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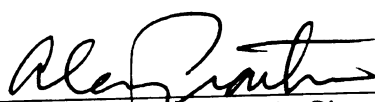
PHENOTYPES AND FLORAL VARIATION:
A PHYLOGENETIC APPROACH

presented by

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**PHENOTYPES AND FLORAL VARIATION:
A PHYLOGENETIC APPROACH**

By

Anna Kirsten Monfils

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ABSTRACT

PHENOTYPES AND FLORAL VARIATION: A PHYLOGENETIC APPROACH

By

Anna Kirsten Monfils

Biological diversity is created by evolution. To adequately explore biodiversity and examine processes in evolution, scientists need perspective on past evolutionary events. In this study, phenotypic diversity was investigated at several taxonomic levels by examining floral morphological characters against a backdrop of phylogenetic hypotheses. Floral traits were measured and phylogenetic hypotheses were generated across the species' *Pedicularis densiflora* and *Pedicularis aurantiaca*, within the tropical genus *Cantua*, and throughout the family Brassicaceae.

Floral morphological variation among populations of *P. densiflora* s.l. was examined and two distinct floral morphological groups were determined. Phenotypic analysis was then combined with a phylogenetic hypothesis in order to examine the number of times different floral morphs arose, relationships among populations in different localities, and potential pollinator shifts. An investigation of the floral diversity and phylogenetics among populations in the species *P. densiflora* s.l. warranted the splitting of the group into two distinct species, *P. densiflora* and *P. aurantiaca*.

Scanning electron microscopy was used to examine pollen grain morphology within the genus *Cantua*. Pollen characteristics were then assessed relative to a strongly supported

molecular phylogenetic hypothesis. Pollen grain morphology was found to be highly conserved within the genus and synapomorphies in pollen grain characteristics supported relationships hypothesized in the phylogenetic analysis. In addition, a potential correlation between pollen diameter and style length was examined using independent contrast and found to be insignificant. This investigation confirmed the phylogenetic utility of pollen characters and provided no support for the hypothesis that pollen grain diameter is functionally integrated with style length.

Floral morphological traits in the Brassicaceae were used to examine phenotypic variance-covariance matrix (P-matrix) stability relative to a comprehensive phylogenetic hypothesis. The P-matrix stability was highly conserved among some genera in the family and more labile among others. This examination of P-matrix stability within the Brassicaceae used a phylogenetic hypothesis to confirm that matrix stability did not follow a stepwise pattern of similarity corresponding to taxonomic rank.

Although each chapter of the dissertation used a different group of plants, and varied statistical techniques, they all showed the utility of combining both morphological and molecular analysis to examine patterns of floral diversity. The objectives of each study focused on different aspects of patterns of floral diversity. Ultimately, all of the investigations contained a phylogenetic hypothesis that provided a unique historical perspective to the questions being addressed.

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INTRODUCTION

PHENOTYPES AND FLORAL VARIATION:
A PHYLOGENETIC APPROACH

Biologists have long been interested in the origin, pattern, and maintenance of diversity among living organisms. Angiosperms, the dominant plant group, are of particular interest because they have highly variable floral morphologies among species. Theories have been proposed that explain flowering plant diversity as a product of the close relationships among floral form, plant pollinator interactions, and reproductive success. A comprehensive study of flowering plant evolution is central to understanding the pattern and diversity of floral morphological variation (Darwin 1862).

Even with the recent advances in statistics and molecular techniques, diversity among organisms is most often quantified using phenotypic characters. Phenotypes are the manifestation of heritable genetic variation and environmental influences. In order to study floral diversity, we need to consider morphology and variation in an evolutionary context (Felsenstein 1985, Harvey & Pagel 1991).

A phylogeny is a hypothesis of the evolutionary history of a group of organisms. A robust phylogenetic reconstruction can be used to assess patterns of evolutionary changes. Phylogenies are usually displayed as a bifurcating tree representing the evolutionary relationships among taxa, historical relationships between common ancestors, and speciation events. Although we can never know for certain the historical events leading to the diversity currently observed among organisms, phylogenies allow us to generate testable hypotheses of relationships (Hennig 1950). Without such an historical perspective, phenotypic diversity can be interpreted to support erroneous historical relationships and the polarity of floral character traits cannot be tested.

Phylogenetics has made great advances over the last twenty years with the advent of molecular methodologies. Data for cladistic analyses can be generated quickly and relatively cheaply across species, genera, families, and even kingdoms. Phenotypic characters can now be evaluated against an independent phylogenetic backdrop based on molecules.

Phylogenetic approaches have increasingly been applied to questions outside the realm of taxonomy. For instance, phylogenetic hypotheses are being used in the field of community ecology to explore community assemblages and niche structure (Webb et al. 2002). Conservation biologists use molecular systematics to define species, identify biologically important lineages, and set conservation priorities (Moritz 1995, Soltis and Gitzendanner 1999). Population biologists are starting to use comparative methods to explore quantitative genetic questions, thus initiating a new field of research, comparative quantitative genetics (Steppan et al. 2002). Phylogenies are currently used in comparative physiology and development to choose experimental systems, determine trait polarity, study the pace of physiological and developmental change, and establish independent contrasts of traits among related groups (Monson 1996). Plant ecologists and evolutionists alike are using phylogenetic techniques to explore the evolution of plant pollination systems (Armbruster 1993, Bruneau 1997, McDade 1992), breeding systems (Rieseberg et al. 1992, Sakai et al. 1997), hybridization (Rieseberg & Ellstrand 1993, Sang et al. 1995), polyploid evolution (Soltis and Soltis 2000), coevolution (Futuyma 1995), and evolutionary development (Albert et al. 1998).

In this study, I used phylogenies to study floral morphology, functionally integrated floral characters, and variation and covariation among traits. I examined floral morphological variation in three groups: two closely related species of *Pedicularis*, among the species of *Cantua*, and across the family Brassicaceae. A molecular phylogenetic hypothesis was central to the analysis of each group.

Pedicularis densiflora and *P. aurantiaca* were examined to detect and explain patterns of variation among populations of the two species. UPGMA, ANOVA, and PCA analyses were conducted, over 1000 herbarium specimens were studied, and a phylogenetic analysis of *psbA-trnH* and *trnL-trnF* chloroplast sequences and nuclear ribosomal ITS sequences was undertaken. Examination of all three statistical morphological analyses and review of herbarium specimens verified two distinct species, *P. densiflora* and *P. aurantiaca*. *Pedicularis aurantiaca* has a large calyx, floral tubes not fully exerted at anthesis, reduced lower labium, and a large opening in the galea. *Pedicularis densiflora* has a short calyx with a fully exerted floral tube, an enlarged lower labium, and a smaller opening in the galea. Phylogenetic analysis of the two species confirmed they were closely related taxa, sister to a clade containing *Pedicularis semibarbata*. Comprehensive review of the floral variation coupled with a phylogenetic hypothesis justified elevating the subspecies *P. aurantiaca* subsp. *aurantiaca* to species status.

A study of *Cantua* (Polemoniaceae) was undertaken to estimate a phylogeny, examine pollen exine sculpturing and its utility in phylogenetic analysis, and investigate the

potential functional integration between pollen size and style length within the genus. A phylogenetic analysis of the genus using chloroplast (*trnT-trnL*, *trnL-trnF*, partial *ndhF*) and nuclear ITS sequences was generated, scanning electron and light microscopy was used to view pollen morphology, and independent contrasts were used for the pollen grain diameter and style length traits. *Cantua* was found to be monophyletic and several relationships within the genus were resolved. *Cantua volcanica* was shown to be most closely related to *C. quercifolia*. *Cantua flexuosa*, *C. cuzcoensis*, *C. bicolor*, *C. candelilla*, *C. buxifolia*, *C. pyrifolia* and *C. nov. sp.* were closely related and *C. pyrifolia* was sister to *C. nov. sp.* Analyses of the chloroplast and nuclear DNA sequences had conflicting results regarding the monophyly of *C. buxifolia* and its relationship within the clade. Pollen characteristics within *Cantua* were found to be highly conserved. Spheroidal pantoporate pollen with an insulous semitectate sexine is synapomorphic for *Cantua* in the Cobaeoideae, giving further support to the monophyly of the genus. The relationship between *C. quercifolia* and *C. volcanica* was supported by the synapomorphy of supratectal verrucae on the sexine of the pollen grains. Neither a significant regression slope nor correlation was found using independent contrasts of pollen diameter and style length in *Cantua*, which rejects the null hypothesis of a morphological integration between the two traits. To summarize the *Cantua* results, some phylogenetic relationships within the genus were resolved, a review of pollen morphology was completed and the utility of pollen morphology in phylogenetic analyses was confirmed, and pollen diameter and style length was found to be statistically unrelated in *Cantua*.

My research on the Brassicaceae was designed to test the hypothesis that variance-covariance matrices diverge and change following a step-wise structured pattern identical to the hierarchical family level phylogeny. Six floral morphological traits were measured in 24 Brassicaceae species to generate phenotypic variation-covariation matrices (P-matrix) for each species. A phylogenetic hypothesis of the same 24 species was generated using sequences from the *ndhF* coding region. Common principal component analysis was used to compare matrices among groups of taxa which corresponded to clades in the phylogenetic hypothesis. Equality in matrices between different species was found between *Barbarea verna* and *B. vulgaris* and proportional matrices were accepted between *Raphanus raphanistrum* and *Raphanus sativus*, as well as *Nasturtium officinale* and *Cardamine concatenata*. Proportionality among matrices in five genera was found in the *A. lyrata* – *Cardamine concatenata* clade. Within *Brassica*, species had low levels of shared structure. In the Brassicaceae clade and its sister clade *Sisymbrium altissimum* / *Stanleya pinnata* low levels of matrix stability were found among genera. This was also true of the *Hesperis matronalis* / *Matthiola* clade and the *Lobularia* / *Iberis* clades. The results of this study confirm that P-matrix, and potentially G-matrix, stability is highly variable and the phylogenetic level of the matrix comparison did not appear to predict the level of stability found among matrices, although generally comparisons at higher taxonomic levels resulted in lower levels of shared structure.

Each chapter of my dissertation used a different group of plants to examine patterns of floral diversity using phenotypes, as well as different statistical techniques. The objectives of each study focused on different aspects of floral diversity and extended

from population-level analyses of variation to a family-wide analysis of floral evolution. Ultimately all of the investigations were based on a phylogenetic hypothesis which provided an historical perspective.

CHAPTER 1

FLORAL MORPHOLOGICAL VARIATION, MOLECULAR SYSTEMATICS, AND
DISTRIBUTION IN *PEDICULARIS DENSIFLORA* BENTH. EX HOOK. AND
PEDICULARIS AURANTIACA (E. F. SPRAGUE) MONFILS & PRATHER
(OROBANCHACEAE)

INTRODUCTION

Pedicularis L. is a large (600-800 species), monophyletic genus (Ree 2001) of hemiparasitic herbs, with a northern temperate distribution, and a tremendous amount of diversity in floral morphology. Previously, *Pedicularis* was placed in the family Scrophulariaceae, however recent taxonomic treatments have placed the genus in the Orobanchaceae (Olmstead et al. 2001). *Pedicularis* has undergone a relatively recent diversification, likely in the Pleistocene, and shares a center of diversity in eastern Asia with its primary pollinators, *Bombus* (De-Yaun 1983). Considerable research has been done to investigate the reproductive biology of *Pedicularis* and document the modes of plant-pollinator interaction (Sprague 1960, 1962, Grant 1966, 1967, Macior 1973, 1982, 1983, 1984, 1986a, 1986b, 1995a, 1995b, 1996, and references therein, Robart 2000, Ree 2001).

This study focused on *Pedicularis densiflora*, a species found only in California and southern Oregon, which was first described from a communication with D. Douglas by Bentham, and published in the Flora Boreali-Americana by J. W. Hooker (1838). Sprague (1958) divided the species into two subspecies, *P. densiflora* subsp. *densiflora* Benth. ex Hook. and *P. densiflora* subsp. *aurantiaca* E. F. Sprague. The circumscriptions of the subspecies were based on distribution, reproductive biology, phenology, host affinity, and floral morphology (Sprague 1958, 1960, 1961, and 1962).

Sprague's (1958) treatment indicated that *P. densiflora* subsp. *densiflora* is pollinated by both *Bombus* and hummingbirds while *P. densiflora* subsp. *aurantiaca* is pollinated

exclusively by hummingbirds. Macior (1986a) documented pollinator type, frequency and mode of pollination of both subspecies. Macior's (1986a) research supported Sprague's (1958, 1960, and 1962) conclusions of different pollination between subspecies. Sprague (1962) and Macior (1986a) suggested that hummingbird pollination was driving a change in morphology among populations and creating a shift within the species from a bumblebee pollination syndrome to a hummingbird syndrome. Fundamental to their hypothesis was the concept that the species had diverged into two distinct subspecies *P. densiflora* subsp. *densiflora* and *P. densiflora* subsp. *aurantiaca* with unique floral morphologies and distinct pollinator regimes. Additionally, this hypothesis assumed that the ancestral pollination system in *P. densiflora* s.l. is *Bombus* pollination.

There have been no molecular or detailed quantitative morphological studies to either polarize character traits or definitely document either genetic or morphological divergence within the species. An extensive examination was undertaken to detect and explain patterns of infraspecific variation within the species *P. densiflora* s.l. and determine which pollination system is derived. This work revealed that *P. densiflora* should be more narrowly circumscribed, and that the subspecies *P. densiflora* subsp. *aurantiaca* should be elevated to species status as *P. aurantiaca* (E. F. Sprague) Monfils & Prather. The two taxa will be referred to by their species names for the remainder of this paper.

MATERIALS AND METHODS

Herbarium specimens – A total of 1069 herbarium specimens of *Pedicularis densiflora*, *P. aurantiaca* and *P. semibarbata* A. Gray from CAS, DS, JEPS, MSC, ORE, OSC, POM, RSA, UC, and WILLU were studied. Specimens were screened for both morphological variation and geographic distribution. A preliminary investigation of herbarium material was used to select population study sites and floral characters for measurement. Study populations were selected from throughout the range of both *P. densiflora* and *P. aurantiaca*, sampling a broad elevational, geographic, and environmental spectrum. Populations were representative of the full breadth of morphological diversity. Additional analyses of herbarium specimens were conducted to evaluate utility and reliability of morphological traits in distinguishing separate species and to comprehensively review the distribution of the two taxa.

Analysis of Floral Morphological Variation – During a preliminary field season in 1998 localities were screened and ten populations were chosen for the study of floral morphological divergence. Populations used in the morphological study were from the following ten localities: Bear Valley (Colusa/Lake Co., CA), Hurles Circle (Butte Co., CA), Inskip (Butte Co., CA), McBride Springs (Siskiyou Co., CA), Missouri Flats Road (Josephine Co., OR), Mount Diablo (Contra Costa Co., CA), Paradise (Marin Co., CA), Pinehurst (Jackson Co., OR), Round Valley Historical Marker (Mendocino Co., CA), and Santa Margarita Lake (San Luis Obispo Co., CA) (Table 1 and Figure 1). Voucher specimens were deposited in the Michigan State University Herbarium (MSC).

Table 1. List of populations and voucher specimens for DNA sequence analysis and floral morphological analysis of *Pedicularis densiflora* and *Pedicularis aurantiaca*. All voucher specimens are deposited at Michigan State University Herbarium (MSC)

Species	Location (County, State)	Voucher	DNA Sequence Analysis	Floral Morphological Analysis
<i>P. aurantiaca</i>	Auberry (Fresno Co., CA)	Monfils 4	X	
<i>P. aurantiaca</i>	Hobo Gulch (Trinity Co., CA)	Monfils 9	X	
<i>P. aurantiaca</i>	Inskip (Butte Co., CA)	Monfils 37	X	X
<i>P. aurantiaca</i>	McBride Springs (Siskiyou Co., CA)	Monfils 43	X	X
<i>P. aurantiaca</i>	Pinehurst (Jackson Co., OR)	Monfils 40	X	X
<i>P. aurantiaca</i>	Weaver Camp (Trinity Co., CA)	Monfils 8	X	
<i>P. densiflora</i>	Bear Valley (Colusa/Lake Co., CA)	Monfils 33	X	X
<i>P. densiflora</i>	Briceland (Humboldt Co., CA)	Monfils 14	X	
<i>P. densiflora</i>	Hurles Circle (Butte Co., CA)	Monfils 35	X	X
<i>P. densiflora</i>	Missouri Flat Road (Josephine Co., OR)	Monfils 36	X	X
<i>P. densiflora</i>	Mount Diablo (Contra Costa Co., CA)	Monfils 28	X	X
<i>P. densiflora</i>	Paradise (Marin Co., CA)	Monfils 34	X	X
<i>P. densiflora</i>	Pinnacles National Monument (San Benito Co., CA)	Monfils 20	X	
<i>P. densiflora</i>	Round Valley Historical Marker (Mendocino Co., CA)	Monfils 32	X	X
<i>P. densiflora</i>	San Marcos Pass (Santa Barbara Co., CA)	Monfils 1	X	
<i>P. densiflora</i>	Santa Margarita Lake (San Luis Obispo Co., CA)	Monfils 21	X	X
<i>P. semibarbata</i> A	San Geronio Wilderness (San Bernardino Co., CA)	Holmgren 3591	X	
<i>P. semibarbata</i> B	East Sirretta Pass (Tulare Co., CA)	Twisselman 15760	X	
<i>P. cystopteridifolia</i> A	Red Lodge-Cook City Highway (Carbon Co., WY)	Beaman 1551	X	
<i>P. cystopteridifolia</i> B	Cody (Park Co., WY)	Kirkpatrick 3491	X	
<i>P. bracteosa</i> A	Absaroka Mountains (Freemont Co., WY)	Nelson 10994	X	
<i>P. bracteosa</i> B	Mazama (Whatcom Co., WA)	Churchill 7671512	X	

Figure 1. Map of Oregon and California representing distribution of 16 sampled populations of *P. densiflora* and *P. aurantiaca*. Names refer to population localities. All populations sampled were used in the molecular analysis. Populations with astrix after the name were used in the morphological analysis. Circles represent populations of *P. densiflora* and triangles represent populations of *P. aurantiaca*. All populations sampled were used in the molecular analysis. Populations with asterix after the name were used in the morphological analysis.



Figure 1.

When available, fifty individuals per population were studied. A total of 466 flowers were measured. Within each population, one flower each was removed from 50 plants. Plants were selected by sampling at set intervals along transects encompassing the population range. Flower sampling was based on the most apical, fully developed, intact flower with an exerted stigma. Only flowers that were shedding pollen and had not yet begun to senesce were selected.

Measurements were made using digital calipers and recorded to the nearest 0.01 mm. Floral characters used in the analysis were chosen based on the characters used by Sprague (1958) to differentiate the subspecies, floral traits involved in effective pollination as described by Macior (1986), and floral traits associated with pollination syndromes of *Bombus* and Hummingbird pollination as described by (Citation)Thirteen quantitative characters were measured: galea height, tube height, galea length, tube length, abaxial margin of galea, calyx length, pistil length, stamen length, labium length, angle at the axis of galea and tube, tube exertion (extension of tube above the calyx lobes), corolla length, and labium tip to galea bend (Figure 2). Four additional characters were derived from the initial measurements, treated as ratios, and used to quantify the relationship between shape and size: labium length/galea length, tube length/galea length, tube height/galea height, and abaxial margin of galea/galea length.

