0.11, k = 3, indicating some, but acceptable loss of information when displayed in 3 dimensions. Each point is coloured by whether it was a sample from a bedrock meadow or a riparian meadow.

Model 4. Early season floral community NMDS, elevation, displayed in 3 dimensions, with x, y, and z corresponding to NMDS axe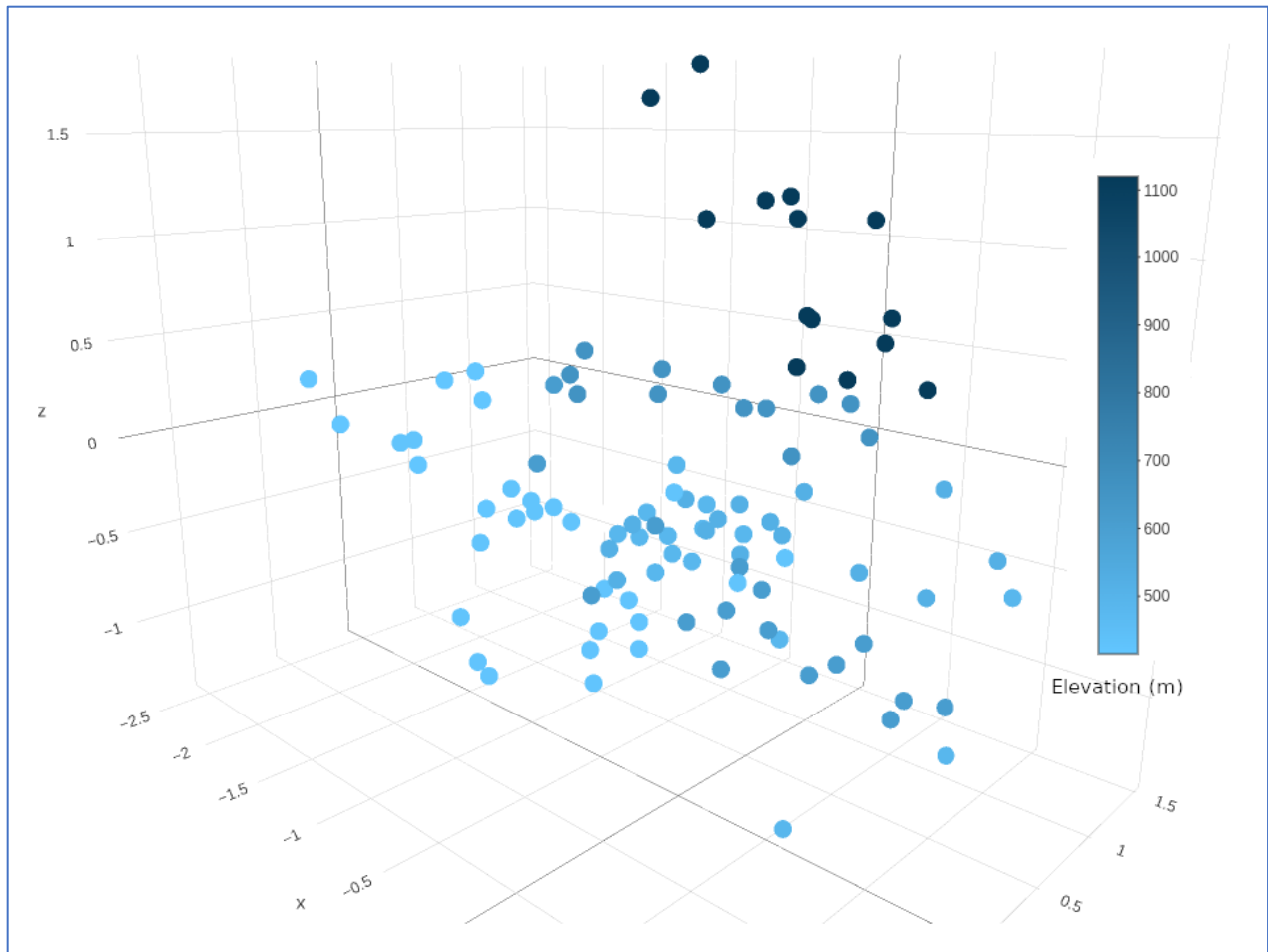s 1, 2, and 3. Stress = 0.12, k = 3, indicating some, but acceptable loss of information when displayed in 3 dimensions. Each point is coloured by the elevation it was sampled at.

