

<sup>1</sup> Metagenomic Barcoding of Pollen Loads Offers Insights on the  
<sup>2</sup> Foraging Patterns of Queen Bumble Bees

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<sup>4</sup> **Abstract**

5) DNA Barcoding has been remarkably successful in nearly all kingdoms of life and has allowed  
6 for the rapid analysis of ecological assemblages. Successful DNA barcoding in the plant kingdom  
7 has been more difficult than other kingdoms. Due to this understanding plants in ecological  
8 contexts and understandings of their syncology in some instances may begin to lag behind other  
9 kingdoms.

10  
11 2) Here we utilize hyb-seq, museum studies, and species distribution modelling, to detect the plant  
12 species present in pollen loads collected from Queen Bumble Bees.

13  
14 3) By utilizing Species distribution modelling we allow for one to process hyb-seq data, create user  
15 specified sequence databases which may use MORE ACCURATE alignment algorithms on personal  
16 computers over realistic time periods.

17  
18 4) We show that hyb-seq using the Angiosperms 353 probes, which are currently being used in the  
19 largest ever plant systematic endeavor, offers significant promise to metagenomic approaches in

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20 real world scenarios.

21

22 5) We conclude that these probes offer promise for the identification of plant tissue in both single  
23 sample, and metasample contexts.

24 **1 | INTRODUCTION**

25 The inability to reliably identify plants down to terminal taxon can limit our understanding of ecosystem  
26 function and interactions (Bortolus (2008)). This is especially true for genera where many species are defined  
27 upon ecological and behavioral rather than morphological properties, and hence often serve as bioindicators  
28 of habitat (e.g. different species of Sagebrush- *Artemisia* L., Willows - *Salix* L., and Sedges - *Carex* L.)  
29 (Gage & Cooper (2013)). The lack of species level data can hinder our understanding of the breadth of  
30 habitat which some species occupy, and the interactions they have with other species. Current methods  
31 to ameliorate this situation include: ignoring these ecologically relevant levels of detail, revisiting plots  
32 as diagnostic material becomes temporally available, assistance from taxonomic specialists, or the use of  
33 barcoding or other molecular techniques (CITE). The identification of organisms to terminal taxon is often  
34 mired by lack of diagnostic characters (e.g. flowers, fruits, roots or combinations thereof), an increasing lack  
35 of taxonomic experts (Hebert *et al.* (2003)) and increasingly the description of cryptic species (Janzen *et al.*  
36 (2017), Oliver *et al.* (2009)). And revisiting field sites to identify material using morphological or chemical  
37 approaches, can be resource intensive and often does not work.

38 Recently barcoding (the identification of a sample from a single organism *e.g.* a piece of leaf), and metabar-  
39 coding (the identification of a sample containing a mix of organisms *e.g.* soil), have shown considerable  
40 promise in all Kingdoms of Life (Ruppert *et al.* (2019)). With plants the identification of members of cer-  
41 tain clades using barcoding has been quite successful (Kress (2017)), whereas with many other clades results  
42 have been elusive (Liu *et al.* (2014), Group *et al.* (2011), Coissac *et al.* (2012)), however metabarcoding  
43 incurs additional challenges to those which exist for the currently implemented barcodes (Li *et al.* (2015),  
44 Kress & Erickson (2007), Group *et al.* (2009), Coissac *et al.* (2012)). Particular challenges with the high  
45 copy number barcodes (e.g. ITS2, *rbcL*, *matK*, *trnH-psbA*) include the utilization their rates of divergence,  
46 gene tree conflict, and hybridization (Coissac *et al.* (2016), Fazekas *et al.* (2009)).

47 Currently the largest plant systematic endeavor ever undertaken, the Plant and Fungal Tree of Life  
48 (PAFTOL) undertaken by the Royal Botanic Gardens Kew, is approaching completion (Baker *et al.*  
49 (2021a)). This data set will contain hybridization capture (Hyb-Seq) data from at least one species in each

50 genus of the plant kingdom using the popular Angiosperms353 (A353) probes, at 353 single-copy orthologous  
51 loci, (Baker *et al.* (2021a), Johnson *et al.* (2019)), resulting in over 14,000 represented species. These  
52 publicly available data serve to provide a taxonomically comprehensive backbone for plant metabarcoding,  
53 and the A353 probes are currently being used in many other plant phylogenetic issues increasing the  
54 sampling depth of many clades (Baker *et al.* (2021b)). Data from the 10kP project, which seeks to develop  
55 reference genomes from a phylogenetically diverse suite of plants will contribute many more species upon  
56 its intended completion, now slated to be by 2030, similar projects which seek to sequence high amounts  
57 of genomes in geographic regions e.g. the ‘Darwin Tree of Life’ which will sequence all described taxa in  
58 Britain and Ireland, are being undertaken which will contribute data sets applicable to enormous spatial  
59 domains (Cheng *et al.* (2018), Life Project Consortium *et al.* (2022), Lewin *et al.* (2022)). These data will  
60 promote the ability to apply metabarcoding to resolve a diversity of questions relevant to theoretical and  
61 applied ecology (Kress (2017), Hollingsworth *et al.* (2016)). However, the application of metabarcoding  
62 still face challenges relating to the enormity of the genomic data sets and the computational power required  
63 to process sequence data. Herein we have resolved major components of the problems of identifying plant  
64 material without diagnostic morphological character states using the A353 Hyb-Seq probes (Johnson *et al.*  
65 (2019)), and custom species sequence databases derived via species distribution modelling, and temporal  
66 filtering.

67 To increase the quality of metabarcoding results in plants, we suggest reducing the number of possible plant  
68 species candidates by generating user selected sequence databases relevant to the the region of study and  
69 its ecological characteristics. To achieve this goal, we first create a list of candidate species using digital  
70 collections gleaned from herbaria, survey work, and citizen science (e.g. iNaturalist), from a region exceeding  
71 the study area. To these candidate species, modelling approaches - such as logistic regression, may be used  
72 to identify taxa which warrant further exploration e.g. modelling to determine their possibility of presence  
73 in metabarcoding samples. We then use species distribution models to create potential distribution maps  
74 for the candidate species to limit the impact of spatial and taxonomic biases in the species list and account  
75 for spatial variations in niche availability throughout the study area. Species distribution models (SDM’s)  
76 examine the ecological conditions associated with known occurrence of a species to identify where else in the  
77 study area might suitable habitats be found. This approach has the additional benefit of greatly reducing  
78 the size of a sequence database, which allows for the usage of genomic size data on personal computers. This  
79 approach can also significantly reduce processing time, particularly as as most next-generation sequence data  
80 is deposited as raw-sequence reads.

81 Considerable amounts of species interactions vary both in space and time (CaraDonna *et al.* (2021)). In many

82 regions of the world, contrasts in the flowering periods of many plant species, can provide an additional filter  
83 for identifying material in certain types of metagenomic samples (Janzen (1967), Newstrom *et al.* (1994)).  
84 In high elevation temperate regions, pollination interactions vary temporally and are characterized by high  
85 turnover in active periods of species (CaraDonna *et al.* (2017)), however the overall shorter extent of the  
86 active growing season in these systems results in the presence of few to any natural breaks, which reduces  
87 the utility of these to operate as filters in the post-processing of sequence matches. Nonetheless, we work  
88 develop a general approach which seems applicable to many areas which utilize the temporal dimension for  
89 classifying sequences in metagenomic samples (but see Davis *et al.* (2022)).

90 We test these metagenomic and informatics approaches to determine whether the foraging record of Queen  
91 Bumble Bee's are consistent across direct observations and the pollen record, an incongruency noted in  
92 several floral visitation networks involving smaller bodied fauna (Barker & Arceo-Gomez (2021), Zhao *et*  
93 *al.* (2019), Alarcón (2010)). The assessment of the plant species compositions of pollen is a desired result,  
94 with several applications, and numerous complications (Poronon *et al.* (2017), Bell *et al.* (2017), Sickel *et al.*  
95 (2015), Bell *et al.* (2019), Suchan *et al.* (2019), Johnson *et al.* (2021)). The two foraging phases of the Queen  
96 Bumble Bee life cycle is essential to 1) increase their weight before diapause, 2) increase their ovary weights  
97 while establishing their recently found nests, both of these time periods represent potential demographic  
98 bottlenecks in bumble bee populations (Sarro *et al.* (2022), ...). Bumblebees are one of the only groups  
99 of insects with unequivocal quantitative evidence for numerous population declines, while simultaneously  
100 serving as the most effective pollinators in many temperate montane ecosystems (Cameron & Sadd (2020),  
101 Goulson *et al.* (2008), Williams (1982), Colla *et al.* (2012), Bergman *et al.* (1996), Bingham & Orthner  
102 (1998), Grixti *et al.* (2009)) often represent the most diverse areas in the temperate and oftentimes offer  
103 the sole potential refugia for multiple dimensions of biodiversity under climate change, whilst simultaneously  
104 experiencing the greatest proportional changes in mean annual temperature (Brito-Morales *et al.* (2018),  
105 Pepin *et al.* (2022)). An immediate understanding of how to manage previously overlooked keystone insect  
106 species, such as bumble bees, is essential if the refugial potential of the temperate mountains are to be  
107 incorporated into their current diversity (Loarie *et al.* (2009), Dobrowski & Parks (2016)).

<sup>108</sup> **2 | METHODS**

<sup>109</sup> **Study System & Field Work**

<sup>110</sup> Observations and sample collection was conducted at The Rocky Mountain Biological Laboratory (RMBL;  
<sup>111</sup> 38°57.5" N, 106°59.3" W (WGS 84), 2900 m.a.s.l.), Colorado, USA (APPENDIX 1 for site information). Pol-  
<sup>112</sup> linator observations of *Bombus* Latreille spp. (Apidae Latreille) were conducted from June - August of 2015  
<sup>113</sup> in six study sites characterized by high-montane/subalpine Parkland vegetation communities. Observations  
<sup>114</sup> of *Bombus* foraging took place for one hour at each field site in three 100m transects, where all flowers were  
<sup>115</sup> also counted and placed into abundance bins. Corbiculae loads were, non-lethally, collected once from all  
<sup>116</sup> Queen individuals encountered.

<sup>117</sup> **2.1 | Spatial Analyses**

<sup>118</sup> **2.1.1 Candidate Species** We downloaded from the Botanical Information and Ecology Network ‘BIEN’  
<sup>119</sup> (Maitner (2022)) all records adjacent to the field sites to develop an ecologically relevant list of vascular  
<sup>120</sup> plant species, with expected biotic pollination, which may be present at the study area . We then generated  
<sup>121</sup> Species Distribution Models (SDMs) to predict their distribution throughout the study area. These maps of  
<sup>122</sup> potential distribution served as a reference to reduce the list of species to include in the genomic sequence  
<sup>123</sup> databases.

<sup>124</sup> In order to minimise the number of species for which SDM’s were to be generated, BIEN was queried at a  
<sup>125</sup> distance of up to 100km from our study area and all plant species records were downloaded. In order to  
<sup>126</sup> emulate the stochasticity of botanical collecting and offset the number of records associated with the research  
<sup>127</sup> station, this data set was bootstrap re-sampled 250 times, with 90% of samples selected, to create a testing  
<sup>128</sup> data set. The median of the logistic regression assessing the probability of occurrence of a species record as  
<sup>129</sup> a function of distance from the study area was used as a threshold distance, under which, to include species  
<sup>130</sup> as candidates for distribution modelling.

<sup>131</sup> **2.1.2 Distribution Modelling** We used all occurrence records from BIEN ( $n = 23,919$ ) within a 50km  
<sup>132</sup> border of the Omernik level 3 ecoregion, which includes the study area (*No. 21 “Southern Rockies”*) to  
<sup>133</sup> construct the species distribution model (Omernik (1987)). These records were copied into two, initially  
<sup>134</sup> identical, sets, one for generating machine learning models (ML; Random Forest, and Boosted Regression  
<sup>135</sup> Tree’s), and the other for Generalised Linear (GLM) and Generalized Additive Models (GAM) (Barbet-

136 Massin *et al.* (2012)). Ensembled predictions have been shown to outperform their constituent  
137 models, on average, and to reduce the ecological signal to the analytical noise of individual runs  
138 (Araujo & New (2007)). No single method of producing SDMs has been shown to universally  
139 outperform others when faced with a large and diverse number of applications, in our case a  
140 great number of species with differing biologies and ecologies (Elith\* *et al.* (2006), Qiao *et al.*  
141 (2015)). In the spirit of these findings, multiple families of models, which can be generated  
142 together as they have similar requirements regarding the number and ratios of Presence to  
143 Absence records were ensembled together (Barbet-Massin *et al.* (2012)).

144 We then generated 4,029 absence points, locations where the focal taxon is anticipated missing, through a  
145 random stratification of 19% of the land cover in the area and included them in (Land Management (2019)).  
146 To achieve a larger absence data set, we generated 1,000 pseudo-absence records for each taxon by randomly  
147 selecting coordinates located at least 10km away from an occurrence record. For ML models, these pseudo-  
148 absences were reduced so that the ratio of presence to absence records were balanced (Barbet-Massin *et al.*  
149 (2012)). To achieve this, we removed absence records inside of 10% of the mean sample value of any predictor  
150 variable the presence records; the required number of absence records were then randomly sampled.

151 To predict the potential distribution of each species we used 26 environmental variables at 30m resolution,  
152 six related to climate, five soil, four topographic, four related to cloud cover, with the remaining reflecting  
153 assorted abiotic parameters (Wilson & Jetz (2016), Wang *et al.* (2016), Hengl *et al.* (2017), Robinson *et al.*  
154 (2014)) (**APPENDIX 6**). These publicly available data sets, were selected as they . . . For linear  
155 regression models these predictors underwent both *vifstep* (theta = 10, max observations = 12,500) and  
156 *vifcor* (theta = 0.7, max observations = 12,500) to detect highly correlated variables, and collinear features  
157 were removed leaving 16 variables (Naimi *et al.* (2014)).

158 Modelling: Random Forest and Boosted Regression Trees, were sub sampled with 30% test and two replicates  
159 each before weighted ensemble based on True Skill Statistics (tss) (Naimi & Araujo (2016)). Generalised  
160 linear models (GLM) and Generalised additive models (GAM) with 30% sub sampling and three replicates  
161 each were also ensembled using the tss (Naimi & Araujo (2016), @). TSS was chosen as the ensemble  
162 criterion as it has been shown to work across a wide range of species occurrences prevalence (Allouche *et*  
163 *al.* (2006)). The results of these models were extracted on a cell-by-cell basis to a polygon feature derived  
164 from a minimum-spanning tree which encompasses the study sites, and species from either ensemble with  
165 greater than 50% mean habitat suitability across all cells were considered present for further purposes (Prim  
166 (1957)).

167 535 species were modelled using Generalized Linear Models and Generalized Additive Models. 534 species

were modelled using Random Forest and Boosted Regression Trees. To evaluate the accuracy of the species distribution models, additional presence records from GBIF ( $n = 61,789$ ), and AIM ( $n = 12,730$ ) were used as test and training sets ( $n = 74,519$ ) for logistic regression (Occdownload Gbif.Org (2021), Land Management (2019)). Additional novel absence records were generated from the AIM data set to create a data set where each species has balanced presence and absences. Eleven or more paired presence and absence records were required for this testing, resulting in 334 species being included in the logistic regression ( $Mdn = 110.0$ ,  $\bar{x} = 223.1$ , max = 1568 record pairs used) with a 70% test split (Kuhn (2022)).

## 2.2 | Molecular Lab Work

All lab work was carried out at The Daniel F. and Ada L. Rice Plant Conservation Science Center at the Chicago Botanic Garden, Glencoe, Illinois, U.S.A.

**2.2.1 | Reference Plant Library Generation** Using five years (2015-2020) of observational data on *Bombus* Queen Bee foraging at these studies sites, we identified the plant taxa most frequently visited by Queens across all years. We sequenced the 12 most commonly visited taxa twice using samples from one site within the Gunnison Basin River Drainage and one individual from another more distal population. In addition, for any of these 12 focal species which did not have a congener pair in this filtered sample, we included a congener - or a species from a closely related genus to serve as an outgroup. We also sequenced another 15 abundant taxa commonly visited by *Bombus* workers, based on the abundances, and immediate access to plant tissue, in the aforementioned data set (APPENDIX 4). Plant collections were identified via a variety, and typically a combination, of dichotomous keys and primary literature as required (Flora of North America Editorial Committee (1993+), Hitchcock & Cronquist (2018), Ackerfield (2015), Lesica *et al.* (2012), Cronquist *et al.* (1977+), Allred & Ivey (2012), Jepson flora project (2020), Mohlenbrock (2002)).

**2.2.2 | Plant Genomic DNA Extraction** Plant genomic DNA was isolated from  $\sim 1 \text{ cm}^2$  of leaf tissue from silica-gel dried or herbarium material using a modified cetyltrimethylammonium (CTAB) protocol (Doyle & Doyle (1987)) that included two chloroform washes. DNA was quantified using a Nanodrop 2000 (Thermo Fisher Scientific, Waltham, Massachusetts, USA) and Qubit fluorometer (Thermo Fisher Scientific).