Statistical analysis –

Statistical Analysis System (SAS Institute, Inc. 1985) was used to perform a non-hierarchical analysis among population means for all 17 floral morphological characters

Figure 2: A. *Pedicularis densiflora* flower X 6. Reproduced from A Manual of the Flowering Plants of California (Jepson, 1925). B. Schematic representation of *Pedicularis densiflora* corolla. Lines represent parameters of quantitative measurements and letters correspond to the following measurements: A. galea height, B. galea length, C. tube length, D. tube height, E. labium length, F. abaxial margin of galea, and G. labium tip to galea bend.

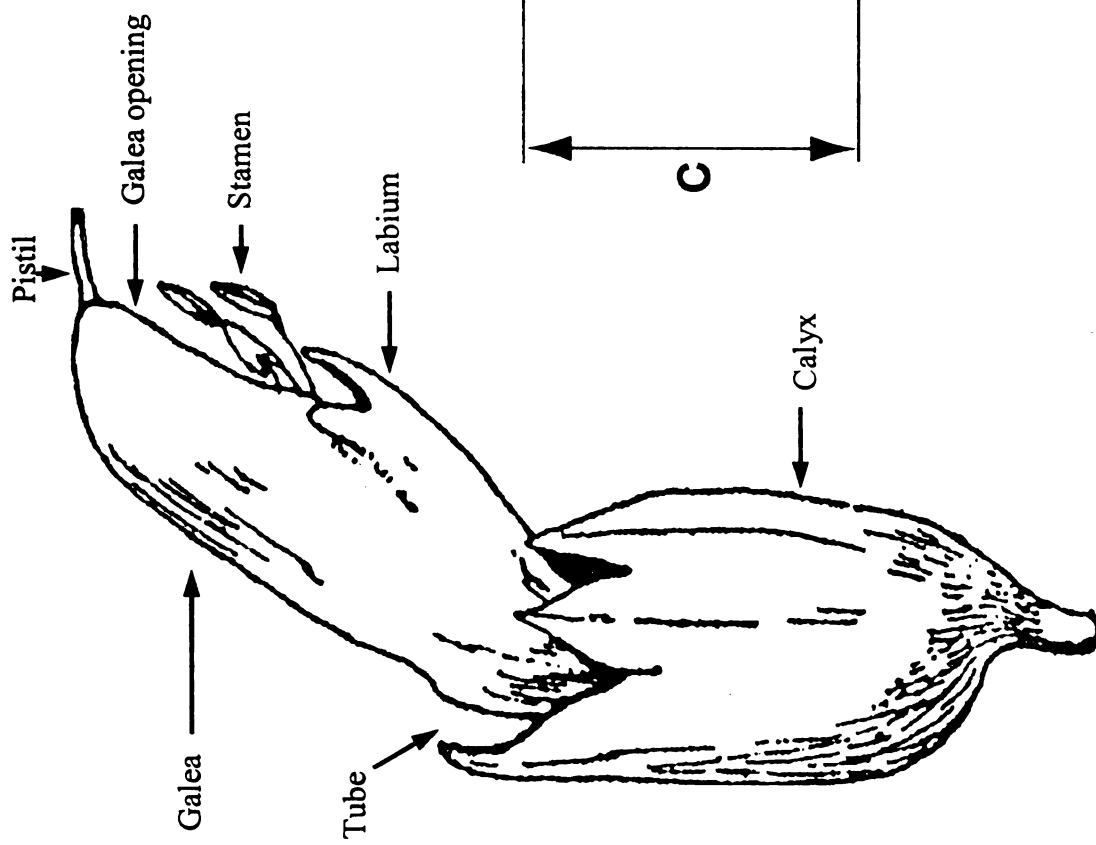


Figure 2A.

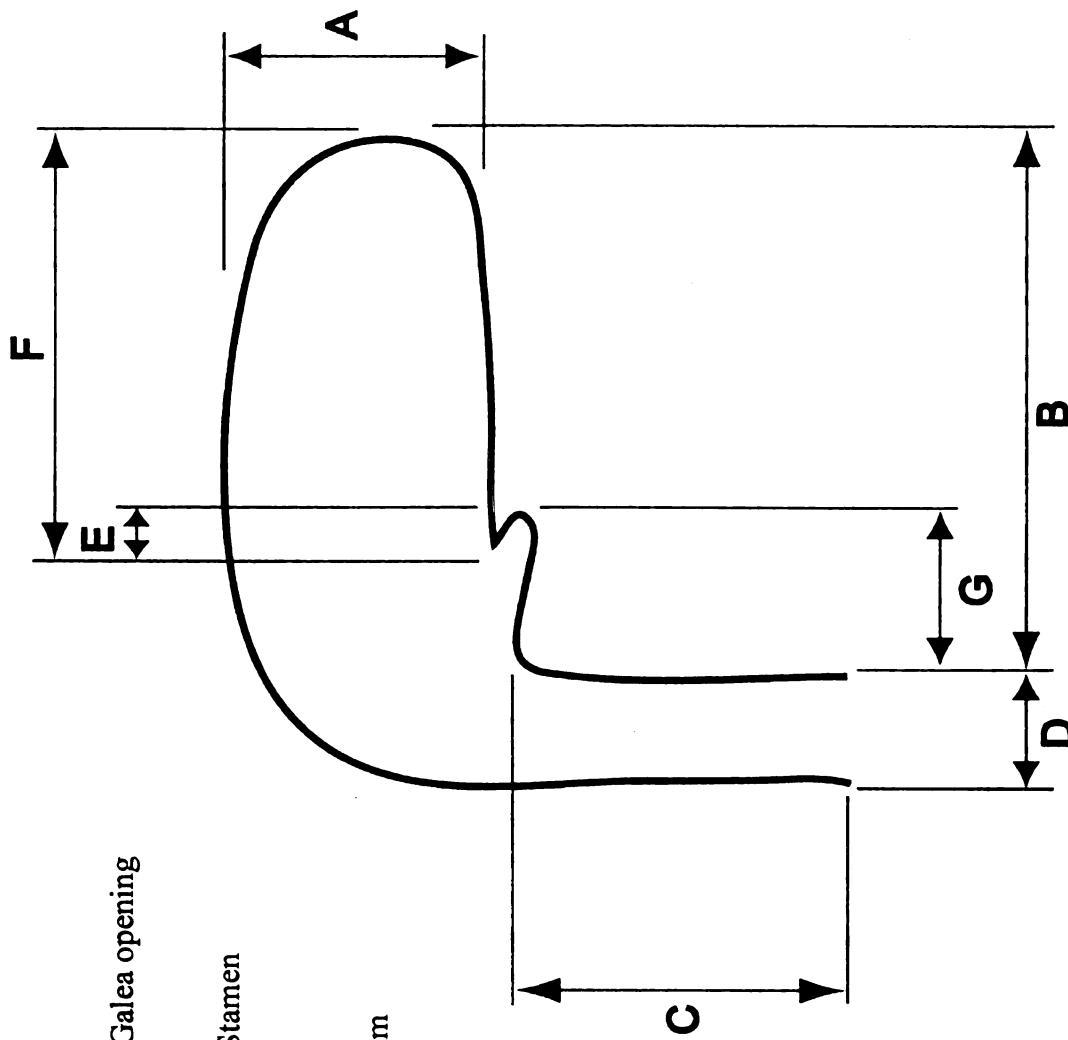


Figure 2B.

using the principal component analysis (PCA). Before analysis, all mean measurements were standardized across the populations with a mean of zero and a variance of one. Varimax rotation (Kaiser 1958) was conducted to maximize the variance of the variable loadings within a factor. The end result is a polarized loading for the variables in each factor closer to zero or one. Varimax rotation simplifies the interpretation of each factor in the PCA analysis (Johnson & Wichern 2002).

Analysis of variance (ANOVA) was performed on all 17 individual characters for the ten sampled populations. The PROC UNIVARIATE and HOVTEST=LEVENE tests were conducted to assure normality and homogeneity of variance, respectively. Where necessary, data were log, square root, or arccosine transformed to fulfill the assumptions of standard variance and normality. Bonferroni (Dunn) T-tests were conducted on each variable to examine differences between all possible pairs of means and significant groupings among means for all ten populations.

A symmetric dissimilarity matrix was created from a rectangular data matrix of the standardized 17 morphological character traits measured in the ten selected populations using the program NTSYSpc version 2.1 (Applied Biostatistics, Inc.). The average “taxonomic” distance coefficient was utilized as a measure of dissimilarity. The unweighted pair-group method of cluster analysis (UPGMA) was performed on the dissimilarity analysis, and a UPGMA phenogram was constructed.

Analysis of Population Level Molecular Variation –

Sampling - Leaf tissue was sampled from throughout the range of *P. densiflora* and *P. aurantiaca* for 16 populations. For the 10 populations used in the morphological analysis, floral tissue was collected and preserved in silica gel. Populations were used in the molecular study from the following sixteen localities: Auberry (Fresno Co., CA), Bear Valley (Colusa/Lake Co., CA), Briceland (Humbolt Co., CA), Hobo Gulch (Trinity Co., CA), Hurles Circle (Butte Co., CA), Inskip (Butte Co., CA), McBride Springs (Siskiyou Co., CA), Missouri Flat Road (Josephine Co., OR), Mount Diablo (Contra Costa Co., CA), Paradise (Marin Co., CA), Pinehurst (Jackson Co., OR), Pinnacles National Monument (San Benito Co., CA), Round Valley Historical Marker (Mendocino Co., CA), Santa Margarita Lake (San Luis Obispo Co., CA), San Marcos Pass (Santa Barbara Co., CA), and Weaver Camp (Trinity Co., CA) (Table 1 and Figure 1). Additional tissue of *Pedicularis* taxa was collected from MSC specimens of the following species: *P. semibarbata*, *P. cystopteridifolia* Rydb., and *P. bracteosa* Benth. ex Hook. (Table 1).

Outgroup and Additional Taxa - *Pedicularis cystopteridifolia*, was chosen as an outgroup and *P. semibarbata* and *P. bracteosa* were sampled to explore potential relationships to *P. densiflora* and *P. aurantiaca*. Outgroup and taxon choice was based on Sprague's (1962) analysis of trait similarity among California species of *Pedicularis*, unpublished nuclear ribosomal internal transcribed spacer (ITS) phylogenies of North American *Pedicularis* (Robart 2000), and morphological studies of herbarium specimens.

Analysis - Total DNA was extracted from either leaf or flower material using the techniques of Loockerman and Jansen (1996) and purified using the Schleicher & Schuell Elu-quick DNA Purification Kit (Keene, NH). Two sets of chloroplast primers were used: *trnL-trnF* primers from Fujii et al. (1997), and *psbA-trnH* from Sang et al. (1997). ITS1, ITS2, and the 5.8s regions of nuclear ribosomal DNA were amplified using ITS-4 primers of White et al (1990) and the modified ITS-5 primer of Sang et al. (1995). Standard amplification protocols were used, including reaction mixture components and the PCR profile (e. g. Prather et al. 2002), and amplifications were performed on a MJ Research PTC-100 thermocycler. PCR products were gel purified using the Schleicher & Schuell Elu-quick DNA Purification Kit, (Keene, NH) and sequenced in both directions using an ABI-373 automated sequencer. Sequencing reactions were conducted using the AmpliTaq DNA Dye Terminator Cycle Sequencing reagents (PE Applied Biosystems, Norwalk, CT).

Edited sequences were aligned using the Sequencher 3.0 software (Gene Codes Corporation, Ann Arbor, MI). Termini of the *trnL-trnF* intergenic spacer region and *psbA-trnH* intergenic spacer region were determined from Fujii (1997) and Ambrosini et al. (1992) respectively. Termini of ITS1, ITS2, and the 5.8s regions of nuclear ribosomal DNA were determined by comparison with published sequences of Beardsley and Olmstead (2002). In the aligned sequences of the *psbA-trnH* intergenic spacer region, 39 base pairs (bp237-bp276) were excluded from the analysis due to ambiguity in alignment. Parsimony methods were implemented using PAUP* (version 4.0b4; Swofford 2000). Heuristic searches were performed using the TREE BISECTION RECONNECTION, and

MULTREES options. All insertion/deletion events, displayed as gaps in the data set, were treated as missing data. Bootstrap analyses were conducted using 10,000 replicates with 100 random addition-sequence replicates per bootstrap. A partition homogeneity test was conducted to test for homogeneity in the distribution of phylogenetic information between the nuclear and chloroplast data sets.

RESULTS

Morphological Variation -

Based on the PCA analysis, 96% of the variance in the data set was explained by the first three factors. Factor one explained 45% of the variation and was weighted for characters of galea height, tube height, abaxial margin of galea, calyx length, tube exsertion, labium tip to galea bend, abaxial margin of galea/galea length. All these features corresponded to floral shape. Factor two explained 40% of the variation and was weighted by the following characters: tube length, pistil length, stamen length, corolla length, and tube length/galea length. These floral characteristics were predominantly attributed to flower size and exsertion of the galea. Factor three explained 11 % of the variation in the data set and was strongly weighted by tube height/galea height (Table 2).

Table 2. List of the 17 floral morphological traits of ten populations of *Pedicularis densiflora* and *P. aurantiaca* analyzed using principal component analysis. The first row shows proportion of variance explained by the first three factors. Varimax rotated factor patterns for the first three factors are listed next to the floral morphological trait

	Factor 1	Factor 2	Factor 3
Proportion of variance explained by factor	45%	40%	11%
Rotated factor pattern for Varimax rotation method			
GALEA HEIGHT	0.93716	0.15449	0.24154
TUBE HEIGHT	0.85129	0.31551	0.37159
GALEA LENGTH	0.46109	0.45989	0.53159
TUBE LENGTH	-0.00203	0.93353	0.21847
ABAXIAL MARGIN OF GALEA	0.89167	0.23682	0.19791
CALYX LENGTH	0.98270	0.07492	0.03785
PISTIL LENGTH	0.18670	0.93626	0.02864
STAMEN LENGTH	0.24642	0.89566	0.32723
LABIUM LENGTH	-0.84662	0.28518	0.15236
ANGLE AT AXIS OF GALEA AND TUBE	-0.40163	0.52962	0.26179
TUBE EXSERTION	-0.88867	0.42396	0.07335
COROLLA LENGTH	0.19754	0.84532	0.37367
LABIUM TIP TO GALEA BEND	0.93273	0.13294	0.21471
ABAXIAL MARGIN OF GALEA/GALEA LENGTH	0.93363	0.15635	0.10176
LABIUM LENGTH / GALEA LENGTH	-0.70018	0.24598	0.29567
TUBE LENGTH / GALEA LENGTH	-0.24703	0.93865	0.00712
TUBE HEIGHT / GALEA HEIGHT	0.19050	0.31215	0.91926

Factor one clearly separated two distinct clusters of populations: One group consisting of Inskip (J), McBride Springs (H), and Pinehurst (I) and the second of Bear Valley (D), Hurles Circle (F), Missouri Flats (G), Mount Diablo (C), Paradise (B), Round Valley (E), and Santa Margarita Lake (A) (Figure 3 & 4). Factor two did not separate the populations into distinct clusters; populations were broadly distributed with Bear Valley (D) and Santa Margarita Lake (A) representing the two extremes (Figure 3 & 5).

Santa Margarita Lake had the smallest size measurements for overall corolla size, galea length, stamen length, tube length, pistil length, abaxial margin of galea/galea length, tube length/galea length, and abaxial margin of galea. Bear Valley had the largest values for tube length and tube exertion. Many of these variables were heavily weighted in the second factor of the PCA analysis and provide an explanation for the separation of Santa Margarita Lake and Bear Valley in the plots with factor two. Factor three displayed a continuum of values with Missouri Flats (G) and Inskip (J) having larger values. Factor three was heavily weighted for tube height/galea height. Missouri Flats (G) and Inskip (J) exhibited the highest ratio of all populations sampled (Figure 4 & 5).

Sixteen of the seventeen variables showed significant variation among population means (p value < 0.0001) in the ANOVA (Table 3). The only character that was not significantly different among populations ($p = 0.0363$) was the angle at axis of galea and tube. This substantiated and quantified the previous reports by Sprague (1958, 1960, and 1962) and Macior (1986a) of a broad spectrum of morphological diversity across the distribution of *P. densiflora* and *P. aurantiaca*.

Figure 3. Plot of factor one by factor two from the principal component analysis of 17 floral morphological characters in ten populations of *Pedicularis densiflora* and *P. aurantiaca*. Letters represent populations as follows: A. Santa Margarita Lake, B. Paradise, C. Mount Diablo, D. Bear Valley, E. Round Valley Historical Marker, F. Hurles Circle, G. Missouri Flat Road. H. McBride Springs, I. Pinehurst, and J. Inskip.

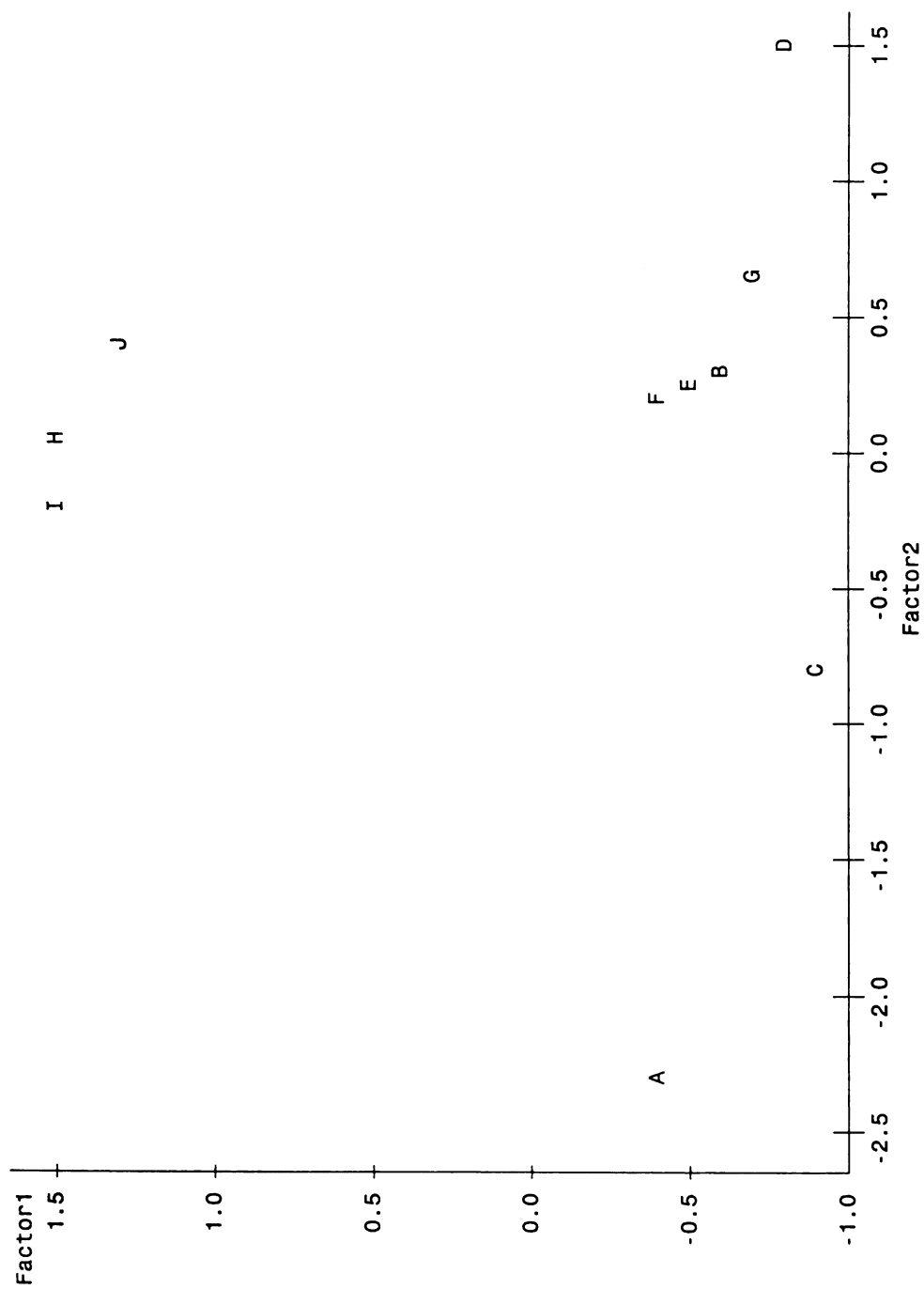


Figure 3.