Appendix E. Checklist of bee species.

Table A. Bee Species from 2020, 2021, and 2022 sampling years, including BC conservation status and COSEWIC assessment. List excludes morphospecies.

Family	Scientific Name	2020	2021	2022	Provincial	COSEWIC	Native Status
Andrenidae	*Andrena aculeata*		X		SU (2016)		N
	Andrena amphibola			X	S5 (2016)		N
	Andrena angustitarsata		X	X	S5 (2016)		N
	Andrena astragali		X	X	S4S5 (2016)		N
	Andrena candida		X	X	S5 (2016)		N
	Andrena candidiformis			X	SU (2016)		N
	Andrena carlini			X	New to BC		New to BC
	Andrena ceanothi		X	X	New to BC		New to BC
	Andrena ceanothifloris			X	SU (2016)		N
	Andrena chromotricha		X		New to BC		N
	Andrena crataegi		X	X	S5 (2016)		N
	Andrena cressonii		X	X	S5 (2016)		N
	Andrena cupreotincta			X	S5 (2016)		N
	Andrena evoluta		X		S2S4 (2016)		N
	Andrena forbesii			X	S5 (2016)		N
	Andrena fuscicauda		X	X	S2S3 (2016)		N
	Andrena hippotes		X		S5 (2016)		N
	Andrena medionitens			X	S5 (2016)		N
	Andrena melanochroa		X		S3S4 (2016)		N
	Andrena miranda			X	S5 (2016)		N
	Andrena miserabilis			X	S5 (2016)		N
	Andrena nigrocaerulea	X	X	X	S5 (2016)		N
	Andrena nivalis	X	X	X	S5 (2016)		N
	Andrena nothocalaidis			X	S2S4 (2016)		N
	Andrena nubecula			X	S3S4 (2016)		N
	Andrena pallidifovea			X	S4S5 (2016)		N
	Andrena perplexa		X	X	SU (2016)		N
	Andrena prunorum	X	X	X	S5 (2016)		N
	Andrena quintiliformis		X	X	S2S4 (2016)		N
	Andrena quintilis		X	X	New to BC		New to BC
	Andrena regularis			X	S5 (2016)		N
	Andrena salicifloris		X	X	S3S4 (2016)		N
	Andrena semipunctata			X	New to BC		New to BC
	Andrena sigmundi		X		S3S4 (2016)		N

Family	Species				Rank	Status	Origin
	Andrena subaustralis		X		S3S4 (2016)		N
	Andrena subtilis			X	SU (2016)		N
	Andrena topazana			X	S5 (2016)		N
	Andrena transnigra	X	X	X	S5 (2016)		N
	Andrena vicina		X	X	S5 (2016)		N
	Andrena vicinoides			X	S5 (2016)		N
	Andrena wheeleri		X		S5 (2016)		N
	Andrena wilkella		X	X	New to BC		New to BC
	Panurginus atriceps		X		S5 (2016)		N
	Anthophora ursina	X	X	X	S3S4 (2016)		N
	Apis mellifera	X	X	X	SNA (2016)		Exotic
	Bombus appositus	X	X	X	S5 (2016)		N
	Bombus centralis	X	X	X	S5 (2016)		N
	Bombus flavidus	X		X	S3S4 (2016)		N
	Bombus flavifrons	X	X	X	S5 (2016)		N
	Bombus insularis	X		X	S4? (2016)		N
	Bombus melanopygus	X		X	S5 (2016)		N
	Bombus mixtus	X	X	X	S5 (2016)		N
	Bombus nevadensis	X	X	X	S5 (2016)		N
Apidae	*Bombus occidentalis*	X			S2S4 (2016)	Threatened	N
	Bombus rufocinctus	X	X	X	S5 (2016)		N
	Bombus vagans	X	X	X	S5 (2016)		N
	Bombus vancouverensis	X	X	X	S5 (2016)		N
	Ceratina acantha	X	X	X	S5 (2016)		N
	Ceratina nanula	X	X	X	S4S5 (2016)		N
	Eucera cordleyi	X	X		SU (2016)		N
	Eucera frater			X	S3 (2016)		N
	Habropoda cineraria	X	X	X	S5 (2016)		N
	Melecta pacifica	X	X		S2S3 (2016)		N
	Melecta thoracica	X		X	S2S3 (2016)		N
	Melissodes robustior		X		New to BC		New to BC
	Colletes compactus	X			S4 (2016)		N
	Colletes inaequalis			X	New to BC		New to BC
	Hylaeus affinis			X	S5 (2016)		
	Hylaeus annulatus		X		S5 (2016)		N
Colletidae	*Hylaeus basalis*			X	S5 (2016)		N
	Hylaeus coloradensis			X	SU (2016)		N
	Hylaeus leptocephalus			X	SNA (2016)		Exotic
	Hylaeus modestus		X		S5 (2016)		N
	Hylaeus wootoni		X	X	SU (2016)		N
Halictidae	*Agapostemon virescens*	X	X	X	S5 (2016)		N
	Dufourea holocyanea		X	X	S3S4 (2016)		N