**2.2.3 | Pollen Genomic DNA Extraction** Pollen genomic DNA was extracted from corbiculae using a CTAB based protocol modified from Lahlamgiah et al. and Guertler et al. (2014, 2014). A SDS extraction buffer (350 $\mu\text{L}$ , 100mM Tris-HCl, 50 mM EDTA, 50 mM NaCl, 10% SDS v/v., pH 7.5) was added followed by

196 vortexing to allow dissolution of corbiculae. Pollen grains were then macerated with Kontes Pellet Pestles,  
197 and the tip of these washed with 130  $\mu$ L of the SDS extraction buffer, samples were then incubated for  
198 1 hour at 30°C. This was followed by the addition of 10% CTAB solution (450ul, of 20 mM Tris-Cl pH.  
199 8.0, 1.4 M NaCl, 10 mM EDTA pH 7.5, 10% CTAB, 5% PVP, ~85% Deionized water) and RNase (10  
200  $\mu$ L of 10 mg/mL) and samples were incubated for 40 minutes at 37°C, on heat block (Multi-Blok, Thermo  
201 Fisher Scientific, Waltham Massachusetts) set to 40°C. After 20 minutes incubation, Proteinase K (15  $\mu$ L of  
202 20mg/ml) and DTT (12.5  $\mu$ L of 1M in water) were added, and the samples were further incubated at 60°C  
203 for 1 hour. Samples were then incubated overnight at 40°C. 500  $\mu$ L of Phenol-Chloroform-Isoamyl alcohol  
204 (25:24:1) were added, vortexed, and centrifuged at 10,000 rpm for 10 minutes and the aqueous phase was  
205 pipetted to a 1.5 ml centrifuge tube.

206 To precipitate the DNA, chilled Isopropyl alcohol & 3 mM Sodium acetate (5:1) equivalent to  $\frac{2}{3}$  of the  
207 volume of sample were added, with 1 hour of chilling at -20°C, followed by 10 minutes of centrifuging at  
208 13,000 rpm. The supernatant was pipetted to a new 1.5 ml centrifuge tube, and 70% EtOH (400  $\mu$ L) were  
209 added before chilling at -20°C for 20 minutes followed by centrifugation at 13,000 rpm for 10 minutes. Both  
210 tubes were then washed with 75% EtOH (400  $\mu$ L), inverted, centrifuged at 13,000 rpm for 4 minutes, and  
211 the solution discarded, then washed with 95% EtOH (400  $\mu$ L), inverted, centrifuged at 13,000 rpm for 4  
212 minutes, and the solution discarded. Pellets were dried at room temperature overnight before resuspension  
213 in nuclease free H<sub>2</sub>O. Extractions were assessed using a Nanodrop 2000 (Thermo Fisher Scientific) and Qubit  
214 fluorometer (Thermo Fisher Scientific). DNA extracts were then cleaned using 2:1 v./v. Sera-Mag beads  
215 (Cytiva, Little Chalfont, UK) to solute ratio following the manufacturer's protocol, eluted in 0.5x TE, and  
216 the eluent allowed to reduce by half volume in ambient conditions. DNA was quantified using a Qubit  
217 fluorometer.

218 **2.2.4 | Fragmentation, Library Preparation & Target Enrichment** Library preparation was per-  
219 formed using the NEBNext Ultra II FS-DNA Library Prep Kit for Illumina (New England BioLabs, Ipswich,  
220 Massachusetts, USA) using slightly modified manufacturers recommendation. Fragmentation was performed  
221 at  $\frac{1}{2}$  volume of reagents and  $\frac{1}{4}$  enzyme mix for 40 minutes at 37°C, with an input of 500 ng cleaned DNA.  
222 Adapter Ligation and PCR enrichment were performed with  $\frac{1}{2}$  volumes, while cleanup of products was  
223 performed with  $\frac{1}{2}$  volume of SPRI beads (Beckman Coulter, Indianapolis, Indiana, USA) and recommended  
224 volumes of 80% v./v. ethanol washes. The exception was the herbarium specimens which were not frag-  
225 mented and only end repaired, with similar library preparation of all samples. Products were analysed on  
226 4% agarose gels, and a Qubit fluorometer. Libraries were pooled and enriched with the Angiosperms 353

227 probe kit V.4 (Arbor Biosciences myBaits Target Sequence Capture Kit) by following the manufacturer's  
228 protocol and Brewer et al. 2019. Sequencing was performed using an Illumina mi-Seq with 150-bp end reads,  
229 (NUSeq Core, Chicago, Illinois).

230 **2.2.5 | Computational Processes and Analyses.**

231 **2.2.5.1 | Reference Library Data Processing** Sequences were processed using Trimmomatic, which  
232 removed sequence adapters, clipped the first 3 bp, discarding reads less than 36 bp, and removing reads  
233 if their average PHRED score dropped beneath 20 over a window of 5 bp (Bolger & Giorgi (2014), Tange  
234 (2021)). Contigs were generated using HybPiper using target files created by M353 (Johnson *et al.* (2016),  
235 McLay *et al.* (2021)).

236 **2.2.5.2 | Sequence Identification** A custom Kraken2 database was created by downloading represen-  
237 tative species of each genus indicated as being present in the study area by the spatial analyses from the  
238 Sequence Read Archive (SRA) NCBI (Wood *et al.* (2019)). These sequences were processed in the same  
239 manner as our novel sequences. The Kraken2 database was built using default parameters. Kraken2 was run  
240 on sequences using default parameters (*APPENDIX 5*). Following Kraken2, Bracken was used to classify  
241 sequences to terminal taxa (Lu *et al.* (2017)). Results from both Kraken2 and Bracken, results were reclas-  
242 sified manually to identify terminal taxa. For example, when only a single species of a genus was known  
243 in the study area, but our database used a representative of another taxon in the genus, this species was  
244 coded as the result. The re-coding of sequences from another representative species for the genus to the sole  
245 RMBL representative allowed the identification of *XX & %* more species.

246 **2.2.5.3 | Identification of Sequence Matching Loci** A local NCBI database was built using the same  
247 processed novel and downloaded sequences as the previous database (Camacho *et al.* (2009)).

248 **2.2.5.4 | Morphological Pollen identification**

249 To develop a reference library of pollen grains which may be present in corbiculae loads, an image reference  
250 collection of fuchsin-jelly stained (Beattie (1971)) slides was assembled from slides previously prepared by the  
251 authors (n = 21), and other researchers (n = 38) (Brosi & Briggs (2013)). Using five years of observational  
252 data on *Bombus* Queen Bee foraging at these studies sites (Ogilvie unpublished), as well as the Vascular  
253 Plant Checklist (Frase & Buck (2007)), an additional 62 voucher slides for species were prepared and imaged

254 at 400x (Leica DMLB, Leica MC170 HD Camera, Leica Application Suite V. 4.13.0) from non accessioned  
255 herbarium collections to supplement the number of species and clades covered (Appendix 3).

256 We used Divisive Hierarchical Clustering techniques to determine which plant taxa were distinguishable via  
257 light microscopy, and to develop a dichotomous key to pollen morphotypes. Ten readily discernible categorical  
258 traits were collected from each specimen in the image collection. These traits were transformed using Gower  
259 distances, and clustered using Divisive Hierarchical clustering techniques (Maechler *et al.* (2022)). Using  
260 the cluster dendrogram, elbow plot, and heatmaps (Hennig (2020)), of these results morphological groups  
261 of pollen which could not be resolved via microscopy were delineated, and a dichotomous key was prepared  
262 (APPENDIX NO.). This key was then used to identify the pollen grains sampled from corbiculae loads to  
263 morphotypes in a consistent manner. To prepare the pollen slides from corbiculae, all corbiculae loads were  
264 broken apart and rolled using dissection needlepoints to increase heterogeneity of samples. *Cerca* 0.5mm<sup>2</sup>  
265 of pollen was placed onto a ~4mm<sup>2</sup> fuchsin jelly cube (Beattie (1971)) atop a graticulated microscope slide,  
266 with 20 transects and 20 rows (400 quadrants) (EMS, Hartfield, PA). The jelly was melted, with stirring,  
267 until pollen grains were homogeneously spread across the microscope slide. Slides were sealed with Canada  
268 Balsam (Ruble Colours, Willits, CA) followed by sealing with nail polish to prevent oxidation; all samples  
269 are noted in APPENDIX 3. To identify the pollen present in corbiculae loads, light microscopy at 400x  
270 (Zeiss Axioscope A1) was used. In initial sampling in three transects, each pollen grain was identified to  
271 morphotype and counted; an additional two transects were scanned for morphotypes unique to that slide,  
272 if either transect contained an unique morphotype than all grains in that transect were also identified and  
273 counted. Subsequent to the first round of sampling, non-parametric species richness rarefaction curves  
274 (Oksanen *et al.* (2022)), and non-parametric species diversity rarefaction curves were used to assess the  
275 completeness of sampling (Chao *et al.* (2014), Hsieh *et al.* (2020)). Slides not approaching the asymptote  
276 of the rarefaction curve were then re-sampled, and analysed iteratively for up to a total of seven transects  
277 APPENDIX 2.

## 278 2.3 | Temporal Analyses

279 To estimate the duration of dates in which plant species were flowering weibull estimates of several pheno-  
280 logical parameters all spatially modelled taxa were developed (Belitz *et al.* (2020), Pearse *et al.* (2017)).  
281 Only BIEN records which occurred in the Omernik Level 4 Ecoregions within 15km of the study area (n =  
282 5 Level 4 Ecoregions, or conditionally 6 ecoregions if enough records were not found in the nearest 5),  
283 and which were from herbarium records were included. To remove temporally irrelevant herbarium records,  
284 i.e. material collected during times which flowering is impossible at the study area due to snow cover, we

used the SnowUS data set (Iler *et al.* (2021), Tran *et al.* (2019)) from 2000-2017 were analyzed for the first three days of contiguous snow absence, and the first three days of contiguous snow cover in Fall. Herbarium records after the 3<sup>rd</sup> quantile for melt, and the 1<sup>st</sup> quantile for snow cover of these metrics were removed. Species with > 10 records had their weibull distributions generated for the date when 10% of individuals had begun flowering, when 50% were flowering, and when 90% of individuals had flowered, we used the initiation and cessation dates, respectively, as effective start and ends of flowering.

## 291 2.4 | Floral Observations

# 292 3 | RESULTS

## 293 3.1 | Spatial Analyses

294 [Table 1 about here.]

295 [Table 2 about here.]

296 The median (25.009 km) of the logistic regression assessing the probability of occurrence of a species record as  
297 a function of distance from the study area was used as a threshold distance to include species for distribution  
298 modelling. A 2-sample test for equality of proportions with continuity correction (X-squared = 13.254, df  
299 = 1, p-value = 0.000136, 95% CI 0.04-1.00) was used to test whether more of the records located in the  
300 broad ecological sites present at the field station, between the distance of the median (25.009 km) to the  
301 third quantile (ca 43.830 km) of the regression distance, were true presences at the field station. Including  
302 these records would have resulted in modelling an additional 222 species distributions of which 30 are true  
303 presences, these taxa were not modelled.

304 Across the entire spatial domain of modelling all ensembled models (n = 968) had an accuracy of 0.84 (95%  
305 CI 0.8356 - 0.8443), kappa = 0.68, p-value < 0.001, sensitivity = 0.80, specificity = 0.87, AUC = 0.92.

306 In the area of the minimum-spanning tree encompassing the field sites, of the 554 vascular plants with biotic  
307 pollination syndromes, the 493 ML ensembles accurately predicted the presence of 362 (65.3%), incorrectly  
308 predicted the presence of 64 (11.6%), incorrectly predicted 34 true presences (6.1%) as being absent, and  
309 correctly predicted the true absence of 33 (6.0%). The balanced accuracy of the ensembled models is 0.627  
310 (Sensitivity = 0.340, Specificity 0.914). Of the 554 vascular plants with biotic pollination syndromes, the  
311 475 LM ensembles accurately predicted the presence of 286 (51.6%), incorrectly predicted the presence of

312 41 (14.3%), incorrectly predicted 93 true presences (16.8%) as being absent, and correctly predicted the  
313 true absence of 55 (9.9%). The balanced accuracy of the ensembled models is 0.664 (Sensitivity = 0.573,  
314 Specificity 0.754). Of the 554 vascular plants with biotic pollination syndromes in the flora 13 (2.3%) were  
315 in the Orchid family and 41 (7.4%) are non-natives, both of which are restricted from the database, and can  
316 only reduce the number of true predicted presences by roughly 10%.

317 At the six study plots, of the 117 plant species identified to the species level across the spatial extents of all  
318 plots and duration of queen bee activity, the ML ensembles predicted the presence of 105 (89.7%) of them,  
319 and LM ensembles 102 (87.2%). Of the missing species two (1.7%) are Orchids, six (5.1%) are non-native,  
320 and one (0.85%) is of contested taxonomic standing, all of which (7.65%) are restricted from the initial query  
321 database.

### 322 3.2 | Microscopic Pollen identification

323 Using the fuchsin jelly preparation and light microscopic analyses of grains and scoring of 10 character  
324 states resulted in the establishment of 28 morphotypes which grains could be classified into. APPENDIX  
325 7. 60 samples were counted and based on rarefaction **had over % of expected morphotypes found**  
326 (morphotype richness,  $\bar{x} = 4.5$ , Mdn = 4, min = 1, max = 9), all samples had expected morphotype diversity  
327 reach the asymptote APPENDIX 8. The number of counted pollen grains in each sample range from (MIN  
328 - 16,293,  $\bar{x} = 2788.685$ , Mdn = 1453).

329 [Figure 1 about here.]

### 330 3.3 | Metabarcoding Pollen identification

331 54 corbiculae loads had DNA extracted and underwent various steps towards hyb-seq, in the end a total of  
332 44 corbiculae samples were sequenced, 7,752,353 reads were recovered from sequencing. The number of reads  
333 per sequence varied widely (range = 76 - 508,795,  $\bar{x} = 176,189.8$ , Mdn = 138,395). Of the possible 353 loci,  
334 the number which were recovered from each sample, and informative to BLAST were range = 24 - 353,  $\bar{x} =$   
335 305.5, Mdn = 331. The number of reads per loci from across all samples had a range of 178 - 506,653,  $\bar{x} =$   
336 20,688, Mdn = 12,616. **APPENDIX X Reads Per Loci.**

337 ... with samples 22, and 41 both having < 100 reads indicates, virtual failure of these records (REMOVE  
338 from analyses).

339 After trimming 7,865,680 sequences remained. 10,682,538 reads were matched using Kraken, of the reads  
340 classified by Kraken 10,160,768 reads were matched using Bracken, of the reads classified by Kraken 7,302,876  
341 reads were matched using BLAST. Based upon subjective review of the three classifiers **APPENDIX X**  
342 **MOLECULAR NETWORKS - 3 DIFFERENT ONES**, BLAST was chosen as the classification  
343 method which yielded the most probable results by the field ecologist, and it's values were used for all  
344 subsequent analyses.

345 [Table 3 about here.]

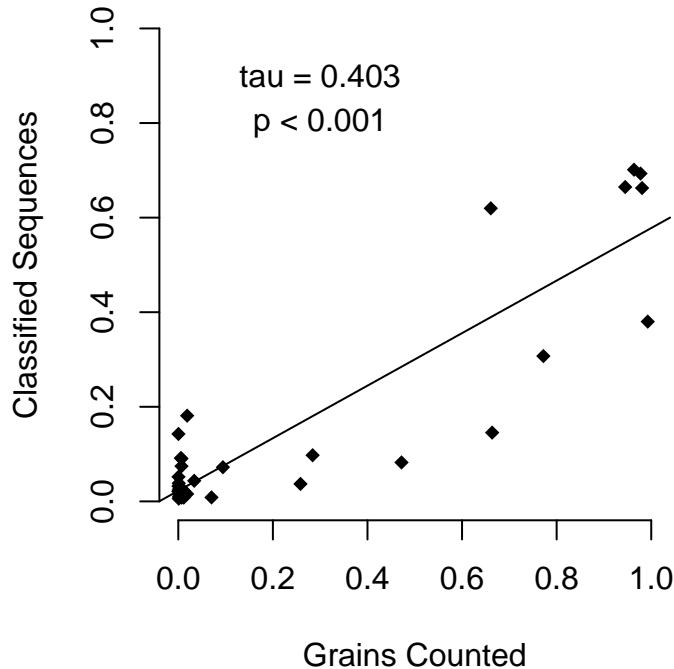
346 The initial classification of sequences which were made by BLAST were reviewed programmatically, using  
347 predicted presence of the species (from spatial modelling), modelled flowering time (from temporal mod-  
348 elling), and taxonomy (from existing sources). A sequential process was utilized which reassigned sequences  
349 based on binary combinations of the factors above (Appendix XX). Given the relative sparsity of the number,  
350 and relatedness, of species represented in the sequence database this was performed to: 1) Identify locally  
351 present species represented by surrogates in the DB 2) Reduce false classifications of focal species 3) Identify  
352 high confidence sequence matches. Each of the top ten taxa which were identified by BLAST from the  
353 aforementioned process composed 438 distinct records, of these 57.08% of the reads were classified to species  
354 46.39% representing of all classified reads, 39.04% of the reads were classified to genus representing 46.39%  
355 of all classified reads, and 3.88% of the records were classified to genus 2.23% of all total sequences.

356 18 classifications which were assigned to genera without any species predicted by spatial analyses, were  
357 investigated by hand after post-processing steps. These were all assigned via post-processing conditions (B:  
358 10, E: 7, F: 1). These were manually assigned to a variety of ranks, occasionally to genus 10 and species  
359 6, by consultation of the alpha-taxonomic literature (Sadeghian *et al.* (2015), Sennikov & Kurtto (2017),  
360 Rabeler & Wagner (2016), Pusalkar & Singh (2015), Moore & Bohs (2003), Weber (1998)).