Figure 4. Plot of factor one by factor three from the principal component analysis of 17 floral morphological characters in ten populations of *Pedicularis densiflora* and *P. aurantiaca*. Letters represent populations as follows: A. Santa Margarita Lake, B. Paradise, C. Mount Diablo, D. Bear Valley, E. Round Valley Historical Marker, F. Hurles Circle, G. Missouri Flat Road. H. McBride Springs, I. Pinehurst, and J. Inskip.

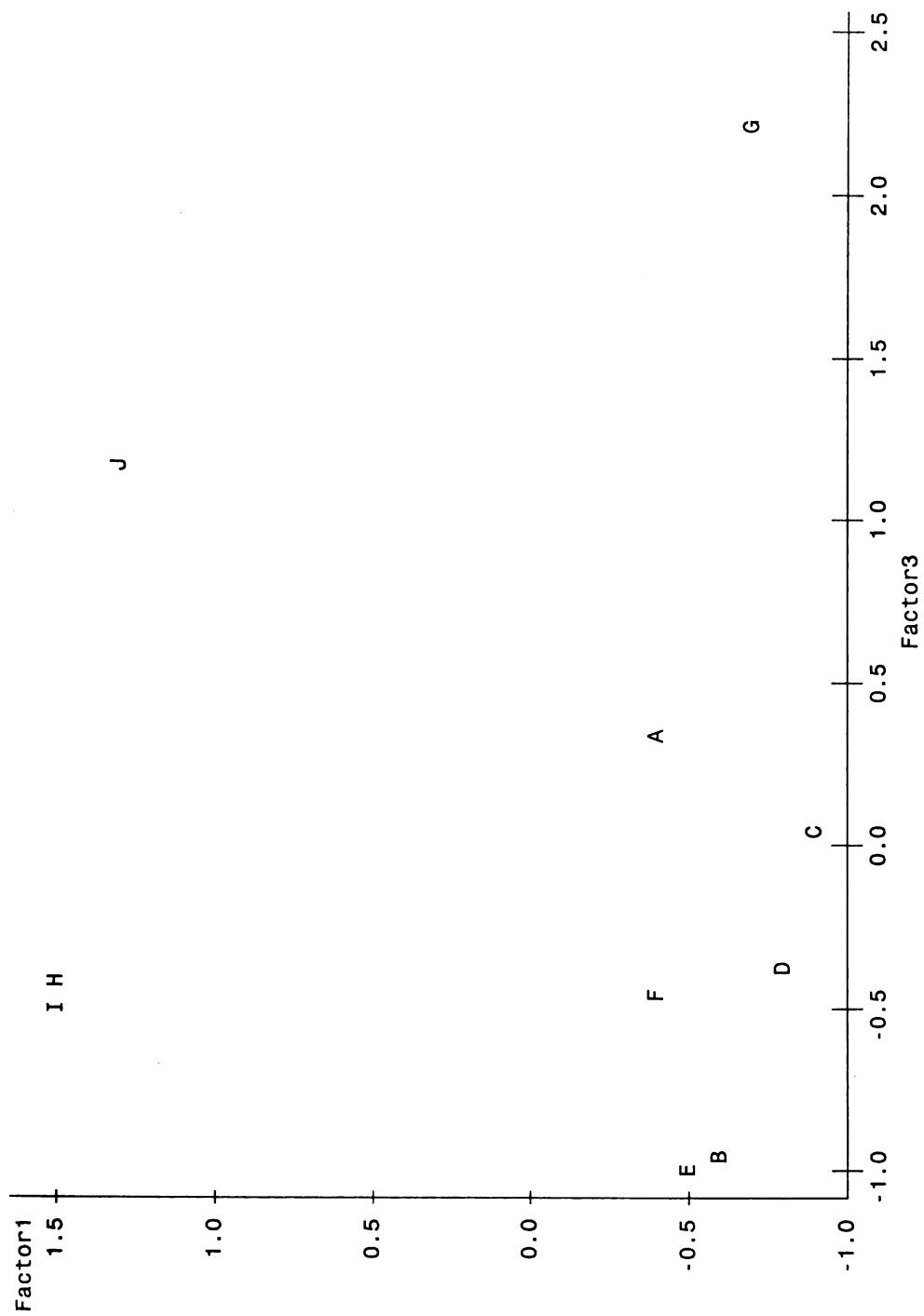


Figure 4.

Figure 5. plot of factor two by factor three from the principal component analysis of 17 floral morphological characters in ten populations of *Pedicularis densiflora* and *P. aurantiaca*. Letters represent populations as follows: A. Santa Margarita Lake, B. Paradise, C. Mount Diablo, D. Bear Valley, E. Round Valley Historical Marker, F. Hurles Circle, G. Missouri Flat Road. H. McBride Springs, I. Pinehurst, and J. Inskip.

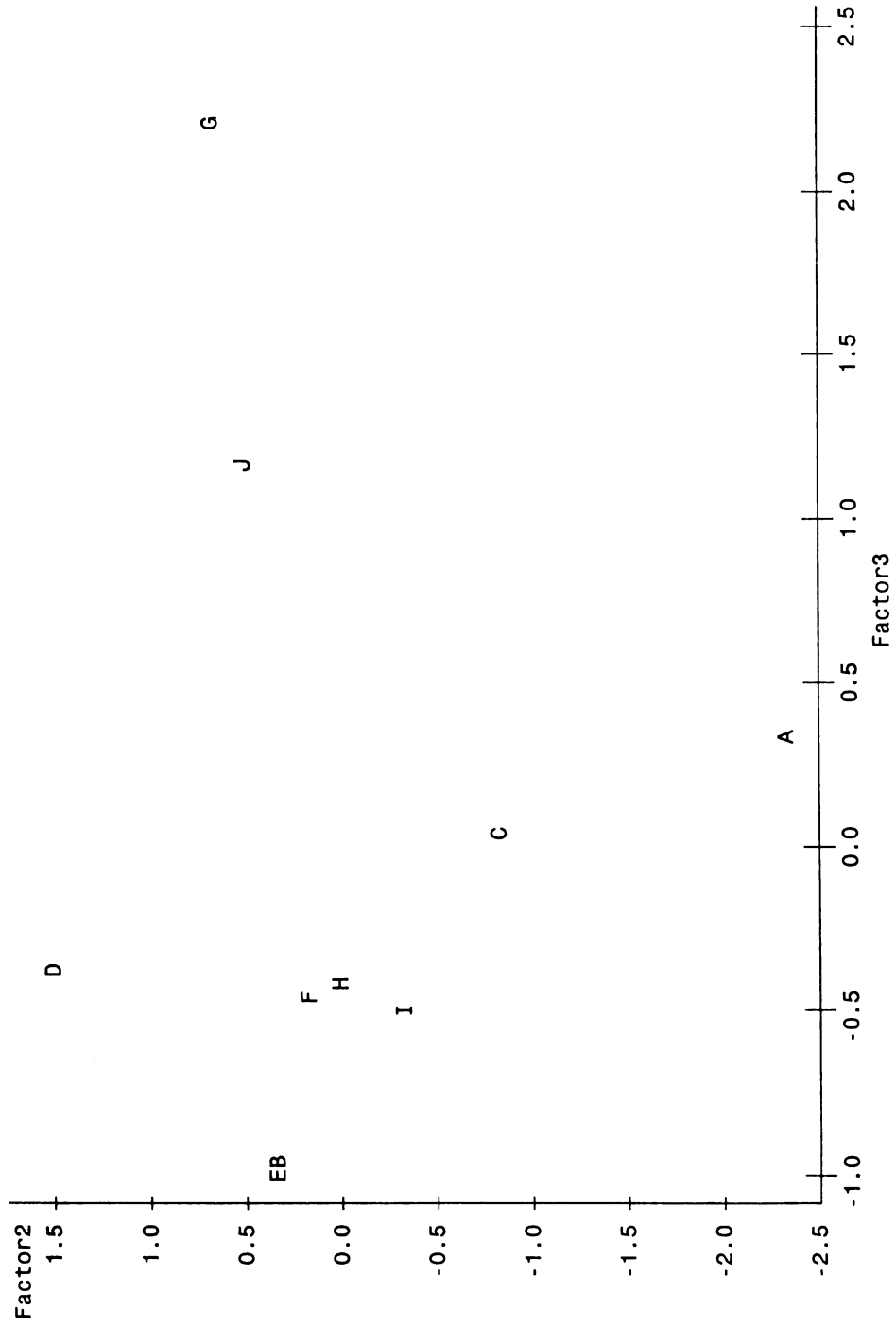


Figure 5.

Table 3. Sample size, means, standard deviations, minima, maxima and results from ANOVA and Bonferroni (Dunn) T-tests for characters studied in the morphological analysis of ten populations of *Pedicularis densiflora* and *P. aurantiaca* sampled from California and Oregon. In Bonferroni (Dunn) T-tests means with same letter are not significantly different. Where necessary, data were log, square root, or arcs transformed, this is denoted in the ANOVA RESULTS column as LOG, SQUARE ROOT, or ARCOS respectively.

POPULATION (Sample size)	MEAN (SD)	MIN.– MAX.	ANOVA RESULTS (p-value)	BONFERRONI (DUNN) T-TESTS	
1. GALEA HEIGHT (mm)					
SANTA MARGARITA LAKE (N=19)	5.27 (0.49)	4.43-6.56	(PR>F=0.0001)	D	C
PARADISE (N=50)	5.12 (0.44)	4.20-6.45	LOG	D	
MOUNT DIABLO (N=46)	5.10 (0.46)	3.99-6.33		D	
BEAR VALLEY (N=50)	5.31 (0.53)	4.20-6.53		D	C
ROUND VALLEY HISTORICAL MARKER (N=51)	5.01 (0.52)	4.02-6.42		D	
HURLES CIRCLE (N=51)	5.58 (0.59)	4.37-7.11		B	C
MISSOURI FLAT ROAD (N=50)	5.68 (0.48)	4.60-6.64		B	
McBRIDE SPRINGS (N=50)	6.27 (0.64)	5.21-8.07		A	
PINEHURST (N=50)	6.19 (0.61)	4.89-7.63		A	
INSKIP (N=50)	6.46 (0.76)	5.08-8.62		A	
2. TUBE HEIGHT (mm)					
SANTA MARGARITA LAKE (N=19)	3.18 (0.31)	2.75-3.91	(PR>F=0.0001)	D	E
PARADISE (N=50)	3.09 (0.32)	2.54-3.88	LOG	E	
MOUNT DIABLO (N=46)	2.99 (0.31)	2.41-3.76		E	
BEAR VALLEY (N=50)	3.39 (0.39)	2.67-4.3		D	
ROUND VALLEY HISTORICAL MARKER (N=51)	3.16 (0.30)	2.54-3.69		D	E
HURLES CIRCLE (N=51)	3.39 (0.33)	2.75-4.05		D	
MISSOURI FLAT ROAD (N=50)	3.70 (0.35)	2.89-4.55		C	
McBRIDE SPRINGS (N=50)	4.00 (0.44)	3.30-4.94		A	B
PINEHURST (N=50)	3.81 (0.38)	3.04-4.79		C	B

Table 3 (cont'd)

POPULATION (Sample size)	MEAN (SD)	MIN.- MAX.	ANOVA RESULTS (p-value)	BONFERRONI (DUNN) T-TESTS
2. TUBE HEIGHT CONTINUED (mm)				
INSKIP (N=50)	4.26 (0.48)	2.97-5.12		A
3. GALEA LENGTH (mm)				
SANTA MARGARITA LAKE (N=19)	18.79 (1.41)	15.39-21.10	(PR>F=0.0001)	E
PARADISE (N=50)	18.95 (1.70)	15.19-22.20	LOG	E
MOUNT DIABLO (N=46)	18.98 (1.94)	15.45-22.88		E
BEAR VALLEY (N=50)	19.72 (1.69)	16.39-23.19		E C D B
ROUND VALLEY HISTORICAL MARKER (N=51)	19.25 (1.38)	16.70-22.40		E C D
HURLES CIRCLE (N=51)	19.07 (1.69)	16.03-22.83		E D
MISSOURI FLAT ROAD (N=50)	21.35 (1.64)	18.00-24.75		A
McBRIDE SPRINGS (N=50)	20.28 (1.85)	16.64-24.87		A C D B
PINEHURST (N=50)	20.41 (1.69)	14.29-24.03		A C B
INSKIP (N=50)	20.60 (2.08)	16.50-25.53		A B
4. TUBE LENGTH (mm)				
SANTA MARGARITA LAKE (N=19)	10.26 (1.69)	7.18-13.53	(PR>F=0.0001)	D
PARADISE (N=50)	12.83 (1.90)	8.90-18.13	LOG	C B
MOUNT DIABLO (N=46)	11.90 (1.52)	7.53-15.27		C
BEAR VALLEY (N=50)	15.29 (2.35)	10.51-20.70		A
ROUND VALLEY HISTORICAL MARKER (N=51)	12.56 (1.77)	9.38-18.70		C
HURLES CIRCLE (N=51)	13.01 (1.83)	9.49-17.85		C B
MISSOURI FLAT ROAD (N=50)	14.63 (2.37)	9.49-20.65		A
McBRIDE SPRINGS (N=50)	12.81 (1.77)	8.60-16.93		C B
PINEHURST (N=50)	11.91 (1.41)	9.05-16.45		C
INSKIP (N=50)	14.18 (2.22)	8.28-19.41		A B

Table 3 (cont'd)

POPULATION (Sample size)	MEAN (SD)	MIN.- MAX.	ANOVA RESULTS (p-value)	BONFERRONI (DUNN) T-TESTS
5. ABAXIAL MARGIN OF GALEA (mm)				
SANTA MARGARITA LAKE (N=19)	11.36 (0.98)	10.05-13.01	(PR>F=0.0001)	D
PARADISE (N=50)	12.30 (1.37)	9.86-15.91	LOG	C
MOUNT DIABLO (N=46)	12.54 (1.63)	9.80-20.01		C
BEAR VALLEY (N=50)	12.66 (1.24)	9.98-15.71		C
ROUND VALLEY HISTORICAL MARKER (N=51)	12.45 (1.13)	10.33-15.01		C
HURLES CIRCLE (N=51)	12.87 (1.39)	10.36-15.99		C
MISSOURI FLAT ROAD (N=50)	14.86 (1.23)	12.18-17.63		B
McBRIDE SPRINGS (N=50)	17.52 (1.86)	14.57-22.07		A
PINEHURST (N=50)	18.15 (1.59)	13.10-22.28		A
INSKIP (N=50)	17.88 (2.04)	14.18-23.27		A
6. CALYX LENGTH (mm)				
SANTA MARGARITA LAKE (N=19)	13.99 (1.20)	12.36-16.78	(PR>F=0.0001)	C
PARADISE (N=50)	12.67 (1.17)	10.13-15.11	LOG	D
MOUNT DIABLO (N=46)	12.70 (1.41)	10.54-16.78		D
BEAR VALLEY (N=50)	14.17 (1.35)	10.72-17.75		C
ROUND VALLEY HISTORICAL MARKER (N=51)	12.39 (1.25)	9.83-16.09		D
HURLES CIRCLE (N=51)	13.66 (1.45)	10.19-16.35		C
MISSOURI FLAT ROAD (N=50)	13.24 (0.97)	10.81-15.60		C D
McBRIDE SPRINGS (N=50)	18.83 (2.31)	13.08-24.03		A
PINEHURST (N=50)	17.14 (1.77)	11.98-21.10		B
INSKIP (N=50)	18.64 (1.69)	15.57-22.92		A
7. PISTIL LENGTH (mm)				
SANTA MARGARITA LAKE (N=19)	25.48 (1.93)	22.47-29.61	(PR>F=0.0001)	E

Table 3 (cont'd)

POPULATION (Sample size)	MEAN (SD)	MIN.- MAX.	ANOVA RESULTS (p-value)	BONFERRONI (DUNN) T-TESTS
7. PISTIL LENGTH CONTINUED (mm)				
PARADISE (N=50)	35.44 (4.79)	24.67-44.08		C D B
MOUNT DIABLO (N=46)	33.18 (3.52)	25.54-42.01		D
BEAR VALLEY (N=50)	38.73 (3.83)	28.50-46.00		A
ROUND VALLEY HISTORICAL MARKER (N=51)	35.92 (2.87)	30.44-43.71		C A D B
HURLES CIRCLE (N=51)	34.08 (4.50)	24.64-43.29		C D
MISSOURI FLAT ROAD (N=50)	37.99 (4.19)	29.33-48.64		A B
McBRIDE SPRINGS (N=50)	36.62 (3.30)	29.74-44.42		C A B
PINEHURST (N=50)	36.09 (4.63)	17.14-44.73		C A D B
INSKIP (N=50)	37.17 (4.89)	27.68-46.03		A B
8. STAMEN LENGTH (mm)				
SANTA MARGARITA LAKE (N=19)	26.42 (3.11)	16.91-30.95	(PR>F=0.0001)	E
PARADISE (N=50)	31.09 (3.45)	23.19-38.63		C
MOUNT DIABLO (N=46)	28.67 (3.45)	21.45-35.49		D
BEAR VALLEY (N=50)	33.29 (3.32)	24.03-40.28		C A
ROUND VALLEY HISTORICAL MARKER (N=51)	31.16 (3.01)	24.39-39.42		C
HURLES CIRCLE (N=51)	31.06 (3.54)	25.18-39.67		C
MISSOURI FLAT ROAD (N=50)	34.46 (3.14)	27.78-41.66		A
McBRIDE SPRINGS (N=50)	31.92 (3.02)	24.62-41.15		C B
PINEHURST (N=50)	31.41 (2.61)	24.09-36.88		C
INSKIP (N=50)	34.13 (3.19)	26.51-40.94		A B
9. LABIUM LENGTH (mm)				
SANTA MARGARITA LAKE (N=19)	3.82 (1.07)	1.12-5.49	(PR>F=0.0001)	D
PARADISE (N=50)	4.09 (0.95)	1.84-7.01	SQUARE ROOT	C D

Table 3 (cont'd)