	Species				Rank	Status
	Halictus confusus		X	X	S5 (2016)	N
	Halictus farinosus	X	X	X	S4S5 (2016)	N
	Halictus ligatus	X	X		S5 (2016)	N
	Halictus rubicundus	X	X	X	S5 (2016)	N
	Halictus tripartitus	X	X		S4S5 (2016)	N
	Lasioglossum abundipunctum		X	X	SU (2016)	N
	Lasioglossum albipenne		X	X	S5 (2016)	N
	Lasioglossum athabascense		X	X	S5 (2016)	N
	Lasioglossum boreale-group		X	X	S4 (2016)	N
	Lasioglossum colatum			X	S3S5 (2016)	N
	Lasioglossum cooleyi		X	X	S5 (2016)	N
	Lasioglossum cressonii	X		X	S5 (2016)	N
	Lasioglossum egregium	X			SU (2016)	N
	Lasioglossum incompletum			X	S5 (2016)	N
	Lasioglossum inconditum		X	X	S5 (2016)	N
	Lasioglossum laevissimum		X		S5 (2016)	N
	Lasioglossum leucozonium	X			New to BC	New to BC
	Lasioglossum mellipes	X			SU (2016)	N
	Lasioglossum nevadense		X	X	S3S4 (2016)	N
	Lasioglossum nigroviride	X	X	X	S5 (2016)	N
	Lasioglossum novascotiae		X		S5 (2016)	N
	Lasioglossum pacatum			X	S4 (2016)	N
	Lasioglossum paraforbesii		X	X	New to BC	New to BC
	Lasioglossum perpunctatum				New to BC	New to BC
	Lasioglossum prasinogaster		X		S5 (2016)	N
	Lasioglossum punctatoventre		X	X	SU (2016)	N
	Lasioglossum quebecense		X	X	S5 (2016)	N
	Lasioglossum ruidosense		X		S5 (2016)	N
	Lasioglossum sagax		X		S5 (2016)	N
	Lasioglossum sandhousiellum		X		S3 (2016)	N
	Lasioglossum sedi		X		S2S4 (2016)	N
	Lasioglossum semicaeruleum		X		New to BC	New to BC
	Lasioglossum sheffieldi			X	New to BC	New to BC
	Lasioglossum tenax		X		S5 (2016)	N
	Lasioglossum versans			X	New to BC	New to BC
	Lasioglossum yukonae		X	X	S2S3 (2016)	N
	Lasioglossum zonulum	X	X	X	SNA (2016)	Exotic
	Anthidium manicatum		X		SNA (2016)	Exotic