361 To determine at which level species in pollen loads could be detected the results of light microscopy were  
362 compared to the molecular results. The pollen samples contained three morphotypes which could readily  
363 be identified via microscopy. Two of these mapped to the clades (Boraginaceae & Heliantheae Alliance),  
364 and one to a Asteraceae less Heliantheae. Boraginaceae grains were detected in 92.9% of samples where the  
365 proportion of target grains were between 0.01-1 ( $n = 14$  Mdn = 0.572). Asteraceae type 1, non-helianthoids,  
366 were detected in 20% of samples where the proportion of target grains were between 0.001-0.01 ( $n = 5$  Mdn  
367 = 0.002) Asteraceae type 2, Helianthoids, were detected in 62.5% of samples where the proportion of target  
368 grains were between 0.001-0.01 ( $n = 8$  Mdn = 0.003); however, Asteraceae were detected in 76.9% of samples  
369 where the proportion of target grains were between 0.001-0.01 ( $n = 13$  Mdn = 0.002). Both morphotypes

370 of Asteraceae pollen were detected in 100% of samples where the proportion of target grains were between  
371 0.01-1 ( $n = 3$  Mdn = 0.011), and Ericaceae were detected in 50% of samples where the proportion of target  
372 grains were between 0.001-0.1 ( $n = 2$  Mdn = 0.01).

## Correlation of Proportion Counted Grains and Sequence Reads



373 To detect whether the sequencing reads were semi-quantitative the subset of all pollen morphotypes distin-  
374 guishable by microscopy were compared to the sequence reads. In all instances sequence reads were pooled  
375 to the highest taxonomic rank associated with the morphotype, e.g. if both species of *Mertensia* Huth, or  
376 one species and read only classified to genus were present in a sample, the reads were summed. The total  
377 percentage of the ten most abundant grains per sample were then were then relativized to constitute the entire  
378 sample.

380 The relationship between the number of pollen grains in a sample and the number of sequence reads is roughly  
381 *curvilinear*, where grains which are present in trace amounts are overestimated by sequence counts, while  
382 grains present in high amounts are underestimated. This is likely due to the proportion of high false positives  
383 which occur in the classification process with NGS (BELL NOVEMBER 2021). There was evidence of a  
384 strong correlation between the proportion of grains per morphotype and the number of sequences per group  
385 (0.403,  $p < 0.0001$ ,  $n = 37$ ).

386 To ascertain the extent to which records of multiple species in a family, which were suspected to be sampling  
387 artefacts occurred in molecular samples an index of similarity, ala jaccard,  $\alpha$  index was used to assess co-

388 occurrence (Mainali *et al.* (2022), Mainali & Slud (2022)). Numerous taxa from the family Ranunculaceae  
389 Jussieu (*Caltha* L. sp., *Thalictrum* L. spp., *Trollius* L. sp., *Aquilegia* L. spp.), had ...  $\alpha$  scores which  
390 indicated that they are only present when a more common confamilial taxa *Delphinium barbeyi* (Huth) Huth  
391 *nuttallianum* Pritz. were recorded. A similar relationship was observed in the Hydrophyllaceae R.Br. with  
392 samples placed in *Nemophila* Nutt., which only occurred when the more abundant *Hydrophyllum* L. species  
393 were present.

### 394 3.4 | Temporal Analyses

395 The first date of modeled snow melt in the Gothic area ( $n = 17$ ,  $\bar{x} = 137.9$ , Mdn = 135, 3<sup>rd</sup> quantile =  
396 151), and the first date of a consistent winter snow base ( $n = 17$ ,  $\bar{x} = 299.9$ , Mdn = 300, 1<sup>st</sup> quantile =  
397 291) from 2000-2017, were used as delimiters for the inclusions of herbarium records in modelling. Of the  
398 439 species predicted likely present in the area via logistic regression, 332 species (64.4%) with more than 10  
399 records in the focal level 4 ecoregions ( $\bar{x} = 35.016$ , Mdn = 35, max = 96) had weibull estimates calculated,  
400 an additional 56 species (11.2%) with enough contributing records from the “Sedimentary Mid-Elevation  
401 Forests”, a large ecoregion generally just beneath the elevation bands occupied by the five ecoregions around  
402 the study area had weibull estimates also calculated ( $\bar{x} = 13.868$ , Mdn = 13, max = 24).

403 Only 58 of these 388 species ( $n = 34.568$ , Mdn = 31) were able to be compared to plot based observational  
404 data from the long term (1974–2012) data set (CaraDonna *et al.* (2014)). Of these species relatively high  
405 accord was observed between the long-term ground truthed data set, and the modelled species. There was  
406 very strong evidence that the weibull estimates were positively associated with the observed onset ( $r^2 =$   
407 0.72,  $p < 0.0001$ ,  $\tau = 0.61$ ) and peak ( $r^2 = 0.70$ ,  $p < 0.0001$ ,  $\tau = 0.65$ ) of flowering, and that the number  
408 of herbarium samples had a moderate effect on the estimates ( $p = 0.004$  and  $p = 0.034$  respectively). There  
409 was very strong evidence that the weibull estimates had a positive association with the observed cessation  
410 of flowering ( $r^2 = 0.4339$ ,  $p < 0.0001$ ,  $\tau = 0.489$ ), however there was no evidence that sample size had an  
411 effect ( $p = 0.349$ ). There was moderate evidence that the weibull estimates, with an effect of sample size,  
412 had a weak positive association with the observed duration of flowering ( $p = 0.0401$ ,  $r^2 = 0.07$ ,  $\tau = 0.17$ ).

413 [Figure 2 about here.]

<sup>414</sup> **3.5 | Floral Observations**

<sup>415</sup> The six sites were surveyed once weekly from May 27-July 27 for a total of 52 hours from . A total of 723  
<sup>416</sup> queen-pollen foraging interactions were observed (range per bee species by week range = 1-18,  $\bar{x} = 3.46$ ,  
<sup>417</sup> Mdn = 2), with a range of total observed interactions per bee species across this time period (min = 1,  $\bar{x}$   
<sup>418</sup> = 59.08, Mdn = 19, max = 184). Plants varied widely in the number of interactions which they partook in  
<sup>419</sup> with each species of bee (range per plant species by week min = 1 - 20,  $\bar{x} = 3.51$ , Mdn = 2), with a range  
<sup>420</sup> of total observed interactions per plant species over this time period (min = 1,  $\bar{x} = 20.26$ , Mdn = 4, max =  
<sup>421</sup> 141). The number of plant species which bees were observed interacting with varied more narrowly (range  
<sup>422</sup> = 1 - 18,  $\bar{x} = 8$ , Mdn = 6).

<sup>423</sup> A total of 66 corbiculae loads were collected from Bees, 64 of them from Queens.

<sup>424</sup> [Figure 3 about here.]

<sup>425</sup> **3.6 | Integrated Observational, Molecular, and Palynological Network**

<sup>426</sup> While the spatial results were used to declare the taxonomic composition of the sequence database, temporal  
<sup>427</sup> results were used in consideration with plant phylogeny to retroactively, reassign the assignment of sequences  
<sup>428</sup> to taxa. Essentially, if a sequence was identified to a taxon which was not known from the field site

<sup>429</sup> For example a common UNKNOWN sequence mapped to the Asteraceae family, but which was flagged  
<sup>430</sup> by temporal filters and is present in both *B. nevadensis* Cresson and *B. rufocinctus* Cresson pollen is  
<sup>431</sup> most likely *Frasera* Walter, failed extraction. A similar likely mismatch could be between what was fide  
<sup>432</sup> molecular evidence as *Agastache pallidiflora* (A. Heller) Rydb. but where feeding was infrequently observed  
<sup>433</sup> on *Pedicularis* L., likely due to this entire order being represented by only a single molecular reference species.

<sup>434</sup> Situations where SDM's led to incorrect results at the species level are evident with classification to *Scabrethia*  
<sup>435</sup> *Scabra* (Hooker) W.A. Weber, this match almost certainly representing *Wyethia arizonica* A. Gray (Weber  
<sup>436</sup> (1998)), a taxon known to be visited by Queen bee's via our floral observations.

<sup>437</sup> It is not unlikely that much of the difference in the results between the observational and molecular work  
<sup>438</sup> are attributable to the challenges in detecting rare events in these smaller sizes. For example, no more than  
<sup>439</sup> 10 bee corbiculae loads per species were sequenced with the Mdn = 5.5 . . . , and the median of interactions  
<sup>440</sup> with the top 5 plant sizes constituted 0.9135611 of the top.

<sup>441</sup> . . . many of our results indicate foraging on *Viola* L. spp, zygomorphic flowers with architecture which

442 would require subtle handling and strength to reach the pollen and nectar loads... (IS FORREST PAPER  
443 WORTH CITING ? IS THIS EVEN WORTH HAVING?)

444 An expected inaccuracy of the classification scheme is in genus level placements, e.g. were *Epilobium* L.  
445 (Onagraceae Juss.) spp. were classified. However, given the small size of their flowers in the study area, these  
446 results more likely indicate that a species of *Chamaenerion* Seg. (a segregate genus) such as *C. angustifolium*  
447 (L.) Scop. or *latifolium* (L.) Sweet is occasionally utilized, as it supported by limited palynology data.

448 Accordingly, combining the results of floral observations, and palynology, molecular sequencing - both pre  
449 and post processing, we subjectively developed reclassifications of the contents of pollen grains...

## 450 4 | DISCUSSION

451 ~ **What we DEMONSTRATED** ~ We have demonstrated how the Angiosperms533 hyb-seq probes may  
452 be used for plant barcoding in a metagenomic context (Johnson *et al.* (2019), Hollingsworth *et al.* (2016)).  
453 This was exemplified in an ecologically relevant scenario, where the results have immediate implications  
454 for natural history driven fundamental science and land management. The test pollen loads contained  
455 a number of closely related taxa, some in notoriously morphologically difficult clades with rapid rates of  
456 diversification (e.g. *Mertensia*, *Lupinus* L.), at naturally occurring proportions (Nevado *et al.* (2016), Nazaire  
457 & Hufford (2014)). We incorporated spatial and temporal approaches for creating custom sequence databases  
458 an approach which is readily applicable to any lab group with the capacity to perform next-generation  
459 sequencing across the entirety of multiple continents, and which we expect to be highly beneficial in many  
460 study areas. By combining insights from these novel approaches with an extensive observational field based  
461 study we show how these methods may be applied to test a variety of hypotheses related to ecological  
462 interactions.

463 ~ **What CHALLENGES we FACED** ~ The SDM's which we generated, with relatively few occurrence  
464 records and few modelling iterations, performed beyond expectations, likely due to the utility of the predictor  
465 variables and strong alignment of vegetation by orographic precipitation in the study area. However, we had  
466 difficulties in evaluating our predictions in an operational context. We utilized the database query approach,  
467 to only model species with a high probability of not being dispersal limited to the focal area, and focused  
468 on a relevant subset of many of these species ranges to reduce the contributions of range wide adaptions  
469 on habitat (Sork (2018), Joshi *et al.* (2001)). While the models worked well compared to both test, and  
470 validation with external point data, moving from points to polygon features was more difficult. We were able

471 to compare our results to 1) a Flora, 2) lists of plants used by Bumble Bees at plots; the former inappropriate  
472 in that it contained a great number of species which we sought to use modelling to reduce *e.g.* all strictly  
473 alpine species, and the latter inappropriate in that it contained only species relevant to *Bombus* but had no  
474 official ‘absence’ data. Further given the, size of the minimum spanning tree (AREA???) which we extracted  
475 points to, a formal floristic inventory would still be a time intensive process. Accordingly, we expect the  
476 real results of our data lay somewhere in between these two evaluations; with an excess of species predicted  
477 present (Dubuis *et al.* (2011), Calabrese *et al.* (2014), Pinto-Ledezma & Cavender-Bares (2021)), but few  
478 enough that they lend themselves to metabarcoding. We observe that our models seemed very capable of  
479 effectively identifying alpine species and removing them in binomial contexts. Difficulties in temporal models  
480 related to variability in drivers of flowering phenology.

481 ~ **WHAT we learned about Bee foraging (BASIC)** ~ These results show that the overall results  
482 between **Bumble Bee ecology** observational and barcoding are largely congruent. But that ... We  
483 analyzed pollen loads from all of the most common bumble bee species in the area (Pyke (1982)) Future  
484 analyses of the long term data set...

485 Results from palynological analyses show that several species of bee show near perfect fidelity to the genus  
486 *Hydrophyllum* on a per visit basis... General results show high congruence between foraging and molecular  
487 results, indicating that concerns regarding mismatch between observational networks need not persist with  
488 *Bombus* studies...

489 ~ **WHAT this tells us about Bee foraging (APPLIED)** ~ Some foraging preferences of *Bombus*,  
490 both at this field site and across a great many localities globally emerge from this work, which reiterates the  
491 needs for land managers to maintain relatively high amounts of members of the Fabaceae, Boraginaceae, and  
492 Ranunculaceae, in Western North American montane landscapes (Goulson *et al.* (2005), Goulson (2010),  
493 Liang *et al.* (2021), Bontsutsnaja *et al.* (2021)). Numerous historic, and some ongoing, land management  
494 practices reduce the ability of many landscapes to support stable populations of *Bombus*. Historic livestock  
495 grazing was often associated with the targeted removal of many species of plants which are known to have  
496 compounds toxic to cattle. In particular, the removal of locoweeds (Fabaceae: *Astragalus* L. & *Oxytropis* DC.)  
497 and larkspurs (Ranunculaceae: *Delphinium*) were common across public lands administered by the United  
498 States Forest Service (Ralphs & Ueckert (1988), Aldous (1919), Ralphs *et al.* (2003)). Further actions,  
499 generally initiated by early settlers, involved the channelization and incising of streams, culling of beavers,  
500 and leaving cattle concentrated on higher order stream banks for significant periods of time, all processes

501 which lower the water tables and reduced the extent of stream-associated [riverine] wetlands and the mesic  
502 meadows fringes which provide habitat for many species of tall *Mertensia* (Boraginaceae, e.g. *M. ciliata* Torr.  
503 G. Don.) widely distributed across Western North America, and to an extent *Delphinium barbeyi* and many  
504 species of native *Trifolium* L. (Dahl (1990), Naiman *et al.* (1988), Belsky *et al.* (1999), Cooke & Reeves  
505 (1976)). Fire suppression further resulted in the succession of many Aspen (*Populus tremuloides* Michx.)  
506 groves to Conifer stands, decreasing the mosaic of age structured habitats in many landscapes, adversely  
507 effects habitat for tall *Mertensia* species and several species of *Delphinium* (Brewen *et al.* (2021), Keane  
508 (2002)). Finally the effects of Nitrogen deposition, especially given the West's rapidly growing population  
509 still pose adverse effects on the abundance of a variety of species of Fabaceae at Urban-Rural interfaces  
510 (see Stevens *et al.* (2018), Fenn *et al.* (2003)). Current solutions to these issues, involve targeted burns,  
511 reintroduction of beavers and beaver habitat analogs, and the possibility of re-seeding a variety of 'locoweeds'  
512 and 'larkspurs' in areas now seldom used, or only used for early, grazing. The highly enthusiastic response of  
513 land managers, and homeowners, to plant *Asclepias* L., using genetically appropriate materials, to improve  
514 Monarch Butterfly (*Danaus plexippus* L.) habitat provides an effective framework for the latter (Oberhauser  
515 *et al.* (2015), Basey *et al.* (2015)).

516 ~ **WHERE we see spatial/temporal going** We have concerns regarding the number of persons training  
517 to become and practice botany, and grave concerns regarding the funding mechanisms for floristic and field  
518 based botanical research and for centralized authorities to produce consensus opinions on alpha taxonomy  
519 (Prather *et al.* (2004b), Kramer & Havens (2015), Prather *et al.* (2004a), Crisci *et al.* (2020), Manzano  
520 (2021), Stroud *et al.* (2022)). To reduce the effects of a low population density of botanists on the mainte-  
521 nance of and production of flora's and to foster meta-genomics across landscapes without field stations we  
522 utilized Species Distribution Modelling to generate predictive species lists. In this proof of concept example  
523 we performed several iterations of modelling runs, and several approaches (i.e. the 'linear models', and the  
524 'machine learning'), which took notable amounts of compute power. We suspect the possible deleterious  
525 nature of this endeavor may be reduced by: 1) more field surveying by crews will reduce the need to generate  
526 as many species 2) fewer runs of models, 3) only running machine learning models which do not require an  
527 explicitly process to reduce spatial autocorrelation. However, given the time required to perform all aspects  
528 of a study, even our amount of computation was negligible. Further, we are very optimistic about the pos-  
529 sibility for persons to perform these tasks, as mentioned we utilized roughly only one quarter of the records  
530 which were digitally available for presence, and we suspect others will have enough records to perform this  
531 process nearly anywhere else in the temperate. In certain scenarios modelling of predicted species via more  
532 formally tailored S(tacked)-SDM or J(oint)-SDM approaches may be beneficial (Wilkinson *et al.* (2021),

533 Pinto-Ledezma & Cavender-Bares (2021), Schmitt *et al.* (2017)).

534 Tandem to the lack of continued expertise required to generate and maintain species lists, is the expertise  
535 required to continue tracking when major phenological events occur in many plant species at relatively fine  
536 scales or under novel climates. Knowledge of these events is currently limited to general time periods of only  
537 a handful of phenological events and groups of organisms (e.g. flowering initiation, or trees) (Prather *et al.*  
538 (2004a), Li *et al.* (2016)). While many programs and initiatives exist to collect phenological information on  
539 subsets of easily identifiable charismatic species to detect major trends in phenology, these capture only a  
540 subset of the extent diversity (Betancourt *et al.* (2005), Havens *et al.* (2007)). In many instances it appears  
541 that while landscapes respond similarly to environmental variables which predict phenological responses,  
542 that individual species vary widely in their responses to similar environmental cues, or respond to different  
543 cues (Augspurger & Zaya (2020), Xie *et al.* (2015), Xie *et al.* (2018), CaraDonna *et al.* (2014)). **As can**  
544 **be seen here, predictions of when a single, major phenological event occurs is already data**  
545 **limited, with sample size having an effect on the subset of species which we could even generate**  
546 **weibull estimates for. ; check assumptions of model again and just do a quasi something A**  
547 more promising approach for the tropics may lay in circular statistics (Park *et al.* (2022)).