POPULATION (Sample size)	MEAN (SD)	MIN.- MAX.	ANOVA RESULTS (p-value)	BONFERRONI (DUNN) T-TESTS
9. LABIUM LENGTH CONTINUED(mm)				
MOUNT DIABLO (N=46)	5.20 (1.32)	3.72-12.23		A B
BEAR VALLEY (N=50)	5.29 (1.19)	3.22-8.98		A B
ROUND VALLEY HISTORICAL MARKER (N=51)	4.65 (0.98)	2.88-6.77		C B
HURLES CIRCLE (N=51)	4.30 (0.91)	2.69-7.44		C D
MISSOURI FLAT ROAD (N=50)	5.85 (1.34)	3.7-12.68		A
McBRIDE SPRINGS (N=50)	2.87 (0.75)	1.30-4.71		E
PINEHURST (N=50)	2.86 (0.70)	1.41-4.24		E
INSKIP (N=50)	3.13 (0.90)	1.64-5.26		E
10. ANGLE AT AXIS OF GALEA AND TUBE (degrees)				
SANTA MARGARITA LAKE (N=19)	144.56 (12.47)	123.50-180	(PR>F=0.0363)	A
PARADISE (N=50)	147.32 (10.86)	122.76-180		A
MOUNT DIABLO (N=46)	145.63 (9.02)	125.60-180		A
BEAR VALLEY (N=50)	149.90 (10.09)	121.68-180		A
ROUND VALLEY HISTORICAL MARKER (N=51)	143.73 (13.98)	99.37-180		A
HURLES CIRCLE (N=51)	149.02 (13.63)	118.10-180		A
MISSOURI FLAT ROAD (N=50)	151.57 (10.14)	132.58-180		A
McBRIDE SPRINGS (N=50)	144.71 (9.90)	117.73- 163.88		A
PINEHURST (N=50)	143.34 (15.45)	109.30-180		A
INSKIP (N=50)	145.90 (11.64)	105.92- 167.81		A
11. TUBE EXSERTION (mm)				
SANTA MARGARITA LAKE (N=19)	-3.74 (1.94)	-7.14-0.16	(PR>F=0.0001)	C
PARADISE (N=50)	0.17 (1.95)	-4.12-5.26		A B
MOUNT DIABLO (N=46)	-0.80 (1.54)	-4.76-2.31		B

Table 3 (cont'd)

POPULATION (Sample size)	MEAN (SD)	MIN.– MAX.	ANOVA RESULTS (p-value)	BONFERRONI (DUNN) T-TESTS	
11. TUBE EXSERTION CONTINUED (mm)					
BEAR VALLEY (N=50)	1.12 (2.17)	-2.99-5.39		A	
ROUND VALLEY HISTORICAL MARKER (N=51)	0.16 (1.93)	-3.76-6.88		A	B
HURLES CIRCLE (N=51)	-0.65 (2.06)	-5.74-4.31		B	
MISSOURI FLAT ROAD (N=50)	1.38 (2.31)	-3.05-7.95		A	
McBRIDE SPRINGS (N=50)	-6.02 (2.00)	-10.33- (-1.63)		E	
PINEHURST (N=50)	-5.36 (1.76)	-9.62-12.19		E	D
INSKIP (N=50)	-4.46 (2.65)	-11.25-2.05		C	D
12. COROLLA LENGTH (mm)					
SANTA MARGARITA LAKE (N=19)	29.04 (2.33)	24.80-32.93	(PR>F=0.0001)	E	
PARADISE (N=50)	31.79 (3.19)	25.06-39.71		C	D
MOUNT DIABLO (N=46)	30.88 (2.95)	23.24-37.05		E	D
BEAR VALLEY (N=50)	35.00 (3.35)	27.98-42.15		A	B
ROUND VALLEY HISTORICAL MARKER (N=51)	31.81 (2.70)	27.99-41.10		C	D
HURLES CIRCLE (N=51)	32.08 (3.23)	26.62-39.99		C	D
MISSOURI FLAT ROAD (N=50)	36.18 (3.61)	28.60-42.24		A	
McBRIDE SPRINGS (N=50)	33.09 (3.04)	25.54-41.80		C	B
PINEHURST (N=50)	32.32 (2.50)	23.97-38.18		C	D
INSKIP (N=50)	34.78 (3.02)	29.33-42.15		A	B
13. LABIUM TIP TO GALEA BEND (mm)					
SANTA MARGARITA LAKE (N=19)	11.26 (1.41)	8.90-13.83	(PR>F=0.0001)	B	C
PARADISE (N=50)	10.54 (1.20)	8.76-13.07	LOG	B	C
MOUNT DIABLO (N=46)	11.64 (1.35)	9.29-14.68		A	B
BEAR VALLEY (N=50)	12.34 (1.28)	9.48-15.54		A	

Table 3 (cont'd)

POPULATION (Sample size)	MEAN (SD)	MIN.- MAX.	ANOVA RESULTS (p-value)	BONFERRONI (DUNN) T-TESTS
13. LABIUM TIP TO GALEA BEND CONTINUED(mm)				
ROUND VALLEY HISTORICAL MARKER (N=51)	11.45 (1.08)	8.74-13.69		A B C
HURLES CIRCLE (N=51)	10.51 (1.36)	8.28-13.56		
MISSOURI FLAT ROAD (N=50)	12.34 (1.28)	9.90-16.09		A
McBRIDE SPRINGS (N=50)	5.63 (0.91)	3.27-7.28		D
PINEHURST (N=50)	5.11 (0.72)	3.62-6.88		E
INSKIP (N=50)	5.85 (0.84)	4.48-7.82		D
14. ABAXIAL MARGIN OF GALEA/GALEA LENGTH				
SANTA MARGARITA LAKE (N=19)	0.60 (0.05)	0.53-0.67	(PR>F=0.0001)	E
PARADISE (N=50)	0.65 (0.04)	0.55-0.72	ARCCOS	C D
MOUNT DIABLO (N=46)	0.66 (0.07)	0.57-1.07		C D
BEAR VALLEY (N=50)	0.64 (0.05)	0.52-0.75		D
ROUND VALLEY HISTORICAL MARKER (N=51)	0.65 (0.04)	0.58-0.73		C D
HURLES CIRCLE (N=51)	0.68 (0.05)	0.53-0.79		B C
MISSOURI FLAT ROAD (N=50)	0.70 (0.05)	0.62-0.96		B
McBRIDE SPRINGS (N=50)	0.86 (0.03)	0.79-0.95		A
PINEHURST (N=50)	0.89 (0.03)	0.82-0.96		A
INSKIP (N=50)	0.87 0.03	0.78-0.94		A
15. LABIUM LENGTH / GALEA LENGTH				
SANTA MARGARITA LAKE (N=19)	0.205 (0.058)	0.060-0.297	(PR>F=0.0001)	B
PARADISE (N=50)	0.216 (0.045)	0.097-.360		B
MOUNT DIABLO (N=46)	0.276 (0.073)	0.166-0.655		A
BEAR VALLEY (N=50)	0.270 (0.063)	0.167-0.525		A
ROUND VALLEY HISTORICAL MARKER (N=51)	0.242 (0.052)	0.150-0.378		A B

Table 3 (cont'd)

POPULATION (Sample size)	MEAN (SD)	MIN.- MAX.	ANOVA RESULTS (p-value)	BONFERRONI (DUNN) T-TESTS
15. LABIUM LENGTH / GALEA LENGTH CONTINUED				
HURLES CIRCLE (N=51)	0.226 (0.042)	0.147-0.341		B
MISSOURI FLAT ROAD (N=50)	0.275 (0.071)	0.188-0.690		A
McBRIDE SPRINGS (N=50)	0.141 (0.034)	0.069-0.214		C
PINEHURST (N=50)	0.141 (0.035)	0.060-0.201		C
INSKIP (N=50)	0.152 (.044)	0.079-0.239		C
16. TUBE LENGTH / GALEA LENGTH (PR>F=0.0001)				
SANTA MARGARITA LAKE (N=19)	0.548 (0.096)	0.365-0.744		E
PARADISE (N=50)	0.677 (0.081)	0.533-0.840		B C
MOUNT DIABLO (N=46)	0.629 (0.079)	0.479-0.824		C D
BEAR VALLEY (N=50)	0.777 (0.115)	0.548-1.106		A
ROUND VALLEY HISTORICAL MARKER (N=51)	0.653 (0.080)	0.488-0.878		B C
HURLES CIRCLE (N=51)	0.682 (0.071)	0.489-0.877		B C
MISSOURI FLAT ROAD (N=50)	0.682 (0.111)	0.497-0.977		B C
McBRIDE SPRINGS (N=50)	0.634 (0.084)	0.491-0.827		B C D
PINEHURST (N=50)	0.586 (0.072)	0.437-0.757		E D
INSKIP (N=50)	0.696 (0.127)	0.364-1.042		B
17. TUBE HEIGHT / GALEA HEIGHT (PR>F=0.0001)				
SANTA MARGARITA LAKE (N=19)	0.606 (0.056)	0.474-0.694		C D
PARADISE (N=50)	0.605 (0.060)	0.445-0.739		C D
MOUNT DIABLO (N=46)	0.589 (0.056)	0.489-0.713		D
BEAR VALLEY (N=50)	0.642 (0.072)	0.481-0.835		C A B
ROUND VALLEY HISTORICAL MARKER (N=51)	0.633 (0.063)	0.509-0.762		C A D B
HURLES CIRCLE (N=51)	0.611 (0.059)	0.479-0.771		C D B

Table 3 (cont'd)

POPULATION (Sample size)	MEAN (SD)	MIN.– MAX.	ANOVA RESULTS (p-value)	BONFERRONI (DUNN) T-TESTS		
17. TUBE HEIGHT / GALEA HEIGHT CONTINUED						
MISSOURI FLAT ROAD (N=50)	0.654 (0.070)	0.501-0.806		A		B
McBRIDE SPRINGS (N=50)	0.639 (0.062)	0.494-0.747		C	A	B
PINEHURST (N=50)	0.618 (0.056)	0.504-0.733		C		D B
INSKIP (N=50)	0.664 (0.078)	0.466-0.921		A		

Bonferroni (Dunn) T-tests indicated that the Inskip, Pinehurst, and McBride Springs populations showed means not significantly different from each other, but distinct from the remaining populations for the following five variables: galea height, abaxial margin of galea, labium length, abaxial margin of galea/galea length, and labium length/galea length. McBride Springs and Inskip had no significant difference in mean calyx length (18.83 mm and 18.64 mm, respectively) but were significantly different from the remaining eight populations. Pinehurst had a mean calyx length of 17.14 mm, which was also significantly different from all other populations (<14.17 mm). In the case of labium tip to galea bend, Pinehurst had the lowest mean at 5.11 mm and was significantly different from all other populations. McBride Springs and Inskip had similar means of 5.63 mm and 5.85 mm, respectively, which were significantly different from the remaining populations and represented the lowest means besides Pinehurst. All other mean measurements of labium tip to galea bend exceeded 10.51mm.

Means for tube exertion were extreme for Inskip (-4.46 mm), Pinehurst (-5.36 mm), McBride Springs (-6.02 mm), and Santa Margarita Lake (-3.74 mm); pair-wise

comparisons of the population means were significantly different from the remaining populations. Three separate groupings of the above populations were assessed as not significantly different: Pinehurst/Inskip, Santa Margarita Lake/Inskip, and McBride Springs/Pinehurst. These taxa were clearly larger and separated from the remaining populations, whose means for tube exsertion from -.0880 mm to 1.38 mm. No distinguishable patterns were observed for the remaining variables; however, the Bear Valley, Missouri Flat, and Inskip populations showed overall larger measurements.

ANOVA results corroborated the reports by Sprague (1958, 1960, 1962) of substantial morphological variation within the species *P. densiflora* and *P. aurantiaca*. Sixteen of the 17 traits measured were significantly different among the ten populations in this study. Examination of population means using the Bonferroni (Dunn) T-tests indicated a cohesive morphology among the McBride Springs, Inskip, and Pinehurst populations.

The UPGMA phenogram summarized potential relationships indicated by the metric of taxonomic distance. Division of the populations into two distinct clusters was substantiated by the phenogram which showed high similarity among the Inskip, McBride Springs, and Pinehurst populations. These three populations formed a cluster while the remaining seven populations, Bear Valley, Hurles Circle, Missouri Flats, Mount Diablo, Paradise, Round Valley, and Santa Margarita Lake formed a second distinct grouping (Figure 6).

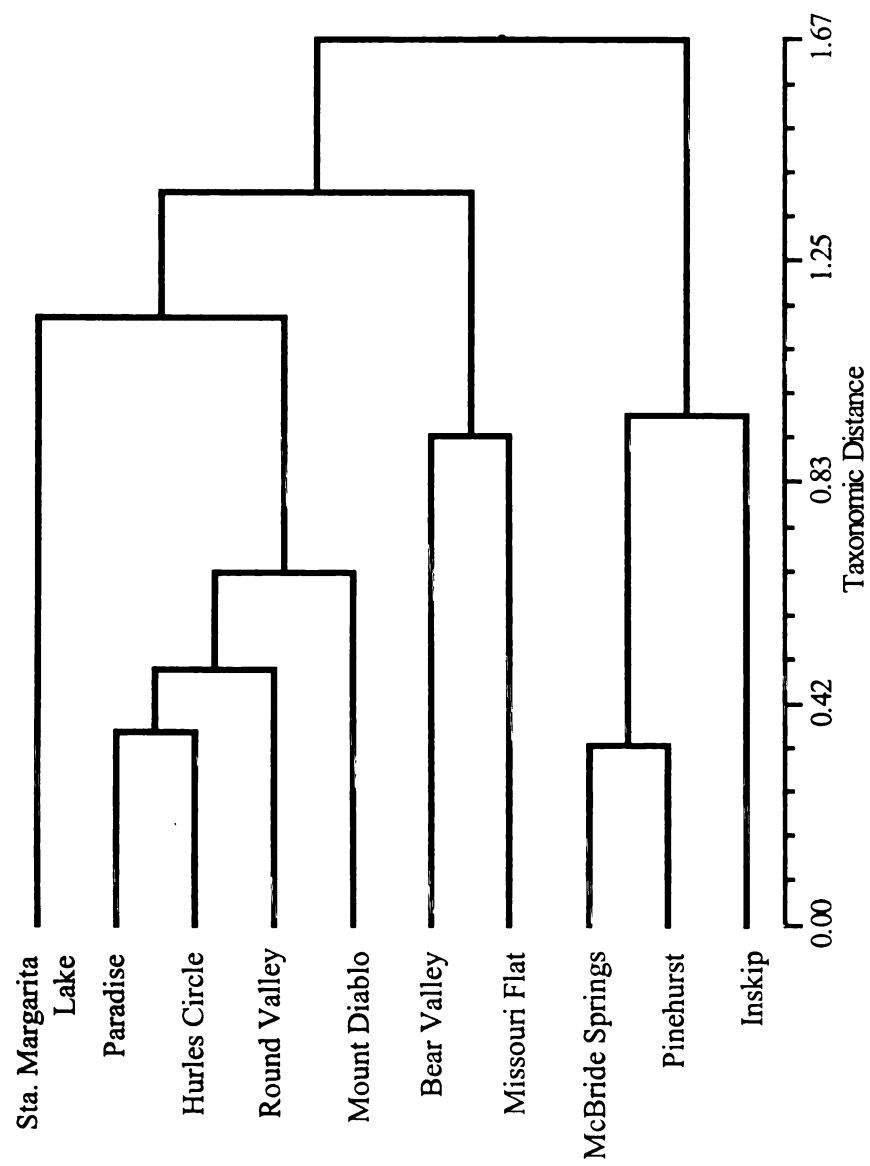


Figure 6. UPGMA phenogram of taxonomic distance based on 17 continuous floral morphological character traits in populations of *P. densiflora* and *P. aurantiaca*. Population names, locations, and voucher information described in Table 1 and Figure 1.

Examination of all three morphological analyses, PCA, ANOVA, and UPGMA, suggested two distinct morphological groups of populations. *Pedicularis aurantiaca* was represented by Inskip, McBride Springs, and Pinehurst populations which formed a well-defined group of populations with similar floral morphology. *Pedicularis densiflora* was represented by seven populations which formed a second distinct group, these included Bear Valley, Hurles Circle, Missouri Flats, Mount Diablo, Paradise, Round Valley, and Santa Margarita Lake populations.

Observations on the ten populations combined with a review of herbarium specimens helped characterize floral traits, phenology and distribution in the two species.

Pedicularis aurantiaca had long calyces (12-24 mm), a reduced ratio of the labium to galea (approx. 1:7), a short labium (1-5 mm), a short region from the labium tip to corolla bend (3.5-7.5 mm), an enlarged abaxial margin of the galea about 7/8 as long as the galea, and a tube that is included in the calyx. *Pedicularis aurantiaca* flowered late April through June and grew at elevations between 100 and 7000 feet. *Pedicularis aurantiaca* was distributed in southeast Oregon in Klamath and Jackson Counties, northern California in the Trinity and Siskiyou Alps, and in the Sierra Nevadas as far south as Kern County (Figure 7 & 8).

Pedicularis densiflora had short calyces (10-18mm), a larger labium to galea ratio (approx. 1:4), a long labium (2-12 mm), a long region from the labium tip to corolla bend (8.5 – 16 mm), an truncated abaxial margin of galea approximately 2/3 the length of the

Figure 7. County map of California. Map shows distribution of *P. densiflora* and *P. aurantiaca* based on morphological analysis of populations in the field and herbarium material cited. Circle represents presence of *P. densiflora* herbarium material in the county. Triangle represents presence of *P. aurantiaca* herbarium material in the county.

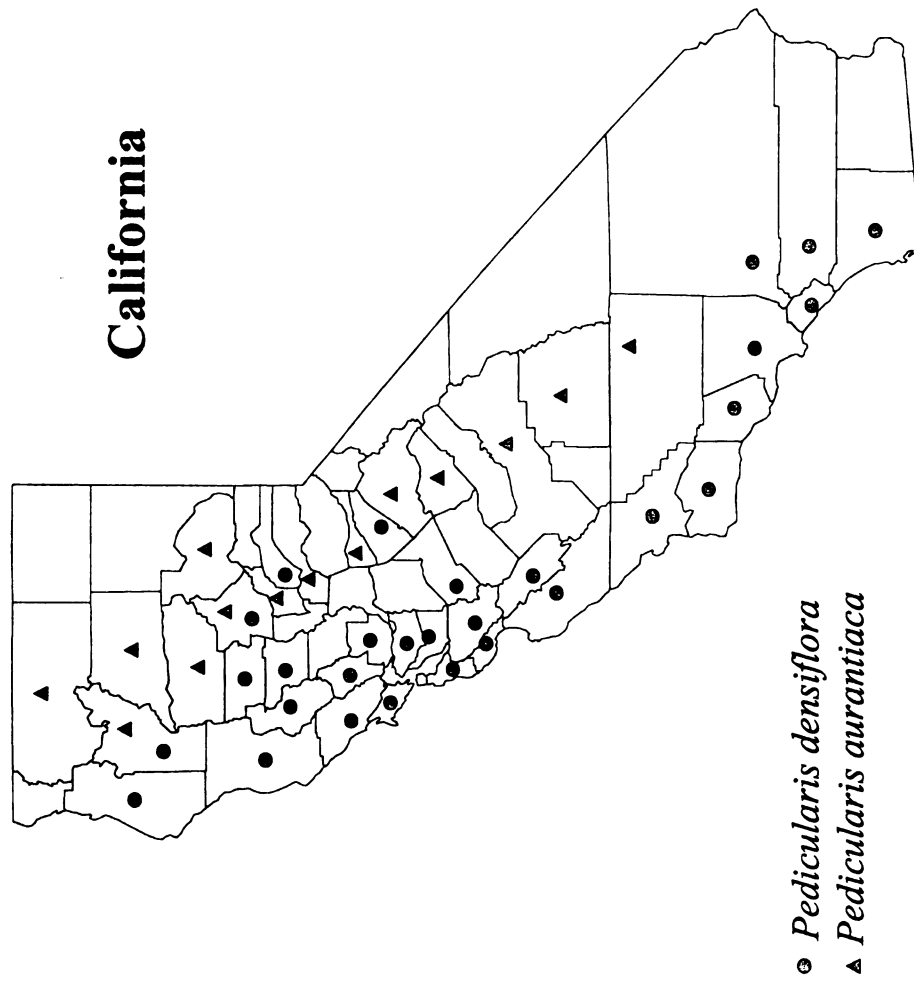


Figure 7.