Family	Species					
Megachilidae	*Chelostoma minutum*			X	SU (2016)	N
	Coelioxys sodalis	X		X	S3S4 (2016)	N
	Heriades carinatus		X	X	S5 (2016)	N
	Hoplitis albifrons		X		S5 (2016)	N
	Hoplitis fulgida		X	X	S5 (2016)	N
	Hoplitis hypocrita	X	X		SU (2016)	N
	Hoplitis producta		X		S5 (2016)	N
	Hoplitis sambuci			X	SU (2016)	N
	Megachile angelarum			X	S3 (2016)	N
	Megachile apicalis		X	X	SNA (2016)	Exotic
	Megachile brevis		X		S5 (2016)	N
	Megachile fidelis		X		S3 (2016)	N
	Megachile gemula			X	S5 (2016)	N
	Megachile melanophaea	X	X	X	S5 (2016)	N
	Megachile montivaga			X	S4 (2016)	N
	Megachile perihirta	X	X	X	S5 (2016)	N
	Megachile relativa			X	S5 (2016)	N
	Megachile rotundata			X	SNA (2016)	Exotic
	Megachile texana			X	S5 (2016)	N
	Osmia albolateralis		X		S5 (2016)	N
	Osmia atrocyanea	X	X	X	SU (2016)	N
	Osmia bella			X	SU (2016)	N
	Osmia brevis		X		SU (2016)	N
	Osmia bruneri	X	X	X	SU (2016)	N
	Osmia bucephala			X	S5 (2016)	N
	Osmia californica	X			S4S5 (2016)	N
	Osmia caraformis		X		New to BC	New to BC
	Osmia coloradensis		X	X	S5 (2016)	N
	Osmia cyanella		X		SU (2016)	N
	Osmia densa	X	X	X	S5 (2016)	N
	Osmia dolerosa		X	X	S5 (2016)	N
	Osmia iridis		X		New to BC	New to BC
	Osmia juxta		X		S5 (2016)	N
	Osmia kincaidii		X	X	SU (2016)	N
	Osmia laeta		X		SU (2016)	N
	Osmia lignaria	X	X	X	S5 (2016)	N
	Osmia longula	X		X	S5 (2016)	N
	Osmia malina			X	SU (2016)	N
	Osmia marginipennis	X			SU (2016)	N
	Osmia mertensiae			X	SNR	N
	Osmia nigrifrons		X		S5 (2016)	N

	Osmia nr. subaustralis		X	X	New to BC	New to BC
	Osmia odontogaster		X	X	S5 (2016)	N
	Osmia proxima		X		S5 (2016)	N
	Osmia sedula		X		S5 (2016)	N
	Osmia simillima	X	X	X	S5 (2016)	N
	Osmia tersula			X	S5 (2016)	N
	Osmia trevoris		X		S5 (2016)	N
	Osmia tristella		X		S5 (2016)	N
	Stelis monticola		X		SU (2016)	N
Melittidae	*Macropis nuda*		X		S3 (2016)	N

## Appendix F. Species accumulation curves for 2021 and 2022.
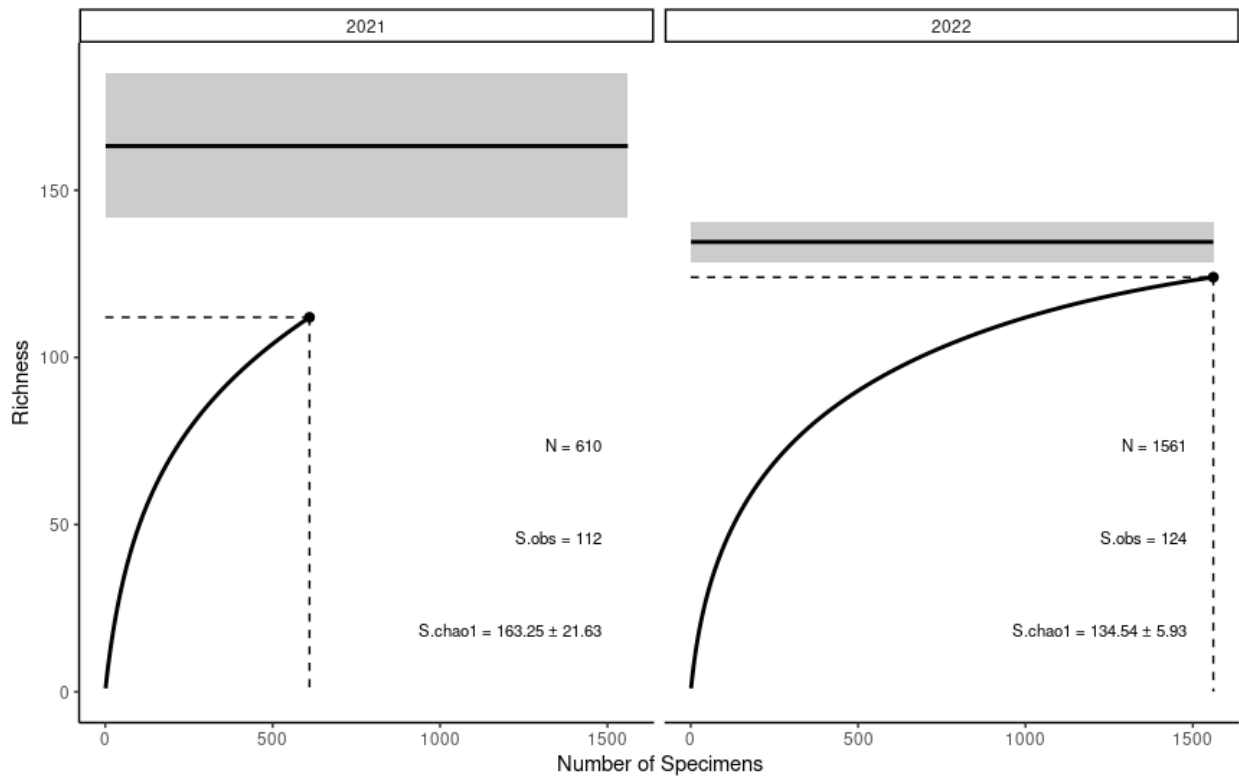
Definitions of Terms