548 ~ WHERE we see MOLECULAR going The nearly complete Plant and Fungal Tree of Life (PAFTOL)  
549 will provide a comprehensive phylogenetic backbone of the entire plant kingdom, and the inclusion of  
550 A353 probes with lineage specific probe sets is common in producing massive genetic datasets (Baker *et*  
551 *al.* (2021b)). We predict that the A353 probes which it is utilizing to work nearly immediately for DNA  
552 barcoding of whole plant material, and that more elaborate validation studies in controlled metabarcoding  
553 settings, utilizing existing experimental designs, will have favorable results (Bell *et al.* (2017), Bell *et al.*  
554 (2019), Bell *et al.* (2021), Lamb *et al.* (2019)). In particular the harvesting of loci with more variation  
555 in certain lineages, and or with more variable flanking regions, will prove promising for identifying closely  
556 related plant material (CITE). We suspect that conserved reaches of genes resulted in the high amounts  
557 of reads in somewhat obscure species. Given that the A353 loci are nuclear, single copy, and a variety are  
558 present the possibility of identifying target loci for quantitative purposes is high, without continual PCR  
559 enrichment is possible; this would align with relatively high efficacy of WGS (Lang *et al.* (2019), Peel *et al.*  
560 (2019), Bell *et al.* (2021)). Recent evidence indicates that the potential for identifying nearly cryptic taxa  
561 and even infra-specific inference, of either whole plant material, and perhaps in metagenomic context are  
562 possible (Ottenlips *et al.* (2021), Wenzell *et al.* (2021), Loke *et al.* in prep, Slimp *et al.* (2021), Beck *et al.*  
563 (2021)). We further believe that in synthetic phylogenetic trees - with incorporation of NGS backbones - will

564 allow in automatic reassignment of reads as a function of phylogenetic distance with measures of uncertainty  
565 (Hinchliff *et al.* (2015), Smith & Brown (2018), Baker *et al.* (2021a)).

## 566 5 | CONCLUSION

567 We believe that the combination of spatial and temporal models, united and guided by localized natural  
568 history knowledge, provides the essential components of a bayesian framework for approaching the coarse  
569 elucidation of ecological interactions using DNA Barcoding. Herein we crudely utilized this thinking via  
570 binary outcomes, should a species predicted be predicted present or not? Is it unequivocally flowering  
571 or not? Myriad data show biological systems and ecological interactions have more variance than can be  
572 reasonably discretely parsed. We expect that within a bayesian framework studies of pollinator behavior  
573 may be enacted via this approach at a landscape level, e.g. the scale of an entire drainage basin such as the  
574 Gunnison which is quickly becoming one of the worlds few model ecosystems. We hope that the promise of  
575 A353 probes as tools for metabarcoding play a role in these endeavors.

576 **AUTHOR CONTRIBUTIONS:** R.C.B conducted botanical collections, conducted all molecular lab  
577 work, lead all analyses, and writing. J.E.O conceived, designed, and conducted all ecological fieldwork,  
578 assisted with analyses, and writing. E.J.W. prepared, imaged, and collected trait data on pollen reference  
579 slides, and assisted with analysis of trait data and writing a dichotomous key. S.T. assisted with spatial  
580 analyses and writing. P.J.C assisted with ecological analyses and writing. J.B.F. conceived, and designed all  
581 lab work, analyses, and integration of approaches, assisted with writing, and secured funding for molecular  
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597 **PEER REVIEW** The peer review history for this document is available at ...

598 **DATA AVAILABILITY STATEMENT** The queries required to download all data used in this project  
599 are located in... All novel sequencing data are located at NCBI...

600 **ORCID**

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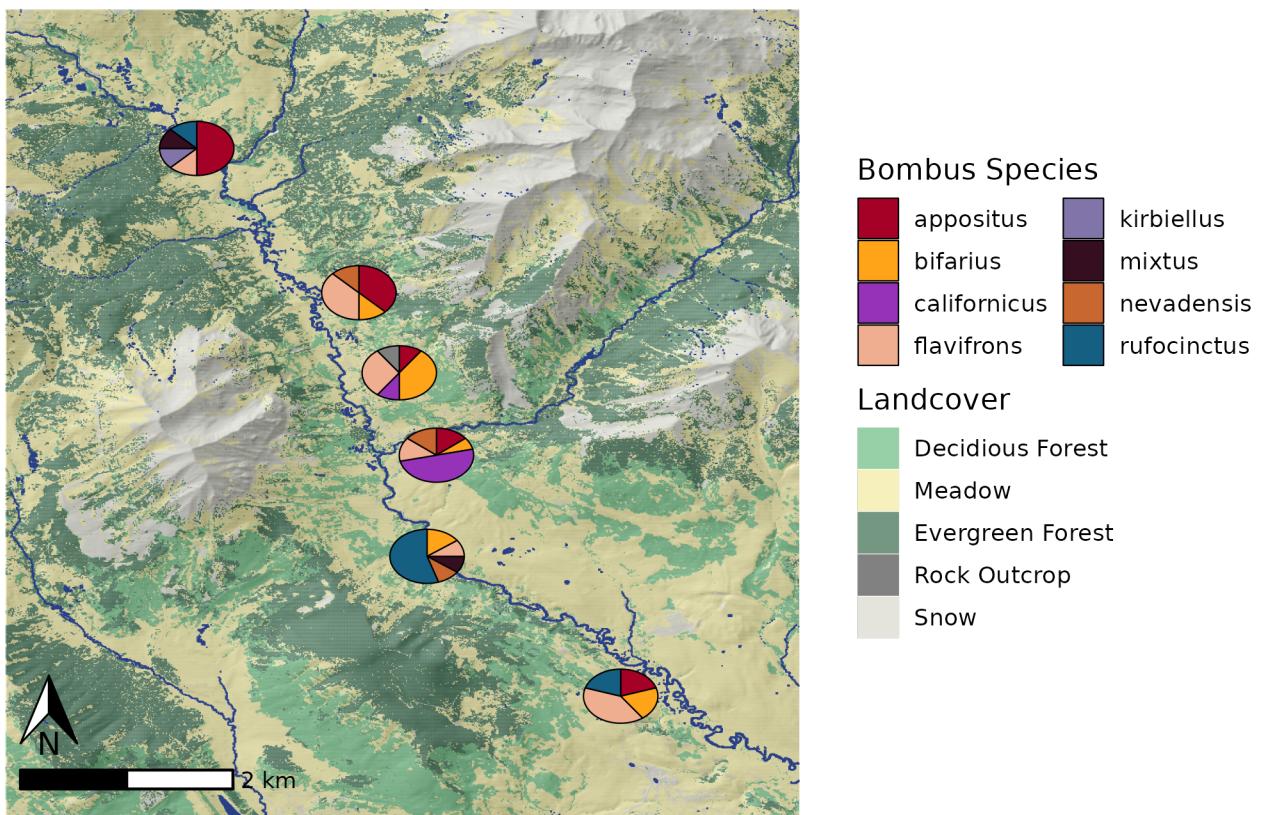
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605 **References**

606 **Supporting**

## Origins of Corbiculae Loads



Upper East River Valley, Colorado

## 609 Appendix 2 - Species Distribution Models Predictors

Layer	LM	Description	Source
1.		Mean annual cloudiness - MODIS	Wilson et al. 2016
2.		Cloudiness seasonality 1 - MODIS	Wilson et al. 2016
3.		Cloudiness seasonality 2 - MODIS	Wilson et al. 2016
4.		Cloudiness seasonality 3 - MODIS	Wilson et al. 2016
5.		Beginning of the frost-free period	Wang et al.
6.		Climatic moisture deficit	Wang et al.
7.		Degree-days above 5C from	Wang et al.
8.		Mean annual precipitation	Wang et al.
9.		Mean annual precipitation as snow	Wang et al.
10.		Temperature seasonality	Wang et al.
11.		2015 Percent Grass/Herbaceous cover - MODIS	(MOD44B)
12.		2015 Percent Tree cover from Landsat 7/8	(GLCF)
13.		Soil probability of bedrock (R Horizon)	SoilGrids
14.		Soil organic carbon (Tonnes / ha)	SoilGrids
15.		Surface soil pH in H <sub>2</sub> O	SoilGrids
16.		Surface soil percent sand	SoilGrids
17.		Soil USDA class	SoilGrids
18.		Topographic elevation	EarthEnv DEM
19.		Topographic elevation, moving window.	EarthEnv DEM
20.		Topographic percent slope	EarthEnv DEM
21.		Topographic wetness index	EarthEnv DEM
22.		Topographic aspect from	EarthEnv DEM
23.		Annual potential solar radiation computed	r.sun
24.		Estimated actual (w-/cloud) solar radiation r.	sun / Wilson et al. 2016
25.		Log-transformed distance to surface water Gl	obal Surface Water Explorer
26.		Percent surface water Gl	obal Surface Water Explorer

Table 1: samples used in creating the Reference Library

Taxon	Family	Accession	Pres.	Locality	Date Col.	GenBank	Dist. (km)
<i>Cirsium parryi</i> (A. Gray) Petr.	Asteraceae	CHIC tba	S	Colorado, Gunnison	20.IX.2020	tba	3.6
<i>Cirsium parryi</i> (A. Gray) Petr.	Asteraceae	CHIC tba	S	Colorado, Gunnison	20.IX.2020	tba	3.6
<i>Ericameria parryi</i> (A. Gray) G.L. Nesom & Baird	Asteraceae	CHIC tba	S	Colorado, Gunnison	20.IX.2020	tba	3.6
<i>Erigeron speciosus</i> (Lindley) De Candolle	Asteraceae	CHIC tba	S	Colorado, Gunnison	18.VII.2020	tba	3.6
<i>Erigeron subtrinervis</i> Rydb. Ex Porter & Britton	Asteraceae	CHIC tba	S	Colorado, Gunnison	20.VII.2020	tba	3.6
<i>Helianthella quinquenervis</i> (Hook.) A. Gray	Asteraceae	CHIC tba	S	Colorado, Gunnison	18.VII.2020	tba	3.6
<i>Helianthus multiflora</i> Nutt.	Asteraceae	CHIC tba	S	Colorado, Gunnison	18.VII.2020	tba	3.6
<i>Heterotheca villosa</i> (Pursh) Shinners	Asteraceae	CHIC tba	S	Colorado, Gunnison	20.IX.2020	tba	3.6
<i>Senecio sera</i> Hook.	Asteraceae	CHIC tba	P	Idaho, Idaho	26.VII.2020	tba	105.0
<i>Symplytrichum foliacum</i> (Lindl. Ex D.C.) G.L. Nesom	Asteraceae	CHIC tba	S	Illinois, McHenry	28.VII.2020	tba	1624.6
<i>Taraxacum officinale</i> F.H. Wigg.	Asteraceae	CHIC tba	S	Illinois, McHenry	28.VII.2020	tba	1624.6
<i>Mertenia ciliata</i> (James ex Torr.) G. Don	Boraginaceae	ID 1754185	S	Idaho, Valley	18.VI.2018	tba	979.3
<i>Mertenia ciliata</i> (James ex Torr.) G. Don	Boraginaceae	ID 169837	P	Idaho, Adams	10.VII.2014	tba	991.5
<i>Mertensia fusiformis</i> Greene	Boraginaceae	RMH 720522	P	Colorado, Gunnison	7.VI.1997	tba	44.8
<i>Campanula rotundifolia</i> L.	Campanulaceae	RMH 720600	P	Colorado, Gunnison	9.VII.1997	tba	38.9
<i>Lathyrus lanszwertii</i> Kellogg var. leucanthus (Ryd.) Dorn	Fabaceae	CHIC tba	S	Colorado, Gunnison	18.VII.2020	tba	3.6
<i>Lathyrus lanszwertii</i> Kellogg var. leucanthus (Ryd.) Dorn	Fabaceae	CHIC tba	S	Colorado, Gunnison	18.VII.2020	tba	3.6
<i>Lupinus argenteus</i> Pursh	Fabaceae	CHIC tba	P	Nevada, Pershing	29.V.2018	tba	971.2
<i>Lupinus argenteus</i> Pursh	Fabaceae	ISU 10387	P	Colorado, Gunnison	29.VI.2010	tba	0.2
<i>Lupinus bakeri</i> Greene	Fabaceae	ISU 10142	P	Colorado, Gunnison	15.VIII.2010	tba	2.6
<i>Vicia americana</i> Muhl. ex Willd.	Fabaceae	CHIC tba	S	Colorado, Gunnison	18.VII.2020	tba	3.6
<i>Vicia americana</i> Muhl. ex Willd. var. minor Hook.	Fabaceae	CHIC tba	S	Montana, Carbon	4.VII.2019	tba	10020.8
<i>Frasera speciosa</i> Douglas ex Griseb	Gentianaceae	RMH 721930	P	Colorado, Gunnison	20.VI.1997	tba	66.2
<i>Frasera speciosa</i> Douglas ex Griseb	Gentianaceae	RMH 719305	P	Colorado, Gunnison	7.VII.1997	tba	19.8
<i>Hydrophyllum capitatum</i> Douglas ex. Benth	Hydrophyllaceae	RMH tba	P	Colorado, Mesa	30.VI.2011	tba	64.6
<i>Hydrophyllum capitatum</i> Douglas ex. Benth	Hydrophyllaceae	RMH tba	P	Colorado, Delta	8.VI.2011	tba	65.3
<i>Hydrophyllum fendleri</i> (Gray) Heller	Hydrophyllaceae	ID 161100	P	Washington, Yakima	9.VI.2008	tba	1429.7
<i>Hydrophyllum fendleri</i> (Gray) Heller	Hydrophyllaceae	ID 164040	P	Idaho, Idaho	27.V.2009	tba	1014.4
<i>Agastache pallidiflora</i> (Heller) Rydberg	Lamiaceae	CHIC tba	S	Arizona, Coconino	17.VII.2020	tba	617.7
<i>Chamerion angustifolium</i> (L.) Holub	Lamiaceae	CHIC tba	S	Colorado, Gunnison	18.VII.2020	tba	3.6
<i>Delphinium barbeyi</i> (Huth) Huth	Ranunculaceae	CHIC tba	S	Colorado, Gunnison	18.VII.2020	tba	3.6
<i>Delphinium nuttallianum</i> Pritz.	Ranunculaceae	ID 166162	P	Idaho, Gem	15.VI.2011	tba	9825.5
<i>Delphinium nuttallianum</i> Pritz.	Ranunculaceae	ID 179376	P	Idaho, Gooding	29.IV.2017	tba	733.7
<i>Potentilla fruticosa</i> Pursh	Rosaceae	CHIC tba	S	Colorado, Gunnison	18.VII.2020	tba	3.6
<i>Potentilla fruticosa</i> Pursh	Rosaceae	CHIC tba	S	Colorado, Gunnison	18.VII.2020	tba	3.6
<i>Potentilla hippiana</i> Lehman.	Rosaceae	CHIC tba	S	New Mexico, Catron	15.VIII.2020	tba	573.8

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Table 1: samples used in creating the Reference Library (*continued*)

Taxon	Family	Accession	Pres.	Locality	Date Col.	GenBank	Dist. (km)
Potentilla pulcherrima Lehman.	Rosaceae	CHIC tba	S	Colorado, Gunnison	18.VII.2020	tba	3.6

<sup>a</sup> Accession includes both Herbarium and Accession number

<sup>b</sup> Pres. refers to Preservation method. 'S' denotes silica gel dried, 'P' denotes pressed