Figure 8. County map of Oregon. Map shows distribution of *P. densiflora* and *P. aurantiaca* based on morphological analysis of populations in the field and herbarium material cited. Circle represents presence of *P. densiflora* herbarium material in the county. Triangle represents presence of *P. aurantiaca* herbarium material in the county.

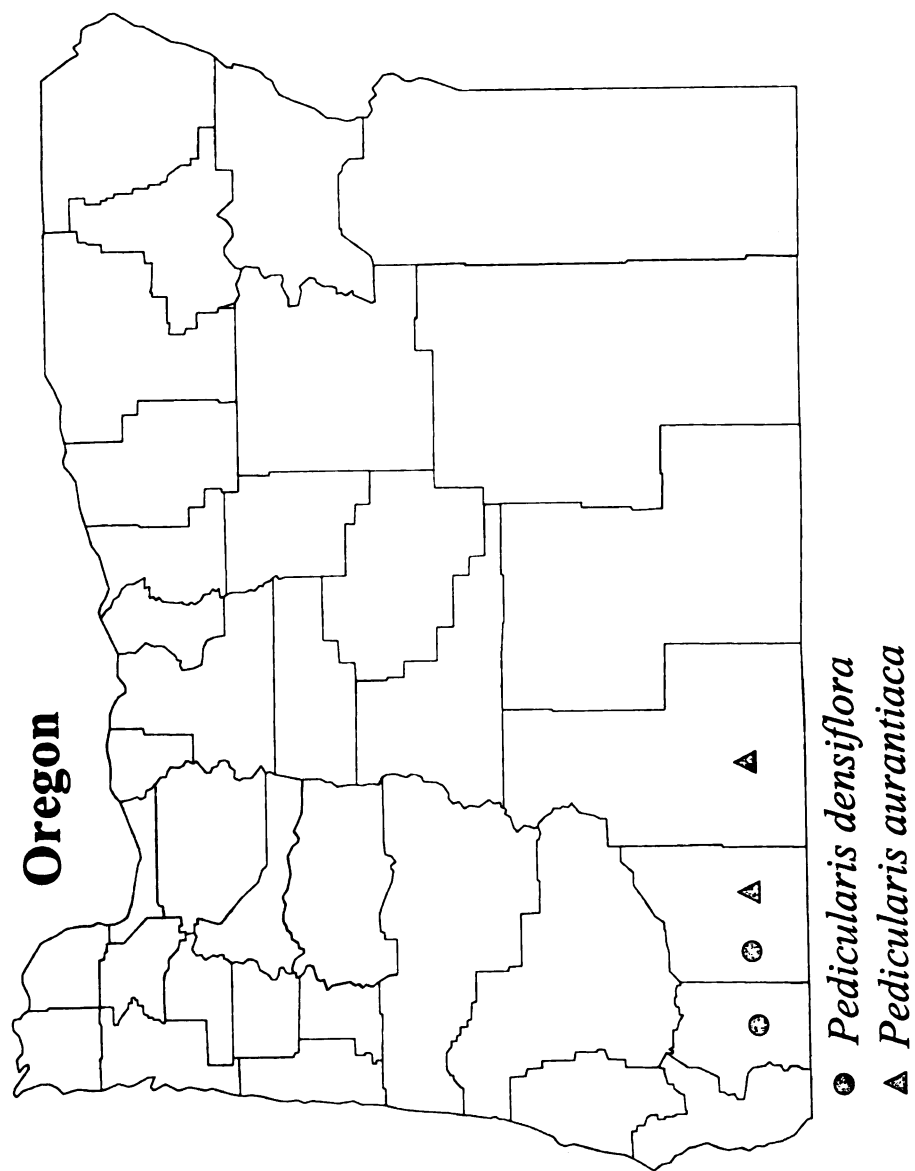


Figure 8.

galea, and a tube that is exerted from the calyx. The species flowered between February and April and grew at elevations ranging from 100-4000 feet. *Pedicularis densiflora* was distributed along the coast from southern California into southern Oregon, with occurrences as far south as Baja, California. Populations occur in the foothills of the Sierra Nevadas in Butte, Calaveras, and Nevada counties. Field observations and a review of herbarium specimens indicate that the distribution of *Pedicularis aurantiaca* is contiguous with that of *P. densiflora* in Jackson County in Oregon and Butte, Calaveras, Colusa, Lake, Nevada and Trinity Counties in California (Figure 7 & 8).

Molecular Variation –

Six of the 16 populations examined in the molecular phylogenetic analysis were representative of *P. aurantiaca*: Auberry, Hobo Gulch, Inskip, McBride Springs, Pinehurst, and Weaver Camp. *Pedicularis densiflora* was represented by ten of the sixteen populations examined: Bear Valley, Briceland Bridge, Hurles Circle, Missouri Flat, Mount Diablo, Paradise, Pinnacles National Monument, Round Valley Historical Marker, San Marcos Pass, and Santa Margarita Lake.

The ITS sequences were 603 bp long, with 74 parsimony-informative characters. There were 16 most parsimonious trees with a length of 114, C.I. excluding uninformative characters (C.I.⁵) = 0.9032, and R.I. = 0.9543. Bootstrap support, as shown on the strict consensus tree (Figure 9), for a clade including McBride Springs, Inskip, and Pinehurst, as well as two geographically proximate sites not measured in our morphological analysis formed a monophyletic group, albeit with weak bootstrap support (bootstrap value of

Figure 9. Figure represents the strict consensus tree of 16 most parsimonious trees and is based on nuclear ribosomal ITS sequences 603 bp long, with 74 parsimony-informative characters. Phylogeny has a tree length of 114, C.I.^c = 0.9032, and R.I. = 0.9543. Numbers above the branches represent bootstrap percentages based on 10,000 replicates. Names represent locations of populations of *P. densiflora*/ *P. aurantiaca*. Populations of *P. aurantiaca* denoted with an asterisk. Location and voucher information is available in Table 1 and Figure 1.

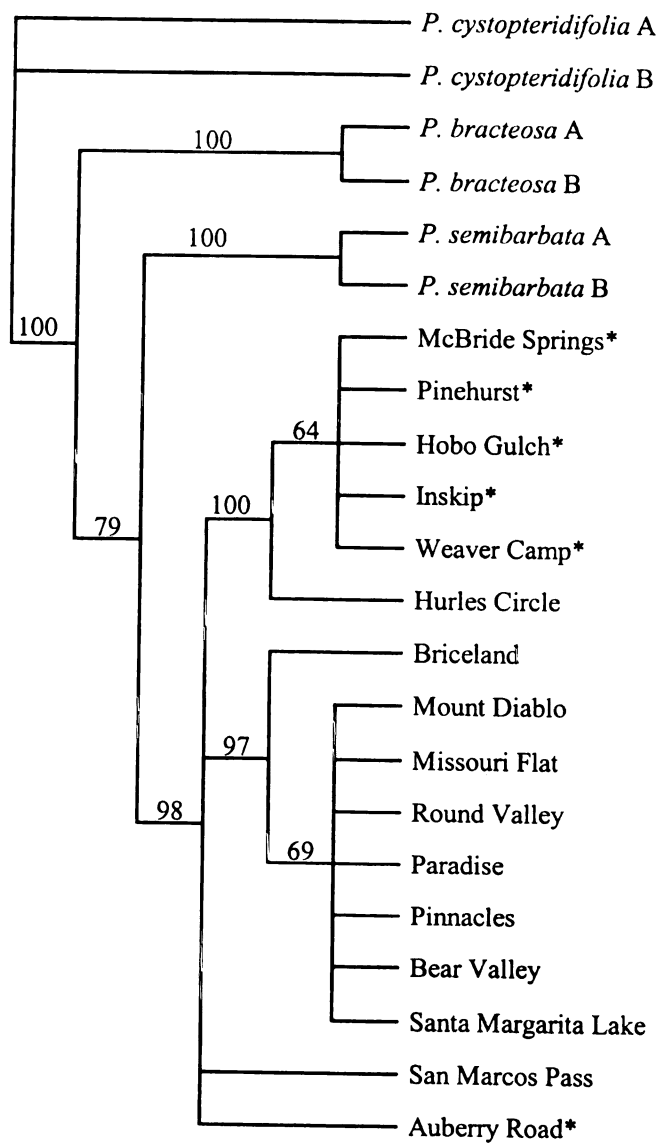


Figure 9.

64%). Inclusion of Hurles circle into the clade McBride Springs – Hurles Circle had 100 % bootstrap support. The clade Briceland- Santa Margarita Lake had strong bootstrap support (97%). San Marcos Pass and Auberry Road populations were part of a polytomy at the base of the *P. densiflora*/*P. aurantiaca* clade. The phylogeny showed 98% bootstrap support for the monophyly of the *P. densiflora*/*P. aurantiaca* clade.

Independent phylogenetic analyses were initially conducted on the two chloroplast regions. The aligned sequences of *psbA-trnH* were 605 base pairs long with 566 base pairs included in the analysis, 20 of which were phylogenetically informative. Thirty nine base pairs (bp238 through bp276) were excluded from the analysis due to ambiguity in alignment. Parsimony analysis of *psbA-trnH* intergenic spacer resulted in 42 most parsimonious trees, with a length of 41, a C.I.^c = 1.00, and a R.I. = 1.00. The aligned sequences of *trnL-trnF* were 404 base pairs long with 12 substitutions, nine of which were phylogenetically informative. Parsimony analysis resulted in six most parsimonious trees, with a length of 12, a C.I.^c = 1, and a R.I. = 1. The *trnL-trnF* base pair data analysis showed no resolution among the populations of the *P. densiflora* and *P. aurantiaca* species. Five *P. densiflora* populations (Briceland, Mount Diablo, Missouri Flat, Round Valley, and Paradise) and one *P. aurantiaca* population (Inskip) share a 51 bp insertion/deletion event (Indel). This indel was treated as missing data in the parsimony analysis.

Data from the chloroplast region was combined for a total of 970 base pairs with 29 parsimony informative characters (Figure 10). Twenty eight most parsimonious trees were generated, with a length of 53, C.I.^c = 1.00, and R. I. = 1.00. Two clades with low support were resolved. Briceland, Missouri flats, and Round Valley formed a polytomy with 63% bootstrap support. The clade that includes a more inclusive clade of those three populations and Mount Diablo had a bootstrap support of 64%. The *P. densiflora*/ *P. aurantiaca* clade has 94% bootstrap support

I did not reject the null hypothesis of homogeneity in distribution of phylogenetic information between the data sets based on the partition homogeneity test ($p=0.59$) and the data were combined for an analysis of relationships among populations of *P. densiflora* and *P. aurantiaca* (Figure 11).

The combined data set had 1573 base pairs with 103 parsimony informative characters. Eight most parsimonious trees resulted from the analysis, with a length of 168, C.I.^c = 0.9194, and R. I. = 0.9600. The clade McBride Springs – Hurles Circle had 100% bootstrap support. The Briceland-Santa Margarita Lake clade formed a monophyletic group with 99% bootstrap support. The San Marcos Pass and Auberry Road populations were part of an unresolved polytomy at the base of the *P. densiflora*/ *P. aurantiaca* clade. The phylogeny had 100% bootstrap support for the monophyly of the *P. densiflora*/ *P. aurantiaca* clade.

Figure 10: Figure represents the strict consensus tree of 28 most parsimonious trees and is based on *psbA-trnH* and *trnL-trnF* sequences 970 bp long, with 29 parsimony-informative characters. Phylogeny has a tree length of 53, C.I.^c = 1.00, and R. I. = 1.00. Numbers above branches are bootstrap percentages based on 10,000 replicates. . Names represent locations of populations of *P. densiflora*/ *P. aurantiaca*. Populations of *P. aurantiaca* denoted with an asterisk. Location and voucher information is available in Table 1 and Figure 1.

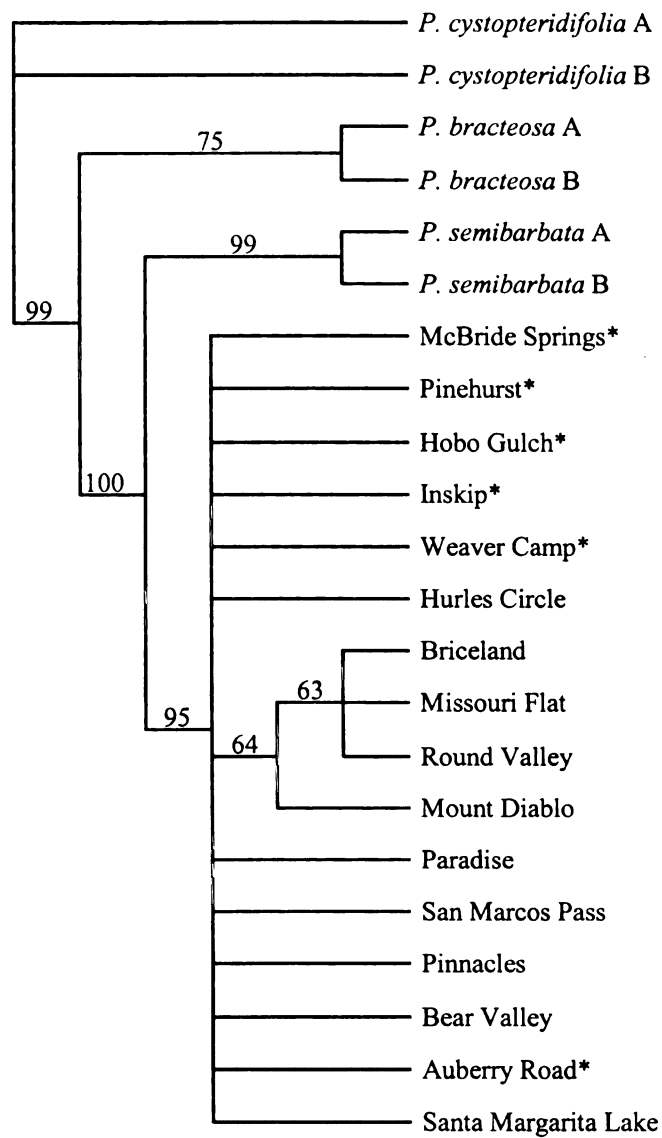


Figure 10.

Figure 11: Figure represents a strict consensus of 8 most parsimonious trees and is based on combined analysis of *psbA-trnH* and *trnL-trnF* chloroplast sequences and nuclear ribosomal ITS sequences 1573 bp long, with 103 parsimony-informative characters. Phylogeny has a tree length of 168, C.I.^c = 0.940, and R. I. = 0.960. Numbers above branches represent bootstrap percentages based on 10,000 replicates. Names represent locations of populations of *P. densiflora*/ *P. aurantiaca*. Populations of *P. aurantiaca* denoted with an asterisk. Location and voucher information is available in Table 1 and Figure 1.

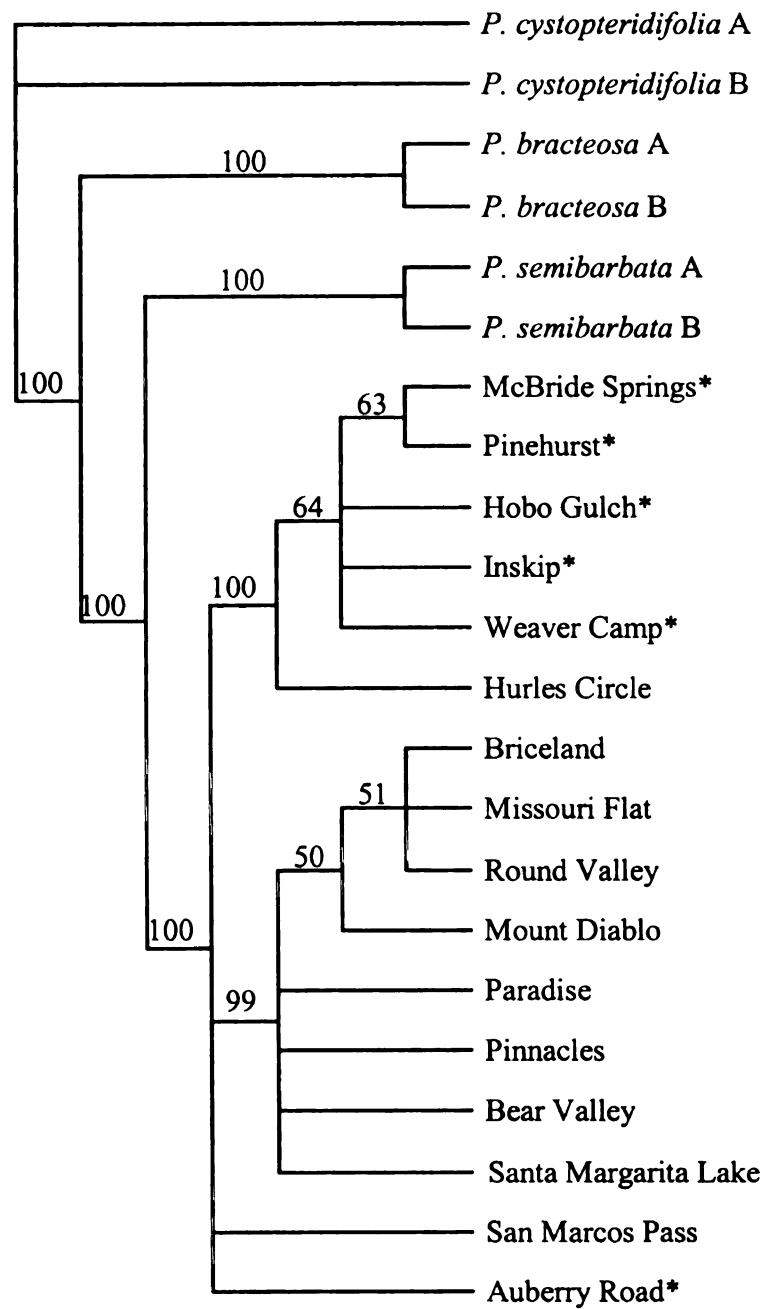


Figure 11.

The chloroplast and ITS primers were used to amplify regions of DNA to assess some inter-specific relationships among closely related *Pedicularis* species. Our combined analysis showed the *P. semibarbata* and *P. bracteosa* clades were monophyletic (100% bootstrap support). *Pedicularis semibarbata* was sister to the *P. densiflora*/*P. aurantiaca* clade (100%) and *P. bracteosa* was sister to the *P. densiflora*/*P. semibarbata* clade with 100% bootstrap support.

CONCLUSION

Morphological Variation –

Quantitative traits measured on ten populations, field observations, and an examination of herbarium specimens showed considerable variation in floral morphological measurements among the populations studied. These results indicated two points: the *P. densiflora*/*P. aurantiaca* group had considerable floral morphological variation among populations, and some of this variation could be attributable to distinct groups, which herein are treated as two species, *P. densiflora* and *P. aurantiaca*.