- N is the number of individuals
- S.obs is the number of taxa observed (note that these numbers include morphospecies lumped into genera as described in section 4.3)
- S.chao1 is the estimate for species richness.

Appendix G. Online links to plant-pollinator interactive networks.

Network Type	Year(s) Represented	Link
Entire Network, Camas Highlighted	2022	https://rowanrampton.github.io/KNPSNet21-22/Cam22Net.html
Camas Only by Bee Family	2022	https://rowanrampton.github.io/KNPSNet21-22/CamasOnlyNet22.html
Entire Network by Family	2022	https://rowanrampton.github.io/KNPSNet21-22/NetByFam22.html
Entire Network by Family	2021 & 2022	https://rowanrampton.github.io/KNPSNet21-22/camasByFam2122.html
Camas Only by Family	2021 & 2022	https://rowanrampton.github.io/KNPSNet21-22/camasOnly2122.html
Entire Network, Camas Highlighted	2021 & 2022	https://rowanrampton.github.io/KNPSNet21-22/camNet2122.html

Appendix H. Partial residual plot of a bee-inflorescence model.
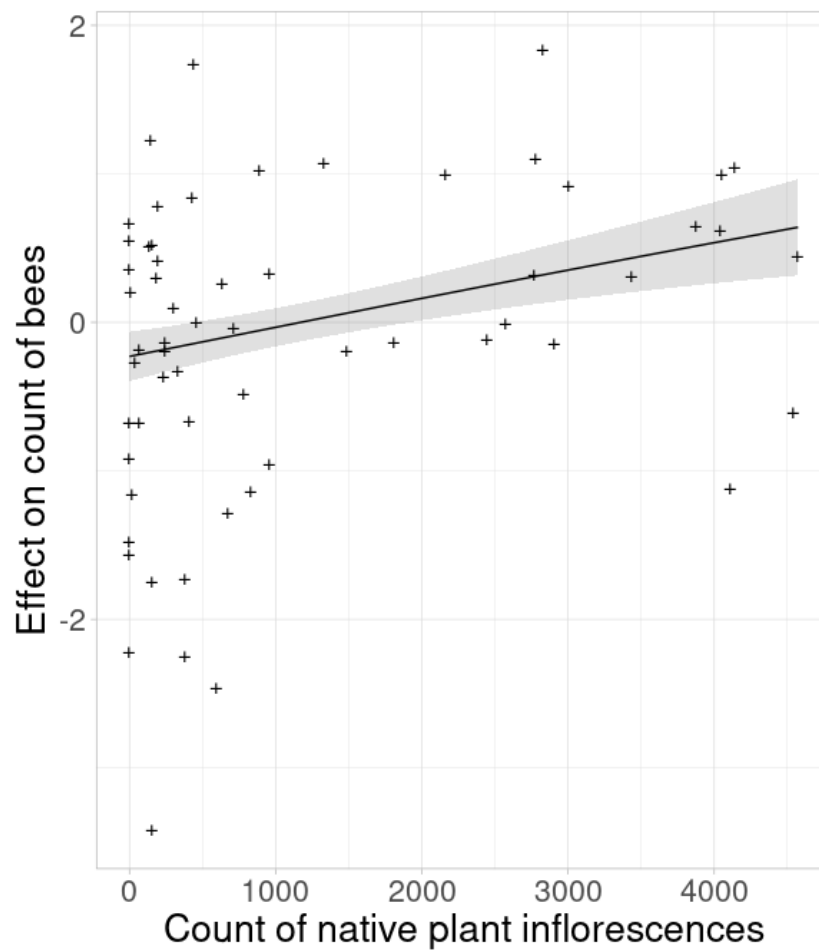
Model Interpretation