<sup>c</sup> All Localities are in the United States of America

613 Appendix 4 - All Pollen Reference Slides Used to Establish Morphotypes

Table 1: All Pollen Voucher Slides Consulted

Taxon	Family	Locality	Accession	Type	Prepared by	Date
<i>Cymopterus lemnoides</i> (J.M. Coulter & Rose) Dorn	Apiaceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Heracleum sphondylium</i> L.	Apiaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Ligusticum porteri</i> J.M. Coulter & Rose	Apiaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Osmorhiza depauperata</i> Phil.	Apiaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Maianthemum stellatum</i> (L.) Link	Asparagaceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Achillea millefolium</i> L.	Asteraceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Achillea millefolium</i> L.	Asteraceae	CO, Gunnison, Washington Gulch	tba	Novo	E.J.W.	2021
<i>Acourtia wrightii</i> (A. Gray) Reveal & King	Asteraceae	NV, Clark, Gold Butte	tba	Novo	E.J.W.	2021
<i>Antennaria racemosissima</i> Hook.	Asteraceae	WY, Park, Ishawooa Mesa	tba	Novo	E.J.W.	2021
<i>Arnica latifolia</i> Bong.	Asteraceae	ID, Blaine, Wildhorse Canyon	tba	Novo	E.J.W.	2021
<i>Artemisia scopulorum</i> A. Gray	Asteraceae	CO, Hinsdale, Uncompahgre Peak	tba	Novo	E.J.W.	2021
<i>Canadanthus modestus</i> (Lindl.) G.L. Nesom	Asteraceae	ID, Idaho, Whiskey Creek	tba	Novo	E.J.W.	2021
<i>Chaenactis douglasii</i> (Hook.) Hook. & Arn.	Asteraceae	MT, Carbon, Pryor Mtn. Rd.	tba	Novo	E.J.W.	2021
<i>Erigeron corymbosus</i> Nutt.	Asteraceae	MT, Carbon, Pryor Mtn. Rd.	tba	Novo	E.J.W.	2021
<i>Erigeron flagellaris</i> A. Gray	Asteraceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Erigeron speciosus</i> (Lind.) DC.	Asteraceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Erigeron speciosus</i> (Lindl.) DC.	Asteraceae	CO, Gunnison, Washington Gulch	tba	Novo	E.J.W.	2021
<i>Helianthella quinquenervis</i> (Hook.) A. Gray	Asteraceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Heliotropium multiflorum</i> Nutt.	Asteraceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Heliotropium multiflorum</i> Nutt.	Asteraceae	CO, Gunnison, Washington Gulch	tba	Novo	E.J.W.	2021
<i>Heterotheca villosa</i> (Pursh) Shinners	Asteraceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Heterotheca villosa</i> (Pursh) Shinners	Asteraceae	AZ, Coconino, Lake Mary Rd. & 209	tba	Novo	E.J.W.	2021
<i>Hymenoxys hoopesii</i> (A. Gray) Bierner	Asteraceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Hymenoxys rusbyi</i> (A. Gray) Cockerell	Asteraceae	AZ, Coconino, Lake Mary Rd. & 209	tba	Novo	E.J.W.	2021
<i>Ionactis stenomeria</i> (A. Gray) Greene	Asteraceae	ID, Idaho, Marshall Mountains	tba	Novo	E.J.W.	2021
<i>Senecio hydrophilus</i> Nutt.	Asteraceae	ID, Custer, E. fl. Salmon River	tba	Novo	E.J.W.	2021
<i>Senecio integrerrimus</i> Nutt.	Asteraceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Senecio serrula</i> Hook.	Asteraceae	CO, Gunnison, Washington Gulch	tba	Novo	E.J.W.	2021
<i>Senecio wootonii</i> Greene	Asteraceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Solidago lepida</i> DC.	Asteraceae	ID, Idaho, American River	tba	Novo	E.J.W.	2021
<i>Symphotrichum foliacum</i> (Lindl. ex DC.) G.L. Nesom	Asteraceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Symphotrichum subspicatum</i> (Nees) G.L. Nesom	Asteraceae	ID, Custer, E. fl. Salmon River	tba	Novo	E.J.W.	2021
<i>Taraxacum officinale</i> F.H. Wigg	Asteraceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Taraxacum officinale</i> F.H. Wigg	Asteraceae	IL, McHenry, Barrington	tba	Novo	E.J.W.	2021
<i>Lappula squarrosa</i> (Retz.) Dumort.	Boraginaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Mertensia ciliata</i> (James ex Torr.) G. Don	Boraginaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Mertensia fusiformis</i> Greene	Boraginaceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Boechera</i>	Brassicaceae	NV, Washoe, Mt. Rose	tba	Novo	E.J.W.	2021
<i>Boechera stricta</i> (Graham) Al-Shehbaz	Brassicaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Cardamine cordifolia</i> A. Gray	Brassicaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Draba aurea</i> Vahl. Ex Hornem	Brassicaceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014

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Table 1: All Pollen Voucher Slides Consulted (*continued*)

Taxon	Family	Locality	Accession	Type	Prepared by	Date
<i>Draba spectabilis</i> Greene	Brassicaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Erysimum capitatum</i> (Douglas ex Hook.) Greene	Brassicaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Lepidium montanum</i> Nutt.	Brassicaceae	NM, Catron, Zuni Dry Lake	tba	Novo	E.J.W.	2021
<i>Smelowskia americana</i> Rydb.	Brassicaceae	ID, Blaine, Pioneer Mtns Crest	tba	Novo	E.J.W.	2021
<i>Thlaspi arvense</i> L.	Brassicaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Campanula rotundifolia</i> L.	Campanulaceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Campanula rotundifolia</i> L.	Campanulaceae	CO, Gunnison, Washington Gulch	tba	Novo	E.J.W.	2021
<i>Downingia</i>	Campanulaceae	CA, Nevada, Truckee Meadows	tba	Novo	E.J.W.	2021
<i>Lonicera involucrata</i> (Richardson) Banks ex Spreng.	Caprifoliaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Minuartia nuttallii</i> (Pax.) Briq.	Caryophyllaceae	ID, Blaine, Wildhorse Canyon	tba	Novo	E.J.W.	2021
<i>Stellaria longifolia</i> Muh. Ex. Willd.	Caryophyllaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Parnassia kotzebuei</i> Cham. ex Spreng	Celastraceae	ID, Lemhi, Terrace Lakes	tba	Novo	E.J.W.	2021
<i>Sedum lanceolatum</i> Torr.	Crassulaceae	ID, Lemhi, Terrace Lakes	tba	Novo	E.J.W.	2021
<i>Astragalus robbinsii</i> (Oakes) A. Gray	Fabaceae	ID, Custer, Lake Creek	tba	Novo	E.J.W.	2021
<i>Glycyrrhiza lepidota</i> Nutt.	Fabaceae	ID, Butte, Warm Springs Creek	tba	Novo	E.J.W.	2021
<i>Lathyrus eucomus</i> Butters & H. St. John	Fabaceae	NM, Catron, Zuni Salt Lake	tba	Novo	E.J.W.	2021
<i>Lathyrus lanszwertii</i> var. <i>leucanthus</i> (Rydb.) Dorn	Fabaceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Lathyrus lanszwertii</i> var. <i>leucanthus</i> (Rydb.) Dorn	Fabaceae	CO, Gunnison, Washington Gulch	tba	Novo	E.J.W.	2021
<i>Lupinus argenteus</i> Pursh	Fabaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Lupinus argenteus</i> Pursh	Fabaceae	CO, Gunnison, Washington Gulch	tba	Novo	E.J.W.	2021
<i>Lupinus argenteus</i> Pursh	Fabaceae	NV, Pershing, Star Peak Canyon	tba	Novo	E.J.W.	2021
<i>Lupinus crassus</i> Payson	Fabaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Lupinus sericeus</i> Pursh	Fabaceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Melilotus albus</i> Medik.	Fabaceae	NM, Catron, Hwy 159	tba	Novo	E.J.W.	2021
<i>Trifolium hybridum</i> L.	Fabaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Trifolium pratense</i> L.	Fabaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Vicia americana</i> Muhl. Ex Willd.	Fabaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Vicia americana</i> Muhl. Ex Willd.	Fabaceae	UT, Cache, Spawn Creek	tba	Novo	E.J.W.	2021
<i>Vicia americana</i> Muhl. Ex Willd.	Fabaceae	CO, Gunnison, Washington Gulch	tba	Novo	E.J.W.	2021
<i>Geranium</i>	Geraniaceae	NM, Catron, Jim Smith TH. Rd.	tba	Novo	E.J.W.	2021
<i>Geranium richardsonii</i> Fisch. Trautv.	Geraniaceae	CO, Gunnison, Washington Gulch	tba	Novo	E.J.W.	2021
<i>Phacelia</i> sp.	Hydrophyllaceae	NV, Nye, Toiyabe Crest	tba	Novo	E.J.W.	2021
<i>Iris missouriensis</i> Nutt.	Iridaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Agastache palliflora</i> (A. Heller) Rydb.	Lamiaceae	AZ, Coconino, Lake Mary Rd. & 209	tba	Novo	E.J.W.	2021
<i>Erythronium grandiflorum</i> Pursh	Liliaceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Linum lewisii</i> Pursh	Linaceae	CO, Gunnison, Washington Gulch	tba	Novo	E.J.W.	2021
<i>Zigadenus elegans</i> Pursh	Melanthiaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Anticlea elegans</i> (A. Gray) Zomlefer & Judd	Melanthiaceae	ID, Blaine, Wildhorse Canyon	tba	Novo	E.J.W.	2021
<i>Cistanthe/Calyptidium</i>	Montiaceae	NV, Nye, Toiyabe Crest	tba	Novo	E.J.W.	2021
<i>Chamerion angustifolium</i> (L.) Holub	Onagraceae	CO, Gunnison, Washington Gulch	tba	Novo	E.J.W.	2021
<i>Epilobium obcordatum</i> A. Gray	Onagraceae	ID, Lemhi, Bighorn Crags	tba	Novo	E.J.W.	2021
<i>Castilleja miniata</i> Douglas ex Hook.	Orobanchaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010

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Table 1: All Pollen Voucher Slides Consulted (*continued*)

Taxon	Family	Locality	Accession	Type	Prepared by	Date
<i>Castilleja sulphurea</i> Rydb.	Orobanchaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Pedicularis groenlandica</i> Retz.	Orobanchaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Pedicularis racemosa</i> Douglas ex Benth.	Orobanchaceae	CO, Gunnison, Washington Gulch	tba	Novo	E.J.W.	2021
<i>Corydalis aurea</i> Willd.	Papaveraceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Erythranthe guttata</i> (DC.) G.L. Nesom	Phrymaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Penstemon wilcoxii</i> Rydb.	Plantaginaceae	MT, Missoula, Mission Mtns vic.	tba	Novo	E.J.W.	2021
<i>Collomia linearis</i> Nutt.	Polemoniaceae	CO, Gunnison, Washington Gulch	tba	Novo	E.J.W.	2021
<i>Phlox condensata</i> (A. Gray) E.E. Nelson	Polemoniaceae	CO, Hinsdale, Uncompahgre Peak	tba	Novo	E.J.W.	2021
<i>Polemonium foliosissimum</i> A. Gray	Polemoniaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Polemonium occidentale</i> Greene	Polemoniaceae	ID, Custer, Lake Creek	tba	Novo	E.J.W.	2021
<i>Polemonium viscosum</i> Nutt.	Polemoniaceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2010
<i>Bistorta bistortoides</i> (Pursh) Small	Polygonaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Eriogonum</i> spp.	Polygonaceae	NV, Washoe, Hwy 445	tba	Novo	E.J.W.	2021
<i>Polygala barbeyana</i> Chodat	Polygonaceae	NM, Eddy, Yeso Hills	tba	Novo	E.J.W.	2021
<i>Polygonum polygaloides</i> L.	Polygonaceae	MT, Missoula, Mission Mtns	tba	Novo	E.J.W.	2021
<i>Androsace filiformis</i> Retz.	Primulaceae	ID, Custer, Bradshaw Creek	tba	Novo	E.J.W.	2021
<i>Aquilegia coerulea</i> E. James	Ranunculaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Aquilegia coerulea</i> E. James	Ranunculaceae	CO, Gunnison, Washington Gulch	tba	Novo	E.J.W.	2021
<i>Aquilegia elegantula</i> Greene	Ranunculaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Delphinium barbeyi</i> (Huth) Huth	Ranunculaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Delphinium nuttallianum</i> Pritz. Ex Walp.	Ranunculaceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Ranunculus alismifolius</i> Geyer ex Benth.	Ranunculaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Ranunculus glaberrimus</i> Hook.	Ranunculaceae	ID, Lemhi, Agency Creek	tba	Novo	E.J.W.	2021
<i>Ranunculus inamoenus</i> Greene	Ranunculaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Ranunculus</i> spp.	Ranunculaceae	NV, Washoe, Mt. Rose	tba	Novo	E.J.W.	2021
<i>Thalictrum sparsiflorum</i> Tuzc. Ex Fisch. & C.A. Mey.	Ranunculaceae	ID, Custer, E. fk. Salmon River	tba	Novo	E.J.W.	2021
<i>Dasiphora fruticosa</i> (L.) Rydb.	Rosaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Dasiphora fruticosa</i> (L.) Rydb.	Rosaceae	CO, Gunnison, Washington Gulch	tba	Novo	E.J.W.	2021
<i>Fragaria virginiana</i> Duchesne	Rosaceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Geum triflorum</i> Pursh	Rosaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Potentilla biennis</i> Greene	Rosaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Potentilla hippiana</i> Lehm.	Rosaceae	NM, Catron, Jim Smith TH.Rd.	tba	Novo	E.J.W.	2021
<i>Potentilla pulcherrima</i> Lehm.	Rosaceae	CO, Gunnison, Gothic	None	Physical	P.J.C.	2014
<i>Potentilla pulcherrima</i> Lehm.	Rosaceae	CO, Gunnison, Washington Gulch	tba	Novo	E.J.W.	2021
<i>Salix bebbiana</i> Sarg.	Salicaceae	ID, Custer, Lake Creek	tba	Novo	E.J.W.	2021
<i>Salix geyeriana</i> Andersson	Salicaceae	ID, Butte, Clyde	tba	Novo	E.J.W.	2021
<i>Mitella stauropetala</i> Piper	Saxifragaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Valeriana occidentalis</i> A. Heller	Valerianaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010
<i>Viola canadensis</i> L.	Violaceae	CO, Gunnison, Gothic	None	Image	H.M.B.	2010

\* All Localities are in the United States of America

† Accession refers to whole-plant vouchers, all specimens are deposited at CHIC.

‡ Type Refers to whether both a physical and digital copy exist; 'Image' denotes only digital

§ Date refers to the Date of preparation.

<sup>617</sup> POLLEN CLUSTER RESULTS SHOULD BE HERE

- 1a: Pollen shed in clumps (tetrads/polyads); grains generally triangular, with an annulus subtending the porate apertures (go 34)
- 1b: Pollen generally dispersed as single units (monads); grains seldom if ever with annulus.
- 2a: Apertures porate, always lacking colpi
- 3a: grain outline from equatorial view circular
- 4a: Pores distributed along the equator.
- 5a: Pores > 5 (stephanoporate)
- 6a: Ornamentation homobrochate (~ *MENTZELIA*)
- 6b: Ornamentation otherwise (~ *POLYGALA*)
- 5b: Pores < 5 (*CURRENTLY OPEN*)
- 4b: Pores +/- distributed across grain (pantoporate)
- 7a: Ornamentation with striate ornamentation (~ *POLEMONIUM*)
- 7b: Ornamentation otherwise
- 8a: Ornamentation, slightly irregular - without regularly repeating features (scabrate) (~ *STELLARIA*)
- 8b: Ornamentation forming regularly repeating (reticulate) cells of varying shapes.
- 9a: spacing between the grid cells large (lophate), the walls of the cells with another set of projecting ornamentation (~ *OPUNTIA*)
- 9b: spacing between cells small, the wall of the cells without projecting features.
- 10a: Pores extending beyond the reticulate grids (~ *ARENARIA*)
- 10b: Pores extending beyond the reticulate grids (~ *PHLOX*)
- 3b: Outline from equatorial view otherwise (usually slightly triangular)
- 11a: Outline elliptic (*CURRENTLY EMPTY*)
- 11b: Outline not elliptic, grains often with acute, if rounded, angles along sides (e.g., triangular, polygonal) (*EMPTY*)
- 2b: Apertures with colpi, occasionally also with pores in addition (coporate)
- 12a: Grains with bristles tapering to points (echinate), and tri-colporate.
- 13a: Grains uniformly echinate, less the apertures. (Asteraceae 1)
- 13b: Grains with echinate bristles on ridges of lophae (Asteraceae 2)
- 12b: Grains without echinate ornamentation - this lead includes projections with ornamentation with round tips.
- 14a: Grains with either less than 3 apertures, or with two distinct ornamentation types (generally  $\frac{1}{2}$  psilate,  $\frac{1}{2}$  reticulate).
- 15a. Grains apparently lacking any apertures. (~ *IRIS*)
- 15b. Grains aperturate
- 16a. Ornamentation on one face of grain psilate, the other homobrochate (~ *ZIGADENUS + ANTICLEA*)
- 16b. Ornamentation psilate across both faces of grain (~*ERYTHONIUM*)
- 14b. Grains with either 3 or more apertures, or with an elongated spiral like aperture
- 17a. Grain with spiral like colpi
- 18a. Spiral with deep well-defined furrows (~ *ERYTHRANTHE GUTTATA*, syn. obsolete. *MIMULUS*)
- 18b. Spirals without well-defined grooves, ornamentation evidently perforate (~ *RANUNCULUS ALISMIFOLIUS*)
- 17b. Grains with colpi these not forming irregular spiral motifs.
- 19a. Grains elliptic, essentially perfectly cylindrical along longest axis, except for minor inundations along equatorial region. Apertures, of two types (heteroaperturate). (~ *BORAGINACEAE*)
- 19b Grains shaped similar or not, but never heteroaperturate.
- 20a. From a polar view, grains notably polygonal (hexagonal), also evident when seldom seen from a equatorial view. (~ *PHACELIA*/ maybe *Hydrophyllaceae*, *Hydrophyllum* not sampled)
- 20b. From a polar view, grains not with 6 convex apices