Molecular Variation –

Pedicularis densiflora and *P. aurantiaca* are closely related sister taxa. The phylogenetic analysis indicated the McBride Springs – Weaver Camp clade of *P. aurantiaca* populations was closely related, genetically distinct and derived from within *P. densiflora*/*P. aurantiaca* clade. However the Hurles Circle (*P. densiflora*) population had a shared ancestry with this clade and the *P. aurantiaca* population of Auberry road and a *P. densiflora* population of San Marcos Pass were part of a polytomy at the base of the *P. densiflora*/*P. aurantiaca* clade. In addition, in the *trnL-trnF* spacer region, Inskip (*P. aurantiaca*) shared a 51 bp indel with Briceland, Mount Diablo, Missouri Flat, Round Valley, and Paradise (*P. densiflora*) and this provides some evidence for a shared chloroplast ancestry among these six populations. Therefore no conclusions regarding the monophyly or ancestry of *P. aurantiaca* could be made. More informative markers may provide additional resolution for discerning the relationships among the species.

Sequence data from the sampled species indicated a common ancestor between *P. densiflora*, *P. aurantiaca* and *P. semibarbata*. This relationship was proposed by Li (cited as a personal communication by Sprague) and Sprague (1962). Robart's (2000) ITS sequence phylogeny included the narrow California endemic *P. howellii* A. Gray. This taxon was sister to *P. semibarbata*, in a clade sister to the clade of *P. densiflora* and *P. aurantiaca*. This result was not surprising, *P. densiflora*, *P. aurantiaca*, *P. semibarbata* and *P. howellii* have similar floral morphologies, inhabit similar habitats, are geographically proximate, and parasitize similar woody host plants.

Ancestral Pollination State-

Many studies of reproductive biology of *Pedicularis* in the United States were conducted by Macior (1973, 1977, 1982, 1983, 1984, 1986a, 1986b, 1995a, 1995b, 1996, 1997 and references therein) who noted the close association between *Pedicularis* and *Bombus* pollinators. With some rare exceptions noted in this study, there appeared to be a “virtually exclusive *Bombus/Pedicularis* reproductive association” in the genus (Macior 1997; 1). *Pedicularis cystopteridifolia* (Macior 1983), *P. howellii* (Macior 1986b), and *P. bracteosa* (Macior 1973, Robart 2001) are *Bombus* pollinated. *Pedicularis semibarbata* is pollinated exclusively by small bees, *Osmia tristella* (Macior 1977). *Pedicularis densiflora* is pollinated by both *Bombus* and hummingbird pollinators and *P. aurantiaca* is pollinated exclusively by hummingbirds (based on overlapping populations studied by Macior 1986a, and Sprague 1960, 1962).

Long corolla tubes, abundant nectar, lack of floral scent, and red coloration are floral traits present in both *P. densiflora* and *P. aurantiaca* which have an association with hummingbird pollinators (Sprague 1960, Grant & Grant 1968, Faegri & van der Pijl 1966). In *P. densiflora* young flowers are visited by *Bombus* pollinators before the floral tubes are fully exerted and while the nectar is accessible to the short-tongued pollinators (Macior 1986). The lower labium of *P. densiflora* is larger and capable of serving as a landing platform for *Bombus* pollinators. In *P. aurantiaca* the calyx is larger and supports the corolla tube. This trait can serve to protect the flower during the nectar probing of hummingbird visitation (Faegri & van der Pijl 1966). The labium is also significantly smaller and the abaxial margin larger in the *P. aurantiaca* vs. *P. densiflora* flowers. The labium reduction eliminates the *Bombus* landing platform and the enlarged abaxial margin can accommodate the larger head of the hummingbird pollinators.

Detailed pollination ecology studies (Macior 1973, 1977, 1983, 1986 a and b, Robart 2001, and Sprague 1960, 1962), were coupled with phylogenetic sequence data from the chloroplast and nuclear genome and the ITS sequence phylogeny of Robart (2000). This work supported the hypothesis of a major pollination shift in *P. semibarbata* with a transition from *Bombus* to small bee pollination. In addition, there are two potential evolutionary scenarios for pollinator shifts within *P. densiflora* and *P. aurantiaca*: A. The ancestral state of *Bombus* pollination in the outgroup of *P. cystopteridifolia* and *P. bracteosa*, with a partial switch to a shared pollination biology of *Bombus* and hummingbird pollinators in *P. densiflora* and a complete transition to exclusive hummingbird pollination in *P. aurantiaca*, or B. The ancestral pollination state of

Bombus pollination in the outgroup of *P. cystopteridifolia* and *P. bracteosa*, with a complete loss of *Bombus* pollination and a switch to hummingbird pollination in the *P. aurantiaca*/*P. densiflora* clade, and a second shift to shared pollination biology of regained *Bombus* pollination in addition to hummingbird pollination in *P. densiflora*. Due to the partially unresolved phylogeny among populations of *P. densiflora* and *P. aurantiaca* and the difficulty of mapping polymorphic pollination states, it is not possible to distinguish between the two evolutionary scenarios described.

Taxonomic treatment –

Review of herbarium specimens, statistical analysis including ANOVA, PCA, and UPGMA, show a clear distinction between the species *P. aurantiaca* and *P. densiflora*. *Pedicularis aurantiaca* has a large calyx, floral tubes not fully exerted at anthesis, reduced lower labium and a large opening in the galea. *Pedicularis densiflora* has a short calyx with a fully exerted floral tube, an enlarged lower labium and a smaller opening in the galea. Flowering times and locality are different between the species. *Pedicularis aurantiaca* flowers later in the season, at higher elevations and grows in southern Oregon, and northern California into the Sierra Nevadas. *Pedicularis densiflora* flowers early in the spring at lower elevations, and grows primarily along the coastal mountain ranges of California. A comprehensive review of over 1000 herbarium specimens confirms the morphological distinctions and diagnosability of the two species. Previous work by Sprague (1958, 1960, and 1962) and Macior (1986a) on variation among pollinator regimes indicated exclusive pollination by hummingbirds in *P. aurantiaca* and a shared pollination by *Bombus* and hummingbirds in *P. densiflora*.

Pedicularis aurantiaca is morphologically distinct, has a later growing season, grows at higher elevations, and has a different suite of pollinators than *P. densiflora*. *Pedicularis aurantiaca* is prezygotically isolated from *P. densiflora*. Support for the elevation of *P. aurantiaca* to species status is unambiguous. The appropriate combinations for the species are below.

Pedicularis aurantiaca (E. F. Sprague) Monfils & Prather, comb. et stat. nov. *Pedicularis densiflora* subsp. *aurantiaca* E. F. Sprague, *Aliso*, 4:130. 1962. Type: USA: from a burn in manzanita brush, Yellow Pine Forest, between the campground and the forest, Lake Almanor, Plumas County, California, at 4300 feet, 30 May 1957, *E. F. Sprague 1202* (holotype: RSA; Isotype RSA!)

Description: Perennial herb with woody root. Leaves petiolate, in basal rosette, oblanceolate, bipinnate to pinnate. Inflorescence a raceme, capitate with few open flowers. Bracts of the inflorescence oblanceolate and partially laciniate. Calyx tube 12-24 mm long, hirsutulous, 5 equal, acuminate to acute, erose lobes. Corolla galeate, 23-43 mm, deep red to purple to orange-yellow, galea 14-25.5 mm long, 4.5-8.5 mm deep, abaxial margin 13-23 mm long, lower labium petals 3.5-7.5 mm long from bend in corolla to petal tips. Corolla tube not fully exerted at anthesis. Fruit a capsule.

1000-7000 feet. Flowers April through June. Pine forests.

Note: Plants in diffuse patches, haustoria preferentially parasitize woody plants

Additional material seen: UNITED STATES. Oregon: Jackson County: 1-1.5 miles past Pinehurst Inn. N 42° 07.452', W 122° 20.783', 1167 m, 24 May 1998, *Monfils 12* (MSC); 1-1.5 miles east of Pinehurst Inn. N 42° 07.461', W 122° 20.756', 1131 m, 11 May 2000, *Monfils 40* (MSC); Pinehurst, 20 Jun 1927, *Peck 15044* (DS, WILLU); Pinehurst, 27 May 1948, *Peck 24973* (WILLU, UC); Near Pinehurst, 1219 m, 13 Apr 1934, *Thompson 10347* (CAS, DS, POM, WILLU). Klamath County: Cascade Mnts. Near Long Prairie, along old Klamath Falls-Ashland road, 15 Jun 1895, *Applegate 421a* (DS); Southeast of Topsy, 1372 m, 12 May 1898, *Applegate 2059* (DS); Top of Spencer Mt., Cascade Mts., 11 May 1924, *Applegate 4046* (DS, WILLU); Eastern Cascades, 30 Jun 1902, *Cusick 2851* (DS, ORE, POM); Klamath Falls Road "East of Mt.", 2 Aug 1925, *Henderson s.n.* (ORE); Along Ashland-Klamath Falls road, 18 miles W of Keno, May 1932, *Peck 9302* (DS, WILLU); Mts. Below Klamath Falls near Ore-Calif line, on Klamath river, May 1932, *Sprague s.n.* (OSC). County Unknown: Southern Oregon, 13 May 1907, *Henderson s.n.* (ORE); Location and date unknown, *Bellinger s.n.*, (WILLU).

California: Amador County: Jackson, 12 Apr 1933, *Ball 18269*, (RSA). Butte County, Colby, May 1890, *Austin 111* (UC); Jonesville, 16 Jun 1923, *Bassett s.n.* (CAS); Paradise, May 1898, *Bruce 2419* (DS, POM); Brush Creek, 1907, *Conger 453* (CAS, POM); Chico Meadows in the Sierra Nevada, 1219 m, 11 Jun 1915, *Heller s. n.* (DS); Stirling, 1073 m, 18 May 1919, *Heller 13170* (CAS,DS); Pentz Road, 3 miles below Paradise, 23 Mar 1939, *Heller 15358* (DS); DeSabra, 853 m, 18 Apr 1978, *Howell 52852* (CAS); Above the road between Paradise and Butte Meadows .1 mi. s. of Inskip. T25N, R.4E, Sec. 33, 10 May 1981, *McNeal 2487* (OSC); Inskip on Skyway Road. Elevation N

39° 59.541', W 121° 32.389', 1309 m, 22 May 1998, *Monfils 6* (MSC); Inskip on Skyway Road. N 39° 59.527', W 121° 32.461', 1309 m, 9 May 2000, *Monfils 37* (MSC); Durham, 17 Apr 1932, *Morrison s. n.* (CAS). Fresno County: 5 miles east of Auberry, Big Sandy Bluff, 945 m, 19 Mar 1969, *Ahner s. n.* (CAS); Big Sandy Valley near the foot of ne. slope of Black Mt. Big Sandy Bluff beyond Ridge View Ranch which is across the road from my place, 610 m, 20 Mar 1953, *Carter 157* (CAS, UC); About 2 miles north of Kerckhoff Reservoir, 610 m, 29 May 1967, *McClintock, Roderick & Johnson s. n.* (CAS); Old fire trail road off Auberry Road. N 37° 05.144', W 119° 26.859', 1147 m, 20 May 1998, *Monfils 4* (MSC); R. R. Grade Rd. 1+ m. w. of jct. Hiway 168 at Shaver Xing between Shaver L. & Big Crk. 1st live crk. – small intake with pipe heading down crk. – Big Creek pentstocks in view. Heavy yellow pine for. 4500' - 1000' up s. wall Big Crk. Canyon; 6830' Music Mt. Just sw.; 8107' Black Pt. N. across canyon, San Joaquin R. at 2000' 4 map miles w., 17 Jun 1955, *Quibell 5102* (RSA); 5 miles east of Auberry, Big Sandy Bluff range, 945 m, 19 Mar 1969, *Shannon s. n.* (RSA); Scattered along Old Railroad Grade Road. R.23E., T9S., SW1/4 section 34, 853 m, 22 Mar 1980, *Shevlock 6819* (CAS, MSC); Taken near Fish Camp, 14 Apr 1938, *Whilton s. n.* (RSA); Along road from Shaver Lake to Big Creek Power House. W. slope of Sierra Nevada, 1829 m, 5 May 1929, *Wolf 3682* (RSA); 6 mi. above Auberry on road to Pineridge. W. slope of Sierra Nevada, 18 May 1933, *Wolf 4786* (CAS, RSA, UC). Kern County: Poso Creek narrows, below Poso Flat, 762 m, 9 Mar 1963, *Record 82-1* (CAS-2); Near mouth of South Fork Kern River Canyon, trail along Bartolas Creek, Domeland Wilderness, north of California highway 178 and NW of the Bloomfield Ranch. R35E, T25S, section 23. Lat/Long: 35 degrees 44'45" N, 118 degrees 11'15" W., 1006 m, 20 Apr 1991, *Shevock*

12026 (CAS); Back canyon at the cypress grove, 1265 m, 26 May 1964, *Twisselmann*
950 (CAS-2). Mariposa County; Mariposa, 610 m, 10 Apr 1959, *Ballantyne 236* (CAS);
 Awahnee, 9-16 Apr 1926, *Shank 17471*, (RSA). Placer County: Tahoe Forest, Rebel
 ridge Range, 701 m, 12 Apr 1926, *Smith 53916* (CAS-2). Plumas County: Sw. shore
 Lake Almanor, 2 mi. s. of jct. of State Hwys. 89/36, 1402 m, 23 May 1957, *Balls 22519*
 (RSA, UC); 1 3/10 s. of Drakesbad, 3 Jul 1938, *Cantelow 2323* (CAS); Prattville,
 sSummer 1906, *Coombs s. n.* (CAS); Woodleaf, 3000-4000', 14 Apr 1931, *Rose s. n.*
 (CAS, DS, POM, UC); Lake Almanor, 4300', 30 May 1957, *Sprague 1214* (RSA);
 Growing in dry loam in shade of *Libodedrus decurrens* A low cool draw 6 miles south-
 west of Viola, 2800', 30 May 1957, *Sprague 1231* (RSA). Shasta County: Montgomery
 Creek, 18 Apr 1923, *Beltiel s. n.* (CAS); Near McBride Springs. On banks and under
 chaparral, 24 Jun 1938, *Cooke 11098*, (DS, OSC); Squaw Creek Ranger Station, Jun
 1916, *Drew s. n.* (DS); Mt. Shasta, 21 Jun 1893, *Dudley s. n.* (DS); Burney Butte, 12 Jul
 1912, *Eastwood 1034* (CAS); Shasta Springs, 20 May 1923, *Eastwood 11854* (CAS-2);
 Shasta Springs, 15 May 1918, *Herrin s. n.* (CAS); Shasta Springs, May 1922, *Herrin s. n.*
 (CAS); Open manzanita-oak association 3 miles east of Redding, 500', 17 May 1940,
Hitchcock 6466 (DS, POM); Highway 44, 5 miles west of Lassen National Park, 4600', 9
 May 1974, *Keller 1301* (CAS); Mt. Shasta, McBride Springs. N 41° 20.687', W 122°
 16.506', 4922', 11 May 2000, *Monfils 43* (MSC). Siskiyou County, Bare serpentine
 gravel hillside, Scott Mnt. 8 miles above Callahan, 5150', 17 May 1954, *Barneby 11537*
 (CAS); Near Mt. Shasta, 6000-7000', 1-15 Jun 1897, *Brown 356* (DS); Alpina Mnts.
 Goosenest foothills, 5000', 10 May 1910, *Butler 1324* (DS, POM, UC); N. slope of Scott
 Mnt., 4000', 20 May 1936, *Cantelow 1435* (CAS); Scott Mountain campground, 10 miles

S. of Callahan, 5350', 21 May 1949, *Constance*, *Bonar*, *Holm & Wood* 3288 (UC); 0.8 miles N of Scott Mnt. Summit on Hwy 3. South Slope, 5200', 5 Jun 1975, *Davidson* 2684, (RSA); Bald mountain in road from Mt. Hebron to Montague, 5500', 15 May 1940, *Gould* 1242 (DS); Mi. Eddy in open gravelly places in the forest, 6800', 15 Jul 1915, *Heller* 12085 (CAS, DS, UC); Sugar Creek, Salomon Mountain Range, 5500', 26 May 1949, *Parker* 257 (UC); Weed, 10 Apr 1913, *Smith* 66 (CAS); Dunsmuir, 29 Apr 1913, *Smith* 151 (CAS); Shady hillside near Weed, 28 Mar 1930, *Tebbe* 61 (UC); Salmon Mnts., Klamath National Forest. Near South Fork of Salmon River, 5 to 9 mile southeast of Cecilville, between Lat. 41°03' and 41°06'N., and Long 122°58' and 123°03'W. Vicinity of Blind Horse Creek, 3000-3500', 13 May 1954, *Thomas* 4129 (DS-2); Salmon-Trinity Mnts. about 6 miles SE of Cecilville. West side of Rush Creek, 3800-4000', 21 Jul 1954, *Thomas & Thomas* 4425 (DS). Tehama County: Along road from Viola to Mineral, 9.5 miles south of Viola, 5000', 12 Jun 1962, *Breedlove* 3423 (CAS, DS); Deer Creek Rd. (Rt. 32) at milepost 12, E side of Deer Creek ca 20 airmiles SW of Chester, 3200', 3 May 1989, *Ertter* 8435 (RSA); Mill Crk. Meadows, 6 Jun 1951, *Quick* 51-93 (CAS); Northern Sierra Nevada. Red Bluff – Susanville Road. 3 6/10 mi. below Mineral, 4800', 17 May 1937, *Wolf* 8712 (RSA). Trinity County: T35N, R11W, Sec. 6. North fork of Trinity River, Hobo Gulch Camp and Vicinity. (18 miles NW of Weaverville) Along East Fork Trail, just over on the east side of Backbone Ridge, 4000', 25 Apr 1972, *Carter* 374 (CAS-2); T36N, R11W, Sec. 31. North fork of Trinity River, Hobo Gulch Camp and Vicinity. (18 miles NW of Weaverville) Along trail 0.1 miles north of Hobo Gulch. (Same location as 399-27 Apr. 72), 3100', 8 Jun 1972, *Carter* 399.01, (CAS-2); Scott Mnts. N. of Carrville, 25 Jun 1937, *Eastwood & Howell* 5013 (CAS); 3 miles from

Douglas City on Redding Road, 26 Apr 1954, *Howell 29164* (CAS); Dry open coniferous forest in Canadian Zone, Scott Mt. Summit on road from Carrville to Callahan, 5400', 20 May 1980, *Howell, Fuller & Barbe 53541* (CAS); Weaverville, Spring 1915, *Junkans s. n.* (CAS); Trinity Center, 30 Apr 1928, *Kildale 4605* (DS); Weaverville, 30 May 1931, *Kildale 10812* (DS); Foothills, Weaverville, 4000', 11 Apr 1880, *Kleiberger s. n.* (CAS); East Weaver Campground on East Weaver Creek Road. N 40° 46.399', W 122° 55.371', 4248', 23 May 1998, *Monfils 8* (MSC); Hobo Gulch. N 40° 55.723', W 123° 09.398', 4249', 23 May 1998, *Monfils 9* (MSC); East Weaver Public Camp, East Weaver Creek, 3000', 16 May 1949, *Munz 13256* (RSA); T32N, R9W, Secs. 28 & 33; Mt. Diablo Meridian; Southeast of confluence of Panwauket Gulch and Reading Creek; blue oak-pine woodland, 610 m, 18 May 1975, *Sullivan 88* (RSA); Little East Weaver Creek, 3000', 21 May 1914, *Yates 19370* (CAS). Tulare County: Mineral King, 2000', 11 Apr 1958, *Pawek 418* (DS); Occasional in recently disturbed road bank along Blue ridge, section 10, R.29E., T. 19S. South facing slope, 4900', 12 May 1979, *Shevock 6186* (CAS); Uncommon along Calif. Hwy 245, about one mile west from the junction with Dry Creek Road. R.27E., T.15S. section 15, 2800', 11 Mar 1980, *Shevock 6775* (CAS); Lone Pine Spring, White River, 3350', 8 Mar 1940, *Smith 51*, (CAS). Tuolumne County: Priest Grade, near Big Oak Flat, Yosemite National Park, 20 Feb 1982, *Botti 1489* (CAS). Groveland. Woodland edge of route 120 about 4 miles east of town, 23 Apr 1974, *Churchill 744231* (MSC). Yuba County: Between Dobbins and Bullard Bar Dam, Watershed of North Fork of the Yuba River, 3.1 mi. e. of Dobbins (or 5.5 miles s.w. of Bullard Bar Dam), 2570', 19 Apr 1956, *Bacigalupi, Robbins & Chisaki 5622* (RSA);

Comptonville, 7 Apr 1918, *Eastwood 6795* (CAS). County Unknown: Sterling City, 18 May 1935, *Whitaker s. n.* (OSC).