The model shows that after controlling for changes in bee abundance over time, larger values of native plant inflorescence counts are associated with higher bee abundances.

Appendix I. "ʔíʔtxʷăʔ and təptəpqiṅ workshop 2022: Summary & Guiding Principles;"update provided by B.R. Beckwith, March 2023.

With the support and guidance of Shelly Boyd, Sinixt Cultural Advisor (Colville Confederated Tribes), the Kootenay Native Plant Society (KNPS) hosted a one-day workshop and gathering called "ʔíʔtxʷăʔ (Camas) and təptəpqiṅ (Bees): Exploring Ecological Methods and Value Systems among Western-trained Ecologists and Indigenous Knowledge Keepers" on May 5, 2022. As the weather was cool and rainy, after spending time among the camas in Millennium Park, Castlegar, the group moved the conversation to around a fire under the pavilion at the Mir Centre for Peace at Selkirk College. These are the summarized guiding principles and outcomes from the rich, insightful, and courageous discussions that occurred that day.

M. Graeme

The conversation was guided by Shelly Boyd, Larry Kenoras (Sylix Elder), and Lincoln Best (bee taxonomist). Other participants, who included people representing the Sinixt Confederacy, Okanagan Nation Alliance, Secwépemc Nation, Ktunaxa Nation, FWCP, and KNPS, learned about the diversity of native bees of British Columbia and their important role in pollinating camas meadows. Lincoln, together with graduate student Rowan Rampton, facilitated a demonstration of the collection of insect specimens (lethal, netting) and provided an overview of the purposes and outcomes of this form of research. The conversation bridged the idea of intellectual property including who owns the knowledge, as well as the collected plants and bees themselves, and how and where is the knowledge used. Although the purpose of and need for the research was generally agreed to be worthy among the participants, the approaches to bee collection could benefit from the following considerations:

1. Conduct collections of bees only, when necessary, as a baseline for knowledge building but not as a long-term method.
2. Conduct bee collection in a respectful, careful, and ethical way.

3. Store bee collection samples and data at a publicly accessible location close to their collection site (e.g., Castlegar).
4. Give back to the area regardless of method (e.g., ceremonial, sharing knowledge or a scientific). Ways of giving back that were discussed include:

- Tobacco offering, as an example of a ceremonial method.
- Planting seeds of native plants or weeding out exotic plants.
- Hand pollinating to compensate for any loss of the bee's role in camas reproduction from collection.

The most rewarding outcomes of the day reflect the deeper commitment to do better shared all the participants. It was agreed that real change is needed - reconnection to land, friends, family, history, truth, and self. We need more time together to talk, network, share stories, and learn from each other, from the species/beings around us, and from the land. The loss of species and natural systems has deep, painful impacts for some people and it should for all people. It is important to hear from Elders and other knowledge keepers, and to hear their words, feel their empathy, and to be reminded. The cultural, economic, and nutritional values of camas need to be recognized and ʔíʔtxʷăʔ needs to be used again for the health and wellbeing of Indigenous Peoples. Finally, the camas areas remaining in Millennium Park need deeper recognition for their cultural values and need full protection.

KNPS graciously acknowledges and thanks all participants of this workshop, for taking the time to travel to it, providing their voice to the conversation, and finding a pathway together toward shared learning and respectful dialogue.

Larry Kenoras and Shelly Boyd.

M. Graeme