- 21a. Grains elliptic, with a short colporate aperture on each psilate face, the edges of each face and the apices with a distinct (homobrochate) textured ornamentation. (~ POLYGONUM)
- 21b. Grains otherwise, not featuring a mix of ornamentations independent of the apertures.
- 22a. Ornamentation perforate, the three colpi very short, their longest axis parallel to the equator rather than perpendicular. These colpi often times almost appearing to be slightly raised on an annulus like feature (~ LONICERA)
- 22b. Grains not as described in all aspects of the above.
- 23a. Apertures colporate
- 24a. Outline of grain in equatorial view circular, ornamentation smooth. (~MORPHOTYPE A).
- 24b. Grains otherwise
  - 25a Grains distinctly triangular from polar view (go 26)
  - 25b Grains elliptic (go 27)
    - 26a Grains very large, clearly strongly triangular in cross section. (~ GERANIUM)
    - 26b Grains smaller (SIZE), weakly triangular in cross section (~ POTENTILLA/DASIPHORA in part)
    - 27a Grains elliptic to weakly circular (~MORPHOTYPE B)
    - 27b Grains elliptic, much longer pole to pole than across equator.
    - 28a Grains with evident protrusions of the pore, colpi short, scarcely noticeable (~ APIACEAE)
- 23b. Apertures colpate
  - 30a Ornamentation psilate (~MORPHOTYPE C).
  - 30b Ornamentation otherwise
    - 31a Ornamentation homobrochate (~ MORPHOTYPE D)
    - 31b Ornamentation otherwise
      - 32a. Ornamentation bacculate, grains large, (~LINUM)
      - 32b. Ornamentation otherwise
        - 33a. Ornamentation of minor cross-corrugated grooves (fossulate) (~CORYDALIS)
        - 33b. Ornamentation of scarcely perceptible irregular features (scabrate) (~RANUNCULUS IN PART)

34a: Annula subtending the apertures – making grains appear more or less triangular; Pollen often with viscin threads (ONAGRACEAE)

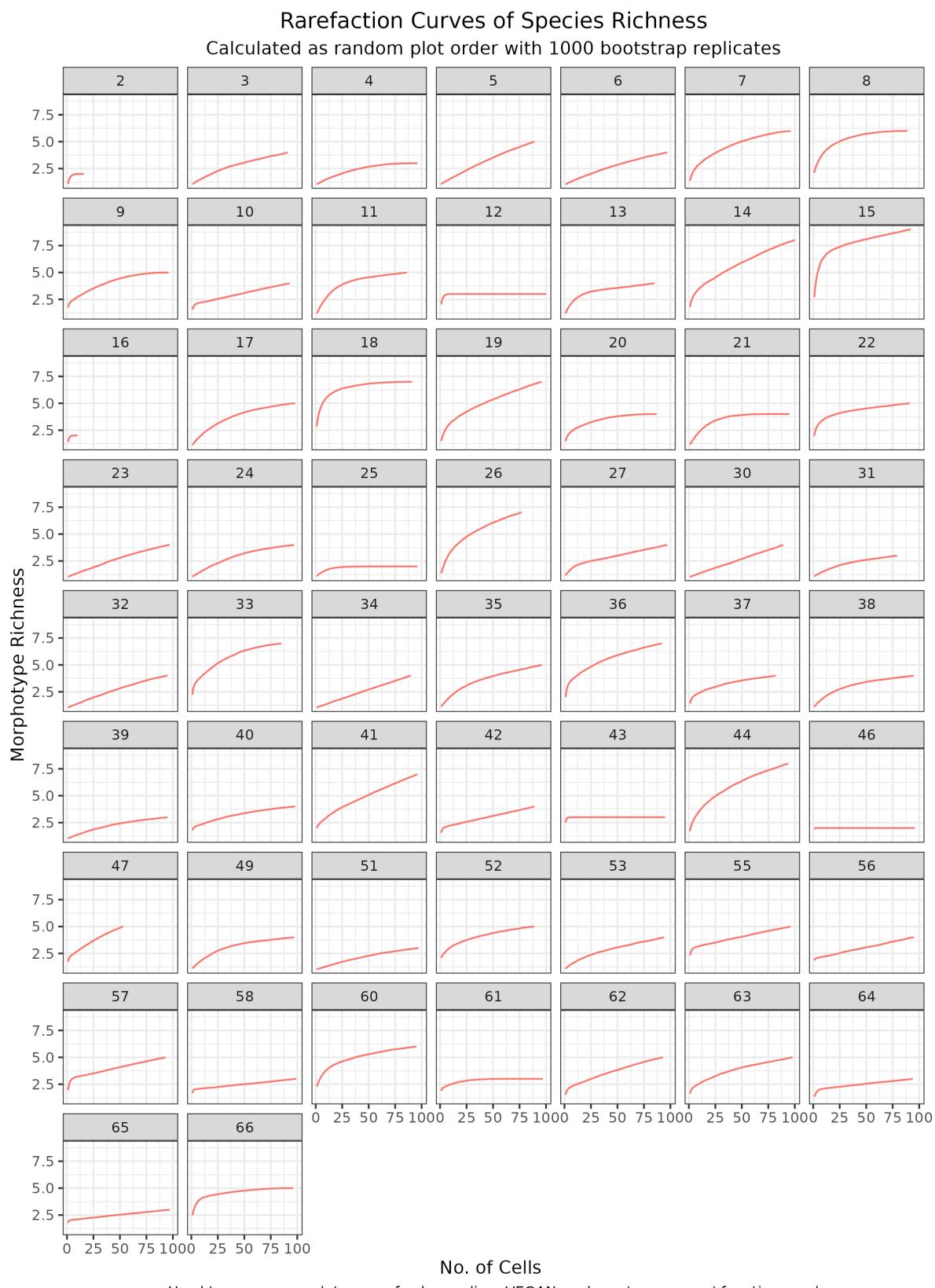
34b: Apertures not annulate – grains appear more or less circular (~ERICACEAE)

Morphotype A: Trifolium, Lupinus, Glycrrhiza, Mitella, Geum

Morphotype B: Lupinus, Lathyrus, Potentilla, Androsace, Bistorta, Vicia

Morphotype C: Jeffersonia, Micranthes, Prunus, Delphinium, Androsace, Penstemon, Orthocarpus, Scutellaria, Aquilegia, Castilleja, Draba)

Morphotype D: Salix, Boechera



### Species Richness Abundance Estimating via Hill Numbers ( $q = 0$ )

Confidence Interval of 99% with 1000 Bootstrap replicates

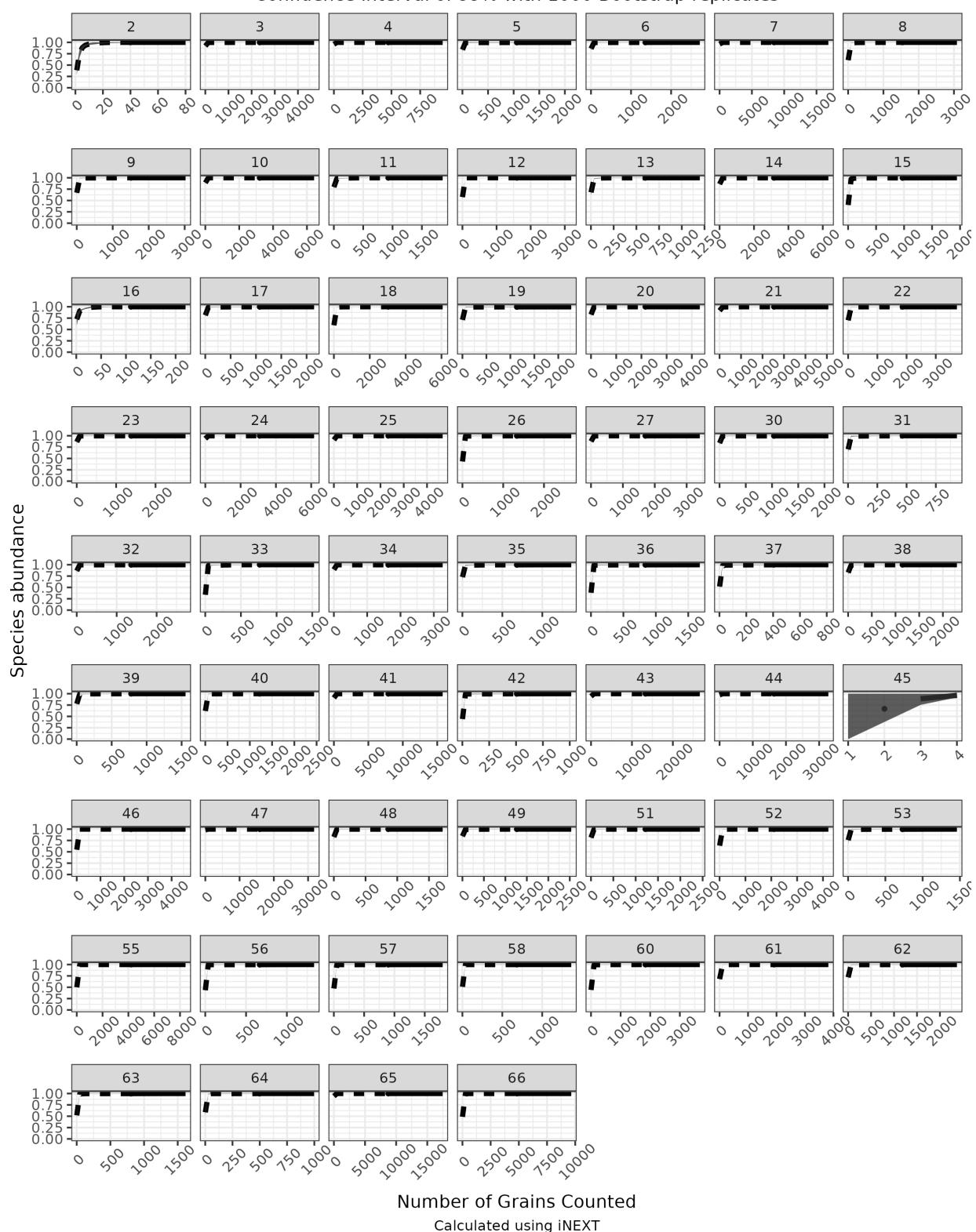


Table 1: All species present in the Reference Sequence Databases  
(Kraken and BLAST)

Order	Family	Taxon
Alismatales	Potamogetonaceae	<i>Potamogeton wrightii</i>
Apiales	Apiaceae	<i>Osmorhiza aristata</i>
Asparagales	Amaryllidaceae	<i>Allium stamineum</i>
	Asparagaceae	<i>Streptopus amplexifolius</i>
Asterales	Asteraceae	<i>Anaphalis margaritacea</i> <i>Antennaria carpatica</i> <i>Antennaria dioica</i> <i>Artemisia sibirica</i> <i>Brickellia dentata</i> <i>Chrysanthemus greenei</i> <i>Cirsium pannonicum</i> <i>Cirsium parryi</i> <i>Cirsium vulgare</i> <i>Crepis pygmaea</i> <i>Ericameria parryi</i> <i>Erigeron ecuadoriensis</i> <i>Erigeron grandiflorus</i> <i>Erigeron rosulatus</i> <i>Erigeron uniflorus</i> <i>Helianthella quinquenervis</i> <i>Heterotheca villosa</i> <i>Hieracium avilae</i> <i>Hieracium jubatum</i> <i>Hymenoxys hoopesii</i> <i>Leucanthemum graminifolium</i> <i>Microseris lindleyi</i> <i>Omalotheca supina</i> <i>Packera quercetorum</i> <i>Pseudognaphalium attenuatum</i> <i>Pseudognaphalium frigidum</i> <i>Pseudognaphalium lacteum</i> <i>Pseudognaphalium oxyphyllum</i> <i>Rudbeckia hirta</i> <i>Scabrethia scabra</i> <i>Senecio adenophyllus</i> <i>Senecio algens</i> <i>Senecio apolobambensis</i> <i>Senecio candollei</i> <i>Senecio chionogeton</i> <i>Senecio formosus</i> <i>Senecio funcii</i> <i>Senecio gilliesii</i> <i>Senecio humillimus</i> <i>Senecio nutans</i> <i>Senecio puchei</i> <i>Senecio rufescens</i> <i>Senecio spinosus</i> <i>Senecio tephrosioides</i>

(Continued on Next Page)

Table 1: All species present in the Reference Sequence Databases  
(Kraken and BLAST) (*continued*)

Order	Family	Taxon
Boraginales	Campanulaceae	<i>Solidago chilensis</i> <i>Stilpnolepis intricata</i> <i>Symphytum foliaceum</i> <i>Taraxacum cucullatum</i> <i>Taraxacum officinale</i>
		<i>Tonestus lyallii</i>
		<i>Townsendia formosa</i>
		<i>Campanula argaea</i>
		<i>Campanula rotundifolia</i>
	Hydrophyllaceae	<i>Cynoglossum amplifolium</i> <i>Cynoglossum anchusoides</i> <i>Cynoglossum pringlei</i> <i>Mertensia ciliata</i> <i>Mertensia fusiformis</i>
		<i>Hydrophyllum canadense</i>
		<i>Hydrophyllum capitatum</i>
		<i>Hydrophyllum fendleri</i>
		<i>Nemophila menziesii</i>
Caryophyllales	Caryophyllaceae	<i>Arenaria globiflora</i> <i>Arenaria serpyllifolia</i> <i>Cerastium arvense</i> <i>Cerastium lanceolatum</i> <i>Minuartia recurva</i> <i>Odontostemma leucasterium</i> <i>Pseudostellaria heterophylla</i> <i>Sagina procumbens</i> <i>Schizotechium monospermum</i> <i>Shivparvatia glanduligera</i>
		<i>Stellaria graminea</i>
		<i>Stellaria holostea</i>
		<i>Stellaria obtusa</i>
		<i>Rumex induratus</i>
		<i>Rumex spinosus</i>
		<i>Parnassia faberi</i>
		<i>Parnassia palustris</i>
		<i>Paxistima canbyi</i>
		<i>Gaultheria prostrata</i>
Celastrales	Ericaceae	<i>Moneses uniflora</i> <i>Orthilia secunda</i> <i>Vaccinium vitis-idaea</i> <i>Collomia grandiflora</i> <i>Ipomopsis aggregata</i>
		<i>Phlox douglasii</i>
		<i>Primulaceae</i>
		<i>Androsace studiosorum</i>
		<i>Androsace vitaliana</i>
	Fabaceae	<i>Astragalus pelecinus</i>
		<i>Lupinus argenteus</i>
		<i>Lupinus sericeus</i>

(Continued on Next Page)

Table 1: All species present in the Reference Sequence Databases  
(Kraken and BLAST) (*continued*)