Pedicularis densiflora Benth. ex. Hook. Fl. Bor. Am. ii. 110. 1838. Type unknown.

Description: Perennial herb with woody root. Leaves petiolate in basal rosette, oblanceolate, bipinnate to pinnate. Inflorescence a raceme, elongated with many open flowers. Bracts of the inflorescence oblanceolate with serrate margins. Calyx tube 10-18 mm long, hirsutulous, 5 equal, acuminate to acute, erose lobes. Corolla galeate, 23-43 mm, deep red to purple to orange-yellow, sometimes white, galea 15-25 mm long, 4-7 mm deep, abaxial margin 9.5-20 mm long, lower labium petals 8-16 mm long from bend in corolla to petal tips. Corolla tube exerted at anthesis. Fruit a capsule.

100-4000 feet. Flowers February through April. Chaparral to pine forest.

Note: Plants in diffuse patches, haustoria preferentially parasitize woody plants,

Additional material seen: UNITED STATES. **Oregon:** Jackson County: Thompson Creek, near Applegate, steep hill slope. Sec. 21 T.38S R.4W, 1400', 19 Mar 1940, *Detling 3864* (ORE); Fls. Deep purple-red open pine woods on alluvium, along Applegate River, 1 1/2 mi. s.e. of Provolt, 28 Apr 1948, *Glownke 11113* (UC); 5 miles S of Applegate, under madronas, 1 Jun 1951, *Hitchcock 19395* (RSA); Applegate Creek, Mar 1921, *Leiberg s. n.* (ORE); Applegate R., Jacksonville, 27 Mar 1936, *Lund s. n.*

(OSC); Pilot Rock, 20 Apr 1932, *Neiman s. n.* (WILLU); Woods along Thompson Cr. 5 mi. S. of Applegate P.O., 26 Jun 1931, *Peck 16423* (WILLU-2); Along the Applegate River, 12 Apr 1927, *Thompson 2225* (DS,ORE). Josephine County: 4 mi. N.W. of Provost, 25 Apr 1943, *Bellinger s. n.* (WILLU); 3 miles south of Grants Pass on New Hope Road, 9 May 1963, *Curtis s. n.* (OSC); Applegate Valley T37S R5W sec. 34, 21 Apr 1942, *Detling 5138* (ORE); In open woods, Fruitvale, 21 Apr 1930, *Henderson 12513* (ORE); Roadside in mixed Oak-Pseudotsuga woods; S. facing; on old river bench. 2 mi E of Murphy R5W; T37S; SE1/4 OF NW1/4, 345 m, 20 Apr 1968, *Lillico 426* (ORE); Missouri Flat Road. N 42° 19.288', W 123° 13.871', 3900', 24 May 1998, *Monfils 13* (MSC); Missouri Flat Road. N 42° 19.288', W 123° 13.871', 3900', 10 Apr 1999, *Monfils 36* (MSC); Applegate River, North Bank Road c. 1 mi. from Redwood Highway; S. of Grants Pass, 1300', 23 Apr 1967, *Pike 111* (ORE); Hillside near Grants Pass, 19 Mar 1918, *Prescott s. n.* (WILLU); Near Williams Creek highway between Provolt and Williams; also on N. side of Applegate River on Missouri Flat. Clayey soil in woods, 13 Apr 1924, *Savage s. n.* (ORE); Fruit Dale, Murphy Road. In open woods, 24 Mar 1926, *Savage s. n.* (ORE); Mixed woods near Takilma, 21 Apr 1930, *White s. n.* (ORE). **California:** Alameda County: Laundry Harm, 29 Jan 1895, *Cannon s.n.* (CAS); Oakland Hills, 28 Feb 1936, *Covel 371* (CAS); Laundry Harm, 26 Apr 1891, *Eastwood s.n.* (ORE); Mines Road s. w. of Livermore, near entrance to Rancho Los Mochos Boy Scout Camp, 1500', 3 Mar 1968, *Gagné s.n.* (CAS). Butte County: Near Hurleton, 1800', 26 Mar 1980, *Ahart 2060* (CAS); Cherokee mine, 29 Mar 1919, *Heller 13097* (CAS, DS, POM); Hurles Circle, in center island. N 39° 29.764', W 121° 22.632', 2050', 22 May 1998, *Monfils 5* (MSC); Hurles Circle, in center island. N 39° 29.764', W 121° 22.632',

2050', 7 Apr 1999, *Monfils 35* (MSC). Calaveras County: Comanche, 16 Apr 1939, *Hoover 4032* (CAS). Colusa County: Wilbur Springs. T15N, R6W, sec. 35, 3500', 14 Apr 1979, *Roth 9* (RSA); Along Brim Rd., 2.9 mi. W jct. Bear Valley Rd., 30 Mar 1996, *Vincent & Rhode 7304* (RSA). Contra Costa County: Martinez, 300', 18 Mar 1931, *Benson 2662* (POM); Mount Diablo, 17 Mar 1922, *Eastwood 11084* (CAS); Rocky Point, Mount Diablo. N 37° 51.814, W 121° 55.770', 2550', 22 Mar 1999, *Monfils 28* (MSC); Rocky Point, Mount Diablo, 2000', 5 Apr 1956, *Sprague 1096* (RSA); Mount Diablo, 2000', 11 Apr 1957, *Sprague 1124* (RSA); Rocky Point, Mount Diablo, 2000', 30 May 1957, *Sprague 1134* (RSA). Glenn County: 2 miles north of Alder Springs, 3900', 19 May 1949, *Munz 13330* (RSA). Humboldt County: T7N, R5E, Sec. 29. Along highway 96, 1.9 miles north of Willow Creek, 1 May 1965, *Anderson 3556* (RSA); In damp fir woods near creek, Boise Creek and Willow Creek, Trinity River, 1 Apr 1947, *Brown 25* (DS); Philabiumsville, south fork of El River, 20 Mar 1927, *Kildale 2909* (DS); Briceland Bridge near Garberville, 375', 17 Apr 1925, *Kildale 3096* (DS, RSA); Briceland Road. N 40° 05.678', W 123° 51.222', 1874', 25 May 1998, *Monfils 14* (MSC); Round Valley Historical Marker. N 39° 43.749', W 123° 15.112', 2160', 25 May 1998, *Monfils 16* (MSC); Kneeland Prarie, in woods in ravine, 2500', 8 Jun 1908, *Tracy 2637* (UC); Vicinity of Garberville, 400', 17 Mar 1923, *Tracy 6160* (UC); Trinity River Valley, near the south fork, 600', 28 Feb 1926, *Tracy 7369* (UC); Hoopa Mnt., near summit on road west from Hoopa to Bair's, 3500', 15 May 1927, *Tracy 8060* (UC); Willow Creek Canyon, 2000', 26 Apr 1931, *Tracy 9340* (UC); Trinity River Valley, at Willow Creek, 500', 3 Apr 1937, *Tracy 15251* (UC); Trinity River Valley, at Willow Creek, 500', 26 Mar 1941, *Tracy 16818* (UC); Harris, in woods, 2500', 31 May 1948,

Tracy 18006 (UC). Lake County: Lakeport, 20 Apr 1917, *Bentley s. n.* (DS); Mt. Kelseyville, Middle N. Coast, Near Cold Creek Canyon River, 1700', 30 Mar 1928, *Benson 87* (POM); Bogg's Lake, Mt. Hanna, Middle N. Coast, Clear Lake watershed, 3500', 18 May 1935, *Benson 6636* (POM); Hannah, 3000', 8 Apr 1923, *Blankinship s. n.* (CAS); Mt. Konocti, 2000', 27 Mar 1926, *Blankinship s.n.* (RSA); Sulphur Banks, Apr 1902, *Bowman s. n.* (DS); E. of Middleton, 7 Apr 1940, *Cantelow 4346* (CAS); 4 mi. below Tollhouse on Middleton Road, 22 Feb 1924, *Duncan s. n.* (DS); Dasheills Mt., Sanhedrin, 23 May 1925, *Eastwood 12912* (CAS); Elk Mt., 17 May 1938, *Eastwood & Howell 5703* (CAS); Clear Lake, 14 Apr 1928, *Galloway s.n.* (CAS), Glenbrook, near Jordan Park, 30 Mar 1931, *Jussel 29* (CAS); Cobb Mt., 30 Mar 1931, *Jussel s. n.* (CAS); Cobb Mt., 31 Mar 1931, *Jussel s. n.* (CAS); Mt. St. Helena, 1 Apr 1933, *La Motte s. n.* (POM); Cobb Mt., 4 Jul 1893, *Leitholt s. n.* (DS); Bear Valley on Brim Road. N 39° 09.504', W 122° 28.778', 2665', 26 May 1998, *Monfils 17* (MSC); Bear Valley on Brim Road. N 39° 09.431', W 122° 28.798', 2180', 26 May 1998, *Monfils 33* (MSC); Butt's Cyn. Rd. near Middleton, 1000', 25 Mar 1972, *Shevock 1437* (RSA); Northeast facing slope, 0.4 mile southeast of Black Oak Villa in Butts Canyon, 1.1 miles from Lake-Napa county line on Pope Valley road, 800', 7 Mar 1953, *Sweeney 971* (UC); Chaparral 11 mi. S. of Lower Lake, 13 Mar 1932, *Wiggins 5769* (DS); 21/2 miles S. W. of Lakeport. Sec. 34, T.14N, R.10W, 1850', 14 May 1937, *Wilson 376* (UC). Los Angeles County: Mts. above Claremont, Johnson Pasture, 15 Feb, *Bragg s. n.* (POM); North slope Sta. Monica Hills, Feb 1903, *Braunton 809* (DS, ORE-2); Topanga Canyon, 28 Mar 1929, *Clare s.n.* (RSA-2); Laurel Canyon, 24 Feb 1929, *Detruers s.n.* (RSA); Mulholland Drive, 6 Mar 1935, *MacFadden 13246* (CAS); Laurel Canon, Mar 1943, *Merritt s.n.* (RSA); Franklyn

Canyon, Santa Monica Mts., 21 Feb, *Peirson 1168* (RSA); Glendora, Little Dalton Trail, 16 Feb 1916, *Perkins s.n.* (RSA); 0.7 mile from Triunfo Canyon, 2 miles west of Cornell, Lobo Canyon, 800', 31 Mar 1959, *Thompson 1010* (CAS, RSA); Hwy. 23 south of Lake Elanor, Santa Monica Mtns., 1000', no date, *Wallace & Wilkin 150* (RSA). Marin County: East side of the Tiburon Peninsula just below the summit, 31 Mar 1981, *Best s. n.* (CAS); On trail 0.5 mi. above Phoenix Lake near jct. of Mt. Tamalpais trail, 1200', 5 Apr 1956, *Campbell 8* (RSA); Mount Tamalpais, 22 Feb 1901, *Chandler 760* (POM, UC); Old hardpacked fire road, 100', 9 Feb 1975, *Edelbrock 4*, (CAS); Summit Alpine Lake Trail above Deer Park, 8 Mar 1936, *Ewan 9408* (RSA); Summit Alpine Lake trail above Deer Park, 8 Mar 1936, *Ewan 9409* (UC); Mt. Tamalpais, 22 Apr 1930, *Forest s. n.* (RSA); Tamalpais T1N R6W, 600', 28 Mar 1935, *French 619* (UC); South side of Mt. Tamalpais, 7 Mar 1902, *Heller & Brown 5008* (DS, MSC, POM); Tiburon, 15 Feb 1938, *Hoover 2739* (UC); San Geronimo Ridge, 25 Feb 1940, *Howell 15388* (CAS); Carson Ridge, 19 Apr 1942, *Howell 16949A* (CAS-2); San Arseloro Canyon, 25 Feb 1940, *Howell s. n.* (CAS); Above Blythedale Canyon, east side of Mt. Tamalpais, 2 Mar 1947 *Howell s. n.* (CAS); Mill Valley, 29 Mar 1891, *Jepson s.n.* (UC); Alpine Dam Road, about 1 mile from Alpine Gulch on Fairfax side, 1040', 10 Mar 1968, *Kawahara 29* (CAS); Marin County, 1868-1869, *Kellogg & Harford 713* (CAS); Ross Valley, Apr 1892, *Michener & Bioletti s. n.* (MSC); Tamalpais, Apr 1892, *Michener & Bioletti s. n.* (MSC); Fire road, south side of Mount Tamalpais, 12 Apr 1969, *Mitchell 4* (OSC); Paradise Beach Park, Tiburin Uplands Nature Preserve. N 37° 53.329', W 122° 26.954', 109', 26 May 1998, *Monfils 18* (MSC); Paradise Beach Park, Tiburin Uplands Nature Preserve. N 37° 53.309', W 122° 27.055', 137', 3 Apr 1999, *Monfils 34* (MSC); Mt.

Tamalpais, 3 Mar. 1930, *Morris s. n.* (RSA); Rcky and clayey bank by Paradise Dr., 0.7 mi. N. Paradise Beach Park, Tiburon Peninsula, 10 Apr 1975, *Norris 2305* (RSA); Tiburon Peninsula, 200', 15 Mar 1930, *Parks 402* (POM, UC); Tiburon, Spring 1926, *Parks* (UC); Alpine Dam Road above Fairfax, 800', 9 Mar 1963, *Sharsmith 5194* (UC); Corte Madera, 1 Mar 1903, *Sheldon 11563* (ORE); Phoenix Lake, Ross, 1000', 4 Apr 1956, *Sprague 1096* (RSA); Carson Ridge, 4 Apr 1957, *Sprague 1120* (RSA); Fairfax, Mar 1928, *Sutcliffe s. n.* (RSA); North slope of hill near Forest Knolls, 21 Mar 1936, *True s. n.* (RSA); Phoenix Lake, Ross, 1000', no date, *no collector* (RSA); Mt. Tamalpais, Apr 1898, *no collector* (CAS). Mendocino County: Abt. 12 mi. e. of U. S. 101, along Calif. 20. In shade above road, 6 Apr 1954, *Clarkson 300* (OSC); Red Mnt., n. Mendocino Co., 21 Jun 1937, *Eastwood & Howell 4663* (CAS); Near Woodville, May 1889, *Howell s. n.* (UC); Ukiah, 25 Apr 1924, *Jones s. n.* (DS-2, POM); Kaiser District, Mar 1903, *McMurphy 306* (DS); 8 miles north of Ukiah, 6 Apr 1938, *Meyer 1384* (UC); Round Valley Historical Marker. N 39° 43.749', W 123° 15.112', 2160', 25 May 1998, *Monfils 16* (MSC); Round Valley Historical Marker. N 39° 43.760', W 123° 15.093', 1966', 29 Mar 1999, *Monfils 32* (MSC); Mad River, 6 Jul 1890, *Price s. n.* (UC); Potter Valley, Apr 1894, *Purpus 1009* (UC); Shady Hills, n. Potter Vall., Mar 1894, *Purpus 3089* (UC); Along rte. 128 at MP24.26, 400', 5 Mar 1979, *Smith & Wheeler 5128* (CAS); Red Flat, ¼ mi. from wooden gate btwn, BLM & Coombs property. Red Mnt. N., 2350', 6 Jul 1981, *Smith et al. 6855* (CAS); Summit area of Red Mountain North, 7 Jul 1981, *Smith et al. 6868* (CAS); Seven miles north of Laytonville near highway 101, 20 Apr 1968, *Thomas 14331* (DS); Rte. 253. South of Robinson Creek Rd., Ukiah, 650', 11 Mar 1978, *Wheeler 60* (CAS); South of Leggett on the Old Redwood Hwy, 1000', 1

Feb 1980, *Wheeler 1298* (CAS); Round Valley Historical Marker, overlooking Covelo on Hwy. 162, 2000', 12 Apr 1979, *Wheeler & Smith 905* (CAS); Little River – Albion Road. Near Little River Airport, 600', 23 May 1979, *Wheeler & Smith 1026* (CAS); On Northwestern slope, 4 miles east of Laytonville, along road to Dos Rios, 20 Mar 1948, *Wiggins 11587* (DS, RSA). Monterey County: Gravel Pitt hill, 27 Jun 1905, *Dudley s. n.* (DS); Monterey, 1874, *Abbott s. n.* (CAS-2); Carmel Highlands, Peter Pan Rd., 200', 21 Feb 1948, *Balls 7834* (RSA); Monterey, 29 Mar 1933, *Detling 1108* (ORE); Pine Cañon, 1500', 27 Mar 1920, *Duncan 86* (DS); Near Cypress Pt., 28 May 1912, *Eastwood 94a* (CAS); Pacific Grove, 8 Mar 1923, *Eastwood 2471* (CAS); Monterey, 9 Mar 1913, *Eastwood 2489* (CAS); Pacific Grove, Apr 1902, *Elmer 3543* (DS-2, POM, UC); Two miles south of Jolon on hilltop, 10 Mar 1952, *Evans s. n.* (CAS); Sand Stone Cliffs near north fork of San Antonio River, 1500', 27 Mar 1920, *Ferris 1810* (DS); Landels-Hill Big Creek Reserve, Gamboa Point Section, Santa Lucia Mountains, sect.4, 2 Apr 1982, *Genetti & Engles 48* (CAS); Del Monte Forest, Pacific Grove, 1 Apr 1955, *Howitt 132* (CAS); Pacific Grove, 12 Apr 1933, *Jussel s. n.* (DS); Summit of Hesperia Mountain, north of Bryson, southern Monterey County, 1550', 2 May 1933, *Keck 2093* (DS-2); Near the school. Francis Simes Hastings Natural History Reservation, Santa Lucia Mts., 2 Apr 1944, *Linsdale 71* (CAS); Santa Lucia Mountains, Apr 1898, *Plaskett 75* (UC) Carmel-by-the-Sea, 3 Mar 1910, *Randell 53* (DS); By trail from Carmel to Monterey, 30 Dec 1909, *Randall s. n.* (DS); Parkfield Road, 1.5 miles east of Vineyard Canyon Summit, 2200', 4 Apr 1956, *Twisselmann 2618* (CAS-2); Del Mouh ur. Salinas Road, 15 Apr 1912, *Woodcock s. n.* (POM). Napa County: Mt. St. Helena Trail, 4 May 1928, *Abrams 12265* (DS); Summit of St. Helena Grade, 3 May 1928, *Abrams s. n.* (DS);