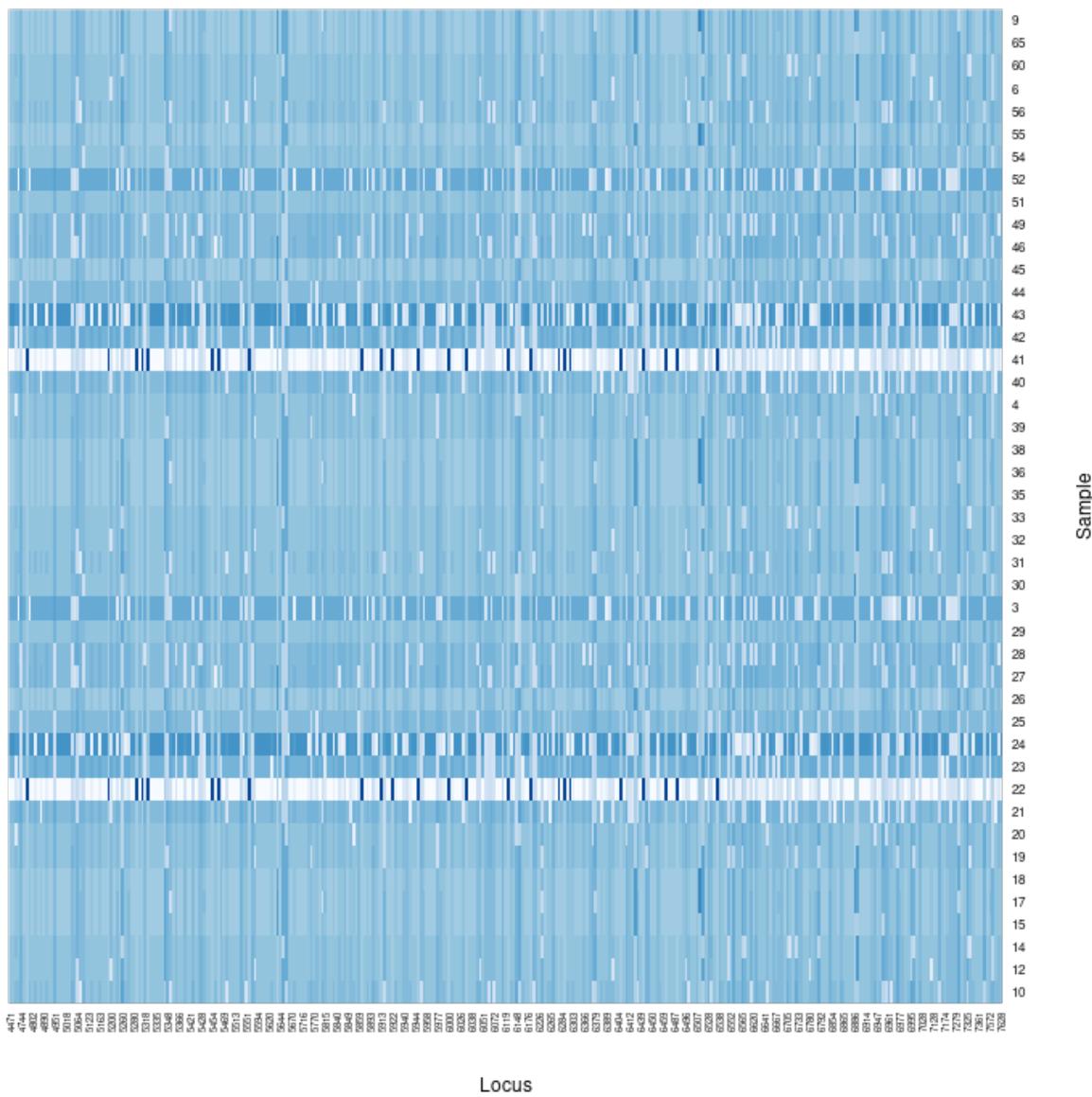
Order	Family	Taxon
Gentianales	Gentianaceae	<i>Vicia americana</i> <i>Frasera speciosa</i> <i>Gentiana cruciata</i>
Hyphomicrobiales	Xanthobacteraceae	<i>Azorhizobium caulinodans</i>
Lamiales	Lamiaceae	<i>Agastache pallidiflora</i>
Liliales	Colchicaceae	<i>Prosartes smithii</i>
	Liliaceae	<i>Erythronium dens-canis</i>
	Melanthiaceae	<i>Anticlea elegans</i> <i>Veratrum viride</i>
Malpighiales	Hypericaceae	<i>Hypericum perforatum</i>
	Salicaceae	<i>Populus alba</i>
	Violaceae	<i>Viola odorata</i>
Myrtales	Onagraceae	<i>Chamaenerion angustifolium</i> <i>Epilobium canum</i> <i>Epilobium parviflorum</i>
Ranunculales	Berberidaceae	<i>Berberis sibirica</i>
	Papaveraceae	<i>Corydalis aitchisonii</i>
	Ranunculaceae	<i>Actaea heracleifolia</i> <i>Anemone anemonoides</i> <i>Anemone obtusiloba</i> <i>Aquilegia ecalcarata</i> <i>Caltha palustris</i> <i>Delphinium barbeyi</i> <i>Delphinium gracile</i> <i>Delphinium nuttallianum</i> <i>Pulsatilla chinensis</i> <i>Thalictrum thalictroides</i> <i>Thalictrum tuberosum</i> <i>Trollius europaeus</i>
Rosales	Elaeagnaceae	<i>Shepherdia argentea</i>
	Rosaceae	<i>Crataegus bipinnatifida</i> <i>Dasiphora fruticosa</i> <i>Geum ternatum</i> <i>Hedlundia austriaca</i> <i>Holodiscus argenteus</i> <i>Karpatiosorbus devoniensis</i> <i>Micromeles japonica</i> <i>Potentilla anserina</i> <i>Potentilla pulcherrima</i> <i>Potentilla tetrandra</i> <i>Rubus chingii</i>
Sapindales	Sapindaceae	<i>Acer campestre</i>
Saxifragales	Crassulaceae	<i>Rhodiola rosea</i> <i>Sedum nudum</i>
	Grossulariaceae	<i>Ribes rubrum</i>
	Saxifragaceae	<i>Lithophragma parviflorum</i> <i>Saxifraga biflora</i> <i>Saxifraga fortunei</i>

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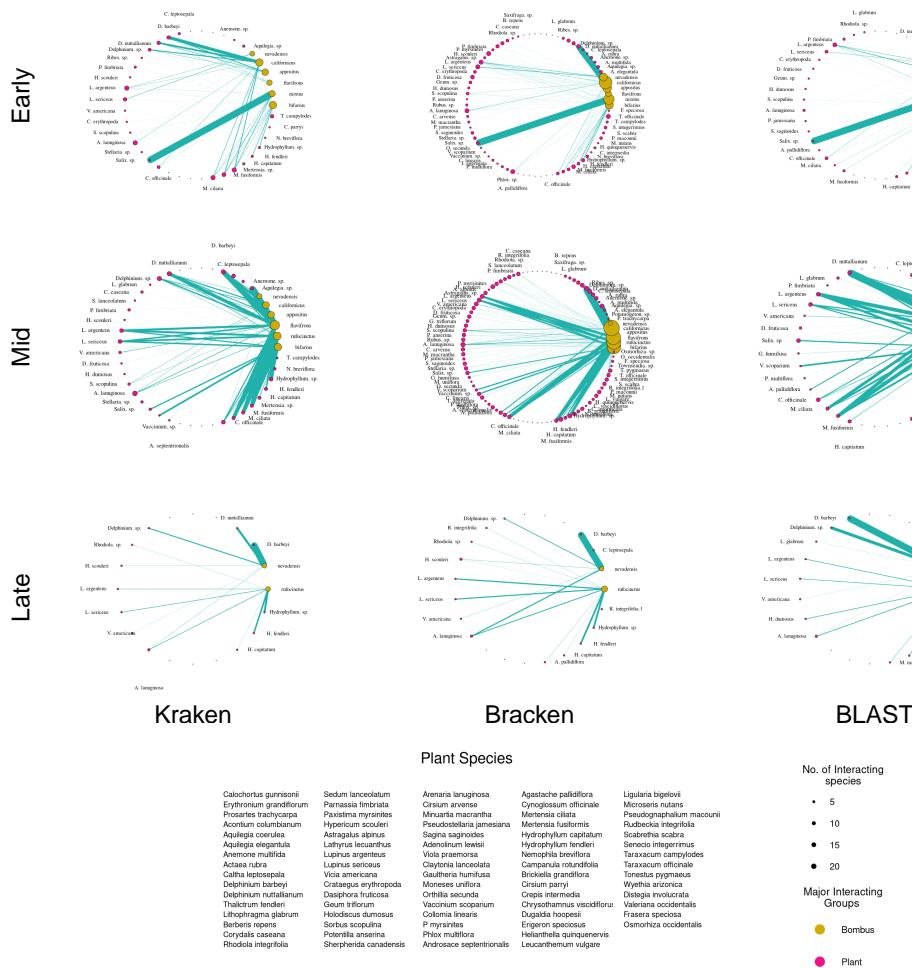
Table 1: All species present in the Reference Sequence Databases  
(Kraken and BLAST) (*continued*)

Order	Family	Taxon
		Saxifraga maderensis
		Saxifraga oppositifolia
		Saxifraga portosanctana
		Saxifraga x geum

x geum\\* \end{longtable}

**Percent matched reads per locus by sample**

## Comparision of Foraging Patterns from Three Sequence Alignment Algorithms



636 Appendix XX - Models used for Species Distribution Model Ensembles

637 *Generalised Linear Models (GLM)*

638 *Generalised Additive Models (GAM)*

639 The two machine learning models utilize Ensemble learning.

640 Decision trees, ...

641 Ensemble learning utilizes many sets of trees, each tree being composed of many binary decisions, to create  
642 a single model. Each independent variable (- or *feature*) may become a node on the tree - i.e. a location on  
643 the tree where a binary decision will move towards a predicted outcome. Each of the decision tree models  
644 which ensemble learning utilizes is a weak model, each of which may suffer due to high variance or bias, but  
645 which produce better outcomes than would be expected via chance. When ensembled these models generate  
646 a strong model, a model which should have more appropriately balanced variance and bias and predicts  
647 outcomes which are more strongly correlated with the expected values than the individual weak models.

648 *Random Forest (RF)* the training data are continually bootstrap re-sampled, in combination with random  
649 subsets of features, to create nodes which attempt to optimally predict a known outcome. A large number  
650 of trees are then aggregated, via the most common predictions, to generate a final classification prediction  
651 tree. Each individual prediction tree is generated independently of the others.

652 *Boosted Regression Tree (BRT)* (or Gradient Boosted tree) An initial tree is grown, and all other trees  
653 are derived sequentially from it, as each new tree is grown the errors in responses from the last tree are  
654 weighed more heavily so that the model focuses on selecting dependent variables which refine predictions.  
655 All response data and predictor variables are kept available to all trees.

656 Random Forest have high bias and low variance, where boosted regressions trees have low bias and high  
657 variances.

Table 1: Subset of Possible Combinations for re-classifying Sequences by Incorporating Ecological Factors

Spatial	Temporal	Congener	Confamilial	Congeners	Confamilials	Condition	Return	Rank
1	1	1	1	0	0	A.1	Input	Species
1	1	1	1	1	0	A.2	Input	Species
1	1	1	1	0	1	A.3	Input	Species
1	1	1	1	1	1	A.4	Input	Species
1	1	1	0	0	0	A.5	Input	Species
1	1	1	0	1	0	A.6	Input	Species
1	1	0	1	0	0	A.7	Input	Species
1	1	0	1	0	1	A.8	Input	Species
1	1	0	0	0	0	A.9	Input	Species
1	0	1	1	0	0	B.1	Congener	Species
1	0	1	1	0	1	B.2	Congener	Species
1	0	1	0	0	0	B.3	Congener	Species
1	0	1	1	1	0	C.1	Congener	Genus
1	0	1	1	1	1	C.2	Congener	Genus
1	0	1	0	1	0	C.3	Congener	Genus
1	0	0	1	0	0	D.1	Confamilial	Species
1	0	0	1	0	1	E.1	Confamilial	Family
1	0	0	0	0	0	F.1	Input	Species
0	0	1	1	0	0	G.1	Congener	Species
0	0	1	1	0	1	G.2	Congener	Species
0	0	1	0	0	0	G.3	Congener	Species
0	0	1	1	1	0	H.1	Congener	Genus
0	0	1	1	1	1	H.2	Congener	Genus
0	0	1	0	1	0	H.3	Congener	Genus
0	0	0	1	0	0	I.1	Confamilial	Species
0	0	0	1	0	1	J.1	Confamilial	Family

Note, for both ‘Congener’ and ‘Confamilial’ (*in the singular*) ‘1’ denotes that a species is present; in a sense the genus is monotypic in space and time. For both ‘Congeners’ and ‘Confamilials’ (*in the plural*), ‘1’ denotes that two or more species are present; ‘Confamilial’ again representing a monotypic entity in space and time.

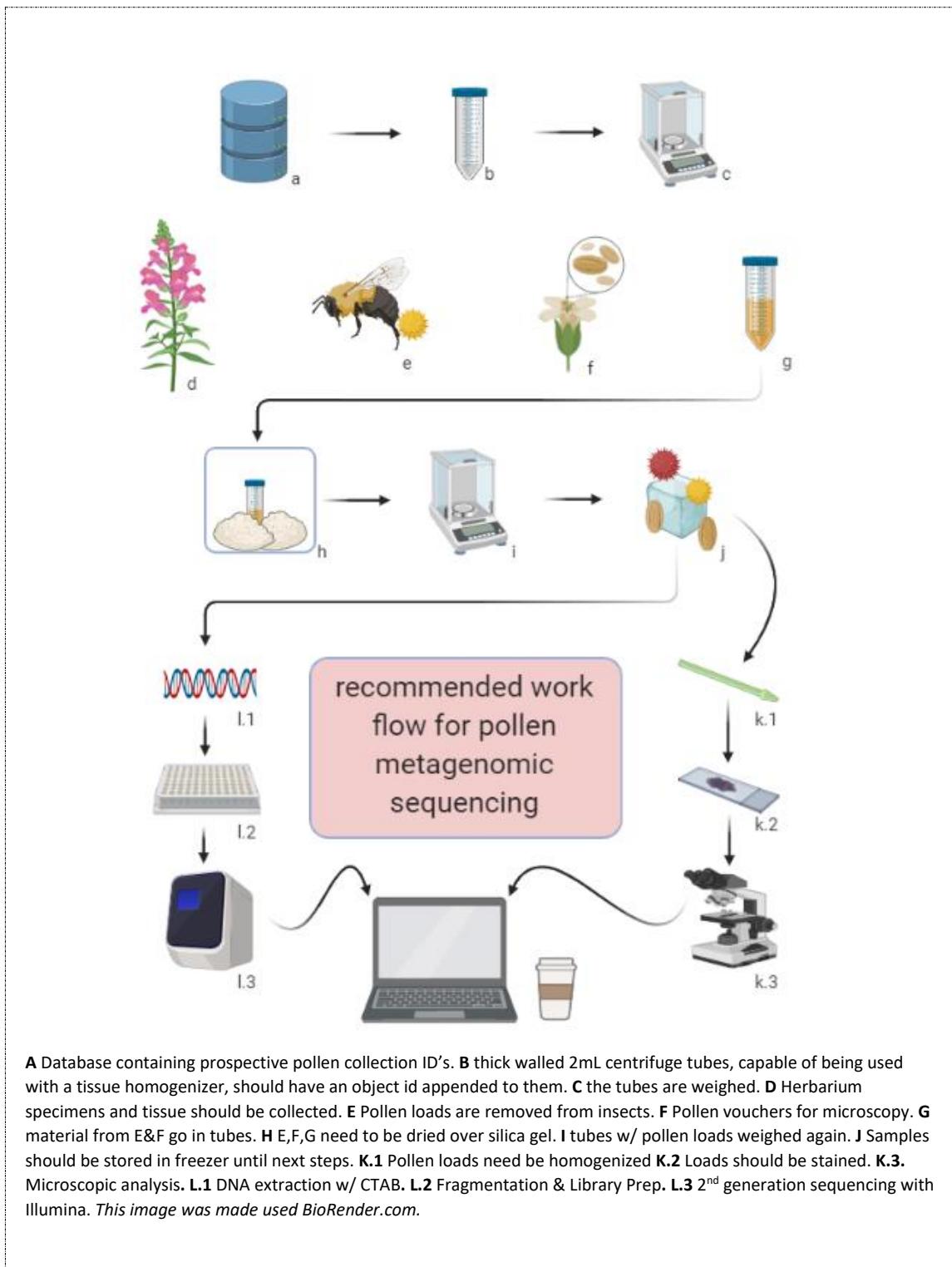
$$\begin{aligned} \text{Spatial} == 1 \& \text{ Temporal} == 1 \sim \mathbf{A} \\ \text{Spatial} == 1 \& \text{ Temporal} == 0 \& \text{ Congener} = 1 \sim \mathbf{B} \end{aligned}$$

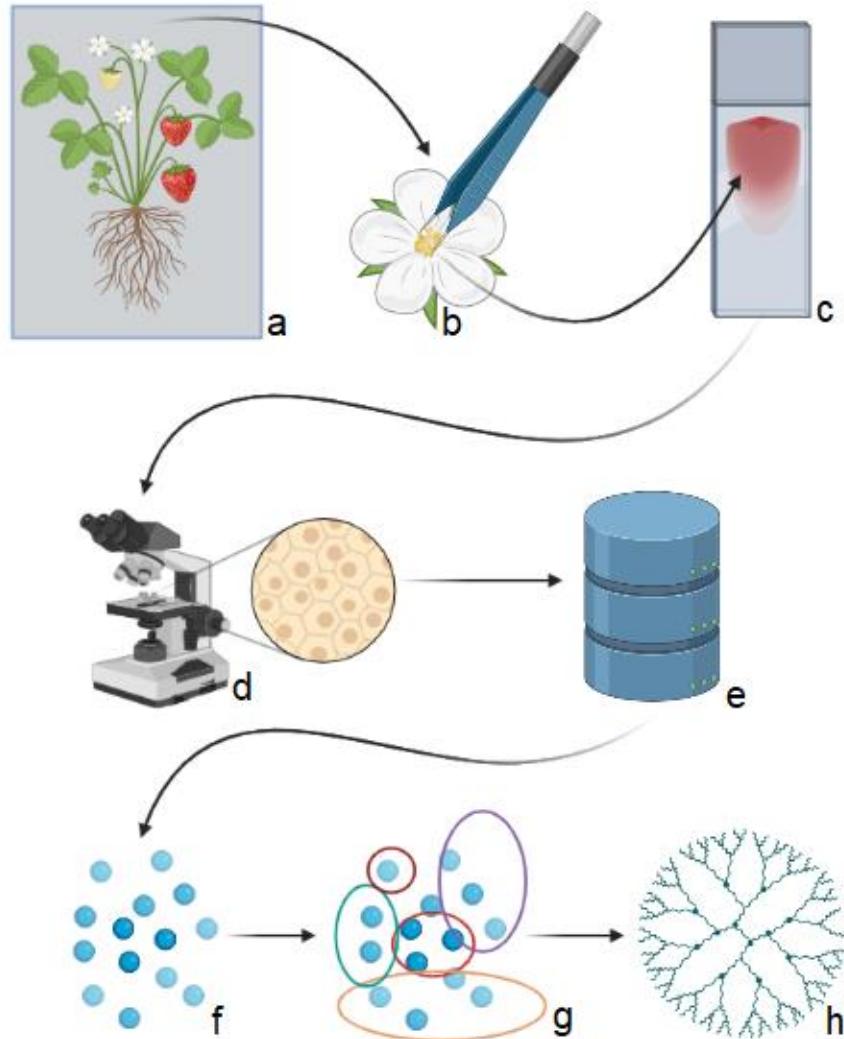
*The temporal dimension is now buffered and a form of  $\mathbf{A}$  is employed*  
 $\text{Spatial} == 1 \& \text{ Temporal} +/- \text{ Buffer} == 1 \sim \mathbf{X}$

$$\begin{aligned} \text{Spatial} == 1 \& \text{ Temporal} == 0 \& \text{ Congeners} >= 2 \sim \mathbf{C} \\ \text{Spatial} == 1 \& \text{ Temporal} == 0 \& \text{ Congeners} == 0 \& \text{ Confamilial} == 1 \sim \mathbf{D} \\ \text{Spatial} == 1 \& \text{ Temporal} == 0 \& \text{ Congeners} == 0 \& \text{ Confamilial} >= 2 \sim \mathbf{E} \\ \text{Spatial} == 1 \& \text{ Temporal} == 0 \& \text{ Congener|s} == 0 \& \text{ Confamilial|s} == 0 \sim \mathbf{F} \end{aligned}$$

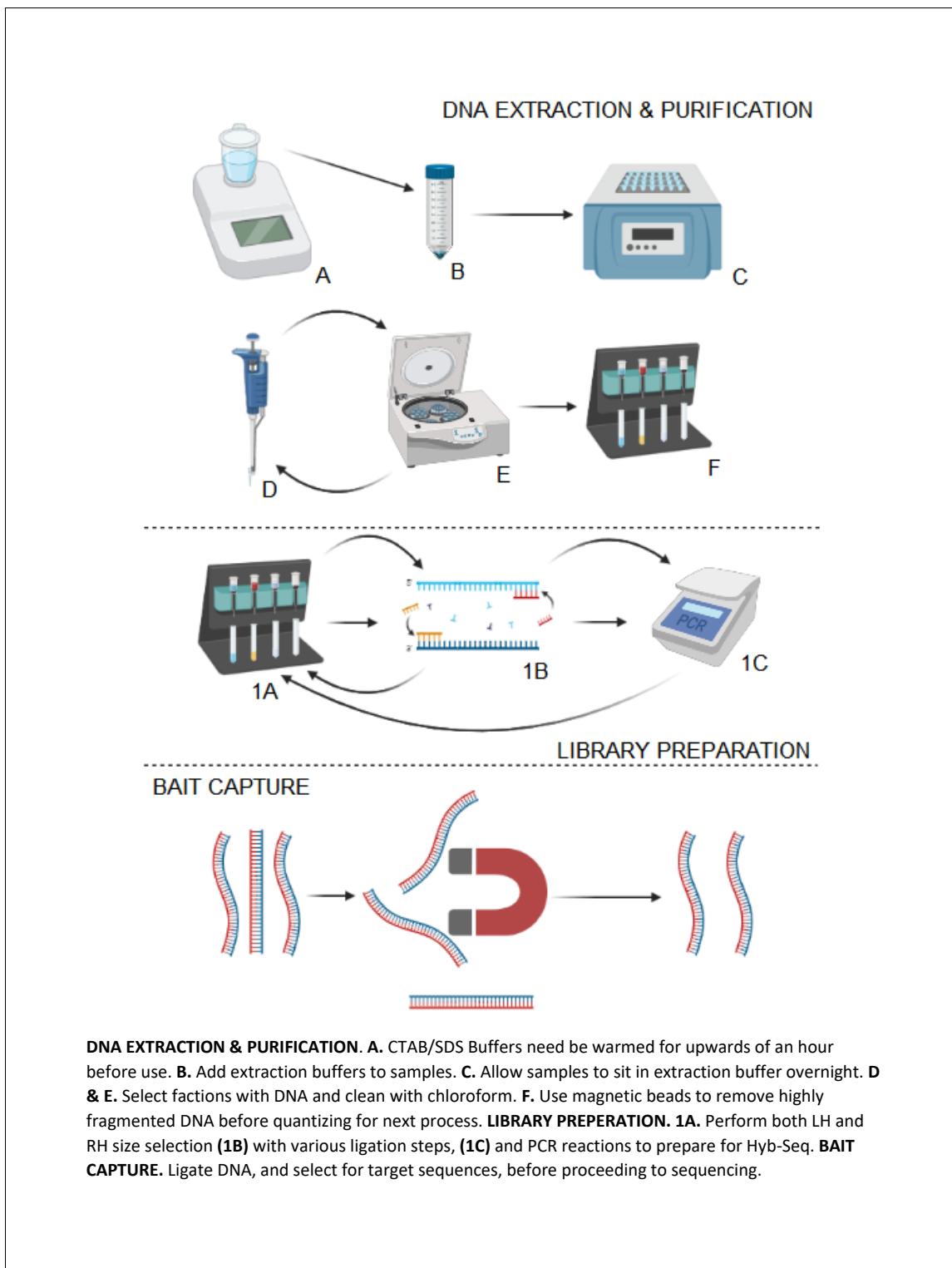
$$\begin{aligned} \text{Spatial} == 0 \& \text{ Temporal} == 0 \& \text{ Congener} == 1 \sim \mathbf{G} \\ \text{Spatial} == 0 \& \text{ Temporal} == 0 \& \text{ Congeners} == 1 \sim \mathbf{H} \\ \text{Spatial} == 0 \& \text{ Temporal} == 0 \& \text{ Confamilial} == 1 \sim \mathbf{I} \\ \text{Spatial} == 0 \& \text{ Temporal} == 0 \& \text{ Confamilials} == 1 \sim \mathbf{J} \end{aligned}$$

While the overall order matters,  $\mathbf{X}$  in particular may significantly alter conclusions.





**A.** An herbarium collection in flower from which pollen may be removed. **B.** The careful removal of pollen from dehiscent anthers using dissection tools. **C.** Place the pollen on a fuchsin jelly cube and melt it with stirring on a hotplate, for ca. 30 seconds. **D.** Microscopic imaging, of specimens and collection of character trait data. **E.** Immediate input and accessioning of files to a database. **F.** Ordination of traits into 2-dimensional space. **G.** Agglomerative clustering of data points into similar groups. **H.** Recovery of bifurcating decisions in development of clusters, or handwritten keys to visually diagnosable groups.



**DNA EXTRACTION & PURIFICATION.** A. CTAB/SDS Buffers need to be warmed for upwards of an hour before use. B. Add extraction buffers to samples. C. Allow samples to sit in extraction buffer overnight. D & E. Select fractions with DNA and clean with chloroform. F. Use magnetic beads to remove highly fragmented DNA before quantizing for next process. **LIBRARY PREPARATION.** 1A. Perform both LH and RH size selection (1B) with various ligation steps, (1C) and PCR reactions to prepare for Hyb-Seq. **BAIT CAPTURE.** Ligate DNA, and select for target sequences, before proceeding to sequencing.

## CTAB-DNA POLLEN EXTRACTIONS

Adapted from Lalhmangiahi et. al & Guertler et al. by Benkendorf, Fant, & Noble.

### SAMPLE PREPARATION AND GRINDING

- a1) Add 380  $\mu$ L extraction buffer (100 mM Tris-HCl, 50 mM EDTA, 50 mM NaCl, 10% SDS, pH 7.5). This solution will need to be warm enough for the SDS to be in solution, requires heat and stirring.
- a2) Vortex samples at speed > 2000, until pellet breaks apart, ca. 20-30 seconds.
- a3) Use the Pellet Pestle Motor (Kontes) for ca. 15 seconds to macerate samples.
- a4) Add 100  $\mu$ L extraction buffer to wash the tip of the pestle into the centrifuge tube, and burst bubbles.
- a5) Allow to sit at 35°C for 1 hour, use vortex occasionally if sedimentation of pollen occurs.

### EXTRACTION AND ISOLATION OF DNA

- b1) Warm CTAB buffer to remove any precipitants if present.
- b2) Add 480  $\mu$ L 10% CTAB buffer.
- b3) Add 10  $\mu$ L RNase (10mg/mL); invert by hand, incubate for 40 minutes at 37°C, increase heat to 60°C wait 20 minutes before continuing to b4.
- b4) Add 15  $\mu$ L proteinase K (20mg/mL) & 12.5  $\mu$ L DTT (1 molar in H<sub>2</sub>O); invert by hand, incubate for 1 hr. at 60°C.
- b5) Incubate overnight at 40°C (*note: this is a hard stopping point*)
- b6) Add 500  $\mu$ L of Phenol-chloroform-isoamyl alcohol vortex samples, centrifuge at 10,000 rpm (10 min.)
- b7) Transfer the uppermost aqueous layer to a new 2 mL centrifuge tube.

### DNA PRECIPITATION

- c1) Add slightly chilled Isopropyl alcohol & Sodium Acetate 3mM 5:1, equivalent to ca. 2/3 of the removed layer. Store at -20°C, 1 hour to allow precipitation.  
*(Note: potential stopping point for a day or more, samples can stay at -20°C for days)*
- c2) Centrifuge at 13,000 rpm for 10 minutes.
- c3) Pour supernatant into new 2mL centrifuge tube, add 400  $\mu$ L 70% EtOH. Store at -20°C for 20 minutes.
- c4) Spin at 13,000 rpm for 10 minutes, discard supernatant.  
*for both tubes the following steps apply*
- c3) Add 400  $\mu$ L of 75% EtOH, invert tube x3, centrifuge at 13,000 rpm for 4 minutes; discard supernatant
- c4) Add 400  $\mu$ L of 95% EtOH, invert tube x3, centrifuge at 13,000 rpm for 4 minutes, discard supernatant
- c5) Dry tubes in vacuum centrifuge for 30 minutes on medium heat at 15 mmHG.

### RESUSPENSION OF DNA

- d1) Add 40  $\mu$ L of dna free H<sub>2</sub>O to sample.
- d2) place on heat block at 37°C until pellet resuspends with occasional use of vortexes.

**NOTES:** a 10% CTAB preparation will not readily stay in solution, maintain it on heatblock until you are ready to use it. After adding it to extraction tubes move them to heat block immediately (*i.e.* in batches of 5-10).

## Solutions

### **Extraction buffer (100 mM Tris-HCl, 50 mM EDTA, 50 mM NaCl, 10% SDS - pH 7.5, ca. 32 mL H<sub>2</sub>O)**

#### For 100 samples (50 mL solution)

10 grams SDS (Sodium Dodecyl Sulfate , d = 1.01 g/cm3)

146.1 mg Sodium Chloride (NaCl, mw = 58.4 g/mol)

930.6 mg EDTA (EthyleneDiamineTetraacetic Acid Disodium Salt dihydrate, mw = 372.24 g/mol)

Add 20 mL deH<sub>2</sub>O

5 mL Tris-HCl pH 8.0 (1 molar- kept in fridge)

Fill to 50 mL with deH<sub>2</sub>O

Auto clave on 'Liquid' setting for 15 minutes.

Dissolution may require heat and stirring (3 & 4 settings respectively, ca. 15 min.)

### **10% CTAB solution (20 mM Tris-Cl pH 8.0, 1.4 M NaCl, 10 mM EDTA pH 7.5, 10% CTAB, 5% PVP, 40 mL DiH<sub>2</sub>O)**

#### For 100 samples (50 mL solution)

add ~30 mL deH<sub>2</sub>O,

1 ml Tris-HCl pH 8.0 (1 molar- kept in fridge; 2-Amino-2-(hydroxymethyl)propane-1,3-diol)

4.08 g Sodium Chloride (NaCl, mw = 58.4 g/mol)

4 mL EDTA pH 7.5 (0.125 molar – kept in fridge; 2,2',2'',2'''-(Ethane-1,2-diyl)dinitrilo)tetraacetic acid)

5 g CTAB (hexadecyl(trimethyl)ammonium bromide, mw = 364.45, FYI this is 274 mM)

Auto clave on 'Liquid' setting for 15 minutes.

2.5 g PVP-40 (1-ethenylpyrrolidin-2-one) – add after autoclave

Fill to 50 mL with deH<sub>2</sub>O

Dissolution of PVP will require 2-3 hrs, at 65°C with stirring. Before use allow one hour of stirring and heat to resuspend all salts in the solution.

### **Sodium acetate solution (3mM)**

#### For 100 samples (10 mL solution)

20.4 mg Sodium Acetate trihydrate (mw = 136.08 g/M)

to 50 mL deH<sub>2</sub>O

Auto clave on 'Liquid' setting for 15 minutes.

### **Phenol-chloroform Isoamyl alcohol (25:24:1) Saturated with 10 mM Tris pH 8.0, EDTA**

#### For 100 samples (50 mL solution) (no need to make, is bought)

25 mL Phenol

24 mL Chloroform (Trichloromethane)

1 mL Isoamyl alcohol

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666 THIS SHOULD BE TURNED INTO A SMALLER PNG, AND HAVE THE NUMBER OF SEQUENCED  
667 METAGENOMIC SAMPLES PLACED INTO THAT COLUMN AND INCLUDED IN TEXT ~~~ NEED  
668 THIS !!!

Table 1: Queen Bee Pollen Loads examined

Subgenus	Species	Author	Tongue Length	Microscope Slides	Metagenome Samples
Subterraneobombus Vogt	<i>B. appositus</i>	Cresson 1879	Long	11	NA
Pyrobombus Dalla Torre	<i>B. bifarius</i>	Cresson 1879	Short	11	NA
Thoracobombus Dalla Torre	<i>B. californicus</i>	Smith 1854	Long	8	NA
Pyrobombus Dalla Torre	<i>B. flavifrons</i>	Cresson 1864	Medium	13	NA
Pyrobombus Dalla Torre	<i>B. mixtus</i>	Cresson 1879	Short	3	NA
Pyrobombus Dalla Torre	<i>B. nevadensis</i>	Cresson 1874	Long	5	NA
Bombias Robertson	<i>B. nevadensis</i>	Cresson 1864	Short	13	NA
Cullumanobombus Vogt	<i>B. rufocinctus</i>	Kirby 1837	Short	1	NA
Pyrobombus Dalla Torre	<i>B. sylvicola</i>				

<sup>a</sup> All subgenera follow the system of Williams et al. 2008, and placements were found from the NMH website.<sup>b</sup> Tongue Lengths collected from Pyke et al. 2012

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## <sup>1041</sup> List of Figures

<sup>1042</sup> 1	Phylogenetic tree of all biotically pollinated plant genera in the study area. The innermost ring indicates every genus which Queen Bee's were observed to visit. The intermediate ring indicates that at least a single morphological pollen voucher slide was prepared for a member of the genus. The outermost ring indicates that sequence data were available for at least a member of that genus. Branch colors follow APG 4. . . . .	63
<sup>1043</sup> 2	Modelled dates of when major flowering events occurred . . . . .	64
<sup>1044</sup> 3	Number of the ten most commonly visited plants which are also in the top ten most common sequences . . . . .	65
<sup>1045</sup>		
<sup>1046</sup>		
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<sup>1049</sup>		

## Biotically pollinated plant genera with morphological or molecular data



Figure 1: Phylogenetic tree of all biotically pollinated plant genera in the study area. The innermost ring indicates every genus which Queen Bee's were observed to visit. The intermediate ring indicates that at least a single morphological pollen voucher slide was prepared for a member of the genus. The outermost ring indicates that sequence data were available for at least a member of that genus. Branch colors follow APG 4.

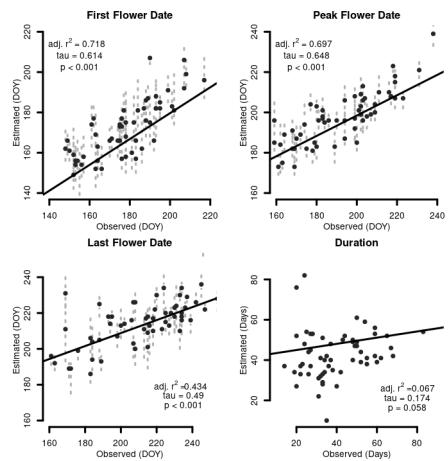


Figure 2: Modelled dates of when major flowering events occurred

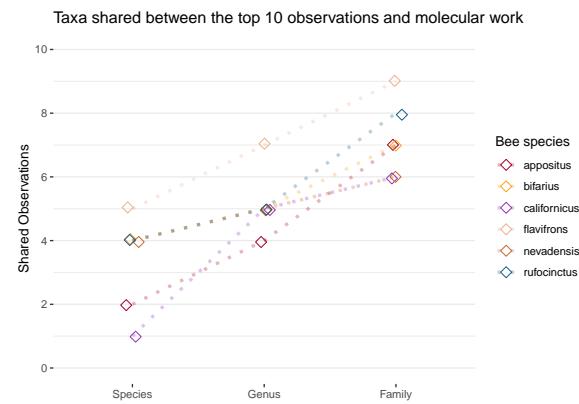


Figure 3: Number of the ten most commonly visited plants which are also in the top ten most common sequences

1050 **List of Tables**

<small>1051</small>	2	Logistic regression assessing accuracy of SDMs . . . . .	67
<small>1052</small>	3	Species Distribution Modeling evaluation contingency table . . . . .	68
<small>1053</small>	4	Post classification of Sequences via Taxonomy and Ecology . . . . .	69

Table 2: Logistic regression assessing accuracy of SDMs

Metric	Value	Metric	Value
Accuracy (Training)	83.75	F-Score	0.84
Accuracy (Test)	84.00	AUC	0.92
Recall	81.03	Concordance	0.92
True Neg. Rate	86.97	Discordance	0.08
Precision	88.04	Tied	0.00

Table 3: Species Distribution Modeling evaluation contingency table

		Training		Testing	
		Absence	Presence	Absence	Presence
Absence	Absence	25620	3838	11130	1653
	Presence	6614	28248	2758	12024

Table 4: Post classification of Sequences via Taxonomy and Ecology

Condition	No. Class.	Prcnt. Class.	Total Seqs	Rank
A	100	22.83	32.96	Species
B	108	24.66	9.35	Species
C	171	39.04	46.39	Genus
D	5	1.14	0.45	Species
E	17	3.88	2.23	Family
F	7	1.60	0.58	Species
X	30	6.85	8.03	Species