Howell Mt., 22 Mar 1936, *Cantelow 1142* (CAS); East slope in the Howell Mountains, 5 miles east of Napa, North Coast Range, 1500', 27 Mar 1938, *Constance 2036* (DS, UC); Northern exposure above Putah Creek, along State Hwy. 128, about 6 miles east of Monticello, 26 Feb 1953, *Crampton 989* (UC); 7.2 miles from St. Helena on road to Pope Valley, 2 Apr 1950, *Finfrock 17* (UC); Wooded slope in the oak belt about 5 miles south of Calistoga, 12 Apr 1924, *Heller 13840* (DS, POM); Near the summit of the ridges east of Napa on the Monticello road on a clay bank among shrubs, 12 Mar 1940, *Heller 15514* (DS); Wooden Valley road, east side of Napa Range, 8 miles from Napa, 2 Apr 1931, *Keck 1030* (DS, POM); Calistoga, 13 Apr 1929, *Linsdale 257* (UC); Old Howell Mountain Road, 1500', 31 Mar 1967, *Muth 596* (RSA); 1 mile from Pacific Union College, beside road to Pope Valley, 1 May 1949, *Popenoe 18* (OSC); Hills just n. of White Sulphur Ck., w. of Saint Helena, 500', 22 Feb 1954, *Raven s. n.* (CAS); Base of Mt. St. Helena, 3 May 1928, *Wolf 1845* (DS); Summit of Mt. St. Helena Grade, north of Calistoga, *Wolf 1845* (RSA); Upper slopes of Mt. St. Helena, 4 May 1928, *Wolf 1856* (RSA). Nevada County: American Ranch Hills, 5 miles south-west of Grass Valley, on McCourtney Rd., 2200', 8 Apr 1962, *True 356* (CAS). Orange County: 14.3 miles east of San Juan Capistrano on State 74, 1100', 9 Mar 1962, *Breedlove 1789* (DS); Santa Ana Mountains, Cleveland Nat. Forest. Pleasants Peak (on Orange-Riverside Co. line), 4000', 18 May 1977, *Davidson 5601* (RSA); Sitton Peak Truck Trail: 0.3 mi W of ranger station near hot springs, on Ortega H'way (SR 74), 25 Apr 1990, *Jaroslow B36* (RSA); Sierra Peak Trail, Santa Ana Mts, 11 Apr 1929, *Johnson 1259* (RSA); 5 miles east of Trabuco Oaks, Trabuco Canyon, Cleveland National Forest, 1300', 6 Apr 1966, *Lathrop 6142* (RSA). Riverside County: Santa Ana Mountains, 3 miles above De Luz on dirt road,

3000', 30 Apr 1966, *Adams s. n.* (RSA); Vail Lake area, summit of "Big" Oak Mtn, N. of lake. T7S, R1W, SW ¼ sec. 34. Saddle between summits, N slope along rd heading N to Black Hills, 2600', 30 Mar 1990, *Boyd, Ross & Arnseth 3944* (RSA); Vail Lake area, saddle at N base of "Big" Oak Mtn, S of Black Hills. T7S, R1W NE ¼, SW ¼ sec. 34, 2400', 30 Mar 1990, *Boyd, Ross & Arnseth 3953* (RSA); Santa Ana Mountains, San Mateo Cyn. Wilderness Area. Tenaja Trail from jtn. W/ Morgan Tr. S to Pigeon Spring area. T6S, R5W sec.32; T7S, R5W sec. 5, 2200-2600', 31 Mar 1992, *Boyd, Ross & Arnseth.6763* (RSA); Aguater, So. Calif., 7 Apr 1929, *Clarkk 2035* (RSA); Corona Skyline Drive, Santa Ana Mts. So. Calif., 7 Apr 1929, *Crow 304* (RSA); Vicinity of Beaumont, 17 Apr 1897, *Hall 476* (UC); Aguanga, 22 Dec 1925, *Jaeger s. n.* (POM); Corona, sec. 22, T4S, R7W, 2800', Mar 1934, *Jensen 318* (UC); 18 miles S. W. of Elsinore. South slope of Tenaja Canyon, 2 Apr 1959, *Lathrop 4408* (RSA); 4 miles west of Corona between Tin Mine Canyon & Santiago Peak, Skyline Drive, 4000', 9 Apr 1969, *Lathrop 6968* (RSA); Beaumont, 2000', 25 Mar 1919, *Munz, Street & Williams 2327* (DS, POM); 4 mi. SE of Oak Flat near west county line on Santiago Pk. Fire road near top of peak west of Santiago Pk., Santa Ana Mts., 4200', 14 Apr 1959, *Olmsted 374* (RSA); Along roadside in red clay soil, about 4 miles west of Beaumont, on road to Redlands, 19 Mar 1921, *Peirson 2741* (RSA); Rancho Calif. area, ca. 8 mi. (airline) NW of Temecula, between Bruce Lane & Via View Dr. (T 7S, R 1W SBBM NW ¼ of SW ¼, sec.27), 2400', 22 Feb 1988, *Pendelton s. n.* (RSA); Santa Ana Canyon, Santa Ana Mountains, 15 Apr 1922, *Pierce s. n.* (POM); 1 mile south of Aguangam, Hwy 79, Agua Tibia Mts., 1940', 12 Apr 1951, *Rush 169* (POM-2); In herbosis, Lambs Canyon proper, Banning, 2300', 25 Apr 1922, *Spencer 1910* (RSA). San Benito County: Eastern

exposure on Peak Trail. Pinnacles National Monument, Paicines, 1500', 22 Mar 1955, *Burgess 84* (UC); Pinnacles Nat. Mon., 550 m, 6 Jun 1931, *Fosberg 35251* (RSA); North slope, the Pinnacles, 29 Mar 1930, *Howell 4611* (CAS); Pinnacles National Monument, High Peaks Trail. N 37° 53.386', W 122° 26.991', 107', 27 May 1998, *Monfils 20* (MSC); Pinnacles National Monument, 1600-1700', 11 May 1940, *Pennell & Powell 25370* (UC); Pinnacles National Monument. Pinnacles Loop Trail, 1200-2500', 27 April 1975, *Thomas 17828* (DS). San Bernardino County: Devore near San Bernardino, 1900', 12 Mar 1928, *Feudge 1960* (POM); Foothills San Bernardino Mts., Apr 1882, *Parish 707* (DS, ORE, UC). San Diego County: Santa Ana Mtns, San Mateo Wilderness Area, "Miller Canyon" on the south base and flank of Miller Mtn from 8S02 upstream to the eastern summit area. T8S,R5W, sec. 10.15, 2100-2900', 3 Mar 1992, *Boyd & Ross 6717* (RSA); W. of Warner Hot Springs, 6 Apr 1929, *Clark 2007* (RSA); South side of Gonzales Canyon, east of Del Mar, 30 Mar 1969, *Copp 69-1* (CAS); Mt. Soledad, 3 Jan 1935, *Gander 103* (RSA, UC); North side of San Miguel Mountain. 32°42'N 116°55 3/4'W, 900', 24 April 1957, *Moran 6000* (DS); Beaumont, 2000', 25 Mar 1919, *Munz, Street & Williams 2327* (ORE); Colorado Desert, 1500', 9 Apr 1921, *Spencer 231* (POM); Potrero Grade, 18 Mar 1917, *Spencer s.n., 9 Apr. 1921* (POM); Grape Vine Canyon, 1200 m, 21 May 1930, *Templeton 1625* (RSA-2); Near Santee, Feb 1915, *Valentien s.n.* (UC). San Louis Obispo County: Atascadero, 22 Mar 1926, *Abrams 10942* (DS); 4.4 miles east of Santa Margarita; La Panza Range, 1200', 29 Mar 1962, *Breedlove 2029* (DS); 3 miles E. of Pozo, sec. 13, T.30S, R.15E, 1800', 27 Mar 1937, *Gifford 801* (UC); 1 mile S. of Bee Rock, Bradley, Sec 7, T.25S, R.10E, 1200', 11 Apr 1938, *Graham 305* (UC); 7X Ranch, Santa Lucia Mountains, 2200', 2 Mar 1956, 2200', *Hardman 143*

(CAS); 7X Ranch, Santa Lucia Mountains, 2200', 2 Mar 1956, 2200', *Hardman 144* (CAS); Santa Rita Canyon, Santa Lucia Mountains, 13 Apr 1956, *Hardman 404* (CAS); L. Delagenna Ranch, Santa Lucia Mountains, 26 Apr 1956, *Hardman 533* (CAS); Calf Canyon, 5 Apr 1967, *Hoover 10334* (CAS); E. side of Santa Margarita Lake, 8 Apr 1986, *Keil 19136* (RSA); 3 miles N. E. of Templeton, Paso Robles, T. 27S, R. 12E, 900', 31 Mar 1937, *Lee 806* (UC); Growing in a disturbed area on a road bank beside Hwy. #229, 5.9 mi. sw. of Hwy. #41 at Creston, 29 Mar 1981, *McNeal 2433* (OSC); Riconda Trail Head off Pozo Road. N 35° 17.214, W 120° 28.659', 2200', 18 May 1998, *Monfils 2* (MSC); Riconda Trail Head off Pozo Road. N 35° 17.267, W 120° 28.677', 2070', 27 May 1998, *Monfils 20*, (MSC); Santa Rita Canyon, 1000', 17 Apr 1957, *Sprague 1136* (RSA); On Cayucos Rd. to Cambira on Jack Mt. Nick Marquat Ranch, 16 Apr 1957, *Sprague 1137* (RSA); Hill by a spring near San Louis Obispo, May 1889, *Summers 527* (CAS); 2 miles north Cuesta Pass, Santa Lucia Mountains, 2000', 4 Apr 1963, *Toschi 63:97* (CAS); Santa Margarita, Eldorado School, 20 Apr 1933, *Wall s.n.* (CAS-2, RSA); Roadside and hills near Adelaide, W. of Paso Robles, 24 Mar 1932, *Wiggins 5847* (CAS, DS, POM); Prefumo Canyon, *no collector* (DS). San Mateo County: Woodside, 16 Mar 1902, *Abrams 2278* (DS); Kings Mountain Road, Santa Cruz Mountains, 500-700', 1 Mar 1914, *Abrams 5058* (POM); Woodside, 3 Mar 1895, *Applegate 421* (DS); Woods on Coal Mine Ridge, 23 May 1937, *Barry 155* (DS); Hill east of Lake Searsville, North Slope, 2 Mar 1929, *Benson 987* (POM); Woodside, Santa Cruz Mtns, near San Fransquito Cr., 600', 28 Feb 1931, *Benson 2610* (POM); Santa Cruz Mountain Peninsula, Crystal Spring Lake, 28 Apr 1920, *Borthwick 97* (DS); Near the intersection of Canada and Edgewood roads. About 3 mi. westward from Redwood City, 13 May 1974, *Cahill 248* (DS); La

Honda Road (from Hwy. 5) to Woodside, 3 mi. from Mt. Home-Portola road, 4 Apr 1956, *Campbell 1* (RSA); Big Basin of Pescadero creek, 9 May 1903, *Copeland 3050* (POM); Santa Cruz Peninsula, near Belmont, no date, *Dudley s.n.* (DS); Woodside, 1903 May, *Elmer 4497* (CAS-2, DS, ORE, OSC, POM, UC); Near Belmont, Mar 1886, *Greene 9* (ORE); San Carlos. Chaparral area north of Malabar Rd. and Melendy Dr. Lat N. 37° 29' 38", Long. 122° 16' 41" W, 600-680', 22 Apr 1973, *Hemphill 737* (DS); Woods near Spring Valley Lakes, Santa Cruz Mountain Peninsula, 29 Apr 1920, *Hickborn s.n.* (DS); Los Trancos, 30 Apr 1908, *Lewis s.n.* (RSA); Kings Mt., May 1902, *McMurphy s.n.* (DS); Mt. above Woodside, 9 Mar 1906, *McMurphy s.n.* (DS); Sawyer's Road, near Crystal Springs lake above Burlingame and Millbrae, 15 Apr 1956, *O'Bannon s.n.* (DS); Sawyer Ridge, 17 Apr 1949, *Oberlander 86* (DS); Santa Cruz Peninsula, Kings Mt., 27 Apr 1907, *Patterson s.n.* (RSA); Santa Cruz Peninsula, Kings Mt. Road, 27 Apr 1907, *Randall 394* (DS); Santa Cruz Peninsula, Kings Mt. Road, 28 Mar 1908, *Randall s.n.* (DS, RSA); Belmont, 24 Feb 1935, *Rose 35016* (RSA); Crystal Springs lake, 500', 12 Apr 1939, *Rose 39061* (RSA, UC); Millbrae Highlands, 300', 31 Mar 1948, *Rose 48031* (RSA); Emerald Lake, w. of Redwood City, 400', 23 Mar 1964, *Rose 64013* (DS, RSA); 2 mi. nw of Woodside, 600', 27 Mar 1969, *Rose 69009* (MSC); King's Mountain, 27 Apr 1907, *Rust 135* (RSA); King's Mountain Road, 29 Mar 1949, *Thomas 195* (DS); Jasper Ridge, about 5 miles southwest of Palo Alto. Lat N. 37° 24.5', Long. 122° 14' W, 500', 5 Apr 1959, *Thomas 7663* (MSC); ½ way up east slope of La Honda Grade, Santa Cruz Mts., 24 Jan 1927, *Wolf 190* (RSA); East side of La Honda Grade, 26 Feb 1927, *Wolf 221* (RSA); Above Searsville Lake, 2 Mar 1927, *Wolf 235* (RSA). Santa Barbara County: Purissima Hills, on road to Mission, 27 Mar 1938, *Abrams 13755*, (DS); North

side of the Point Sal Ridge, 3 ½ mi. west of Corralillos Canyon. Point Sal, 3 Mar 1958, *Blakley & Muller B-2695* (CAS-2, RSA); Beside Refugio Pass Road, 5.4 miles north of U. S. 101, 24 Feb 1962, *Breedlove 1778* (DS); San Marcos Pass. Old Stagecoach Road. N 34° 31.790', W 119° 50.070', 1402', 17 May 1998, *Monfils I* (MSC); Old Freemont Trail and Coach Rd., Santa Ynez Mts., - Area of Refugio Pass, 2200', 18 Mar 1956, *Pollard s.n.* (CAS); Near summit of Refugio Pass, Santa Ynez Mts, 2200', 19 Apr 1968, *Pollard s.n.* (CAS); Stagecoach Road, 1650', 5 Apr 1970, *Shevock 106* (RSA); Entrance to Foster Glen Park, along highway in San Marcos Pass, south side of Santa Ynez Mountains near summit, 11 Mar 1955, *Smith 3918* (RSA, UC); Three miles north of summit of San Marcos Pass, 19 Mar 1961, *Turner, Sphon & Ball C-494* (RSA). Santa Clara County: Santa Cruz Peninsula, charcoal burners, Page Mill Road, Black Mt., 6 Jul 1903, *Dudley s.n.* (DS); Santa Cruz Peninsula, Page Mill Road, Black Mt., 23 Apr 1904, *Dudley s.n.* (DS); Adelante Villa, Palo Alto, 25 Feb 1894, *A. M. K. s.n.* (RSA); Foothills near Stanford University, 9 Mar and 15 May 1902, *Baker 283* (CAS, DS, MSC-2, POM, UC); Black Mt., 9 Feb 1895, *Burnham 9 Feb. 1895* (MSC); Eastern slope of Mount Hamilton, 3000', 31 Mar 1933, *Chambers 144* (UC); Los Gatos, 19 Mar 1897, *Davy s.n.* (UC); North-facing bank, south side of page Mill road, ca. 1 mile west of entrance to Palo Alto Foothills Park, Palo Alto, 1200', 25 Mar 1969, *Doty 593* (RSA); Foothills west of Los Gatos, 25 Mar 1904, *Heller 7281* (DS, MSC, UC); Alpine Creek Road, northeast side of Santa Cruz Mountains, 200', 22 Feb 1932, *Keck 1387* (DS, RSA); Foothills of the eastern side of the Santa Cruz Mountains, 5 miles south of the center of Palo Alto. Los Tracos Trail above Los Tracos Creek, 600-1800', 3 Apr 1974, *Martineau 16* (DS); 23.1 mi. w. of Interstate #5, Patterson exit, in Del Puerto canyon (2.5 mi. e. of

the Mt. Hamilton-Livermore Rd.), 15 Mar 1970, *McNeal 472* (OSC); Fire trail near Loma base above spring, 3400', 21 Mar 1940, *Nelson 71* (UC); Hills 1 ½ miles south of Saratoga, Western Santa Clara County, 800', 1 Mar 1906, *Pendleton 290* (POM); 10 miles south of Black Mountain, s. of Palo Alto, 1200-1300', 16 May 1940, *Pennell & Abrams 25429* (CAS, UC); Seeboy Ridge, Mount Hamilton Range, 2400', 10 Feb 1934, *Sharsmith 537* (UC); South end of Mount Day Ridge above Santa Isabella Creek, Mount Hamilton Range, 1800', 25 Mar 1935, *Sharsmith 1520* (UC); Northwest slope of Black Mountain, 1100', 31 Jan 1948, *Silva 2616* (RSA); Vicinity of Mt. Umunhum, Lat. N. 37° 09.5', Long. 121° 54.2' W, 3400', 23 Apr 1954, *Thomas 3963* (DS). Santa Cruz County: Ben Lomond Mountain area; on Eagle Rock; T9S, R3W, Sec. 16, 2200', 23 Mar 1974, *Halse 986* (OSC); Big Basin, Santa Cruz Mts., *Reed s.n.* (CAS); Santa Cruz Peninsula, Swanton, Spring 1912, *Rich s.n.* (DS); La Honda Rd. Sta. Cruz Mts., 2000', 3 Apr 1956, *Sprague 1095* (RSA); Between Eagle Rock and Locatelli Ranch. Lat. N. 37° 08.7', Long. 122° 12' W, 2400', 27 Mar 1950, *Thomas 1346* (DS); East side of Mill Creek Drainage about 2 miles S-SW of Eagle Rock at Lat. N. 37° 07.3', Long. 122° 12.4' W, 1800-1900', 30 Apr 1954, *Thomas 3035* (DS); Between Eagle Rock and Locatelli Ranch. Lat. N. 37° 08.7', Long. 122° 12' W, 2200', 15 Mar 1954, *Thomas 3776* (DS); Vicinity of Eagle Rock. Lat N. 37 08.8, Long. 122 11.7 W. 2200-2500', 30 Mar 1961, *Thomas 9041* (DS); Halfway down La Honda Rd. Sta. Cruz Mts., 2000', 13 Apr 1957, *no collector* (RSA);. Solano County: Gates Canyon, northwest of Vacaville, 3 Mar 1951, *Kehlor s. n.* (OSC); 3 ½ miles west of Rockville, 25 Mar 1966, *Olson & Gorelick* (RSA-2). Sonoma County: Pepperwood Ranch, Oak woodland between the 2 fir-Redwood canyons, 25 Mar 1981, *Denevers 565* (CAS); Calistoga, 25 Mar 1922, *Eastwood 11097* (CAS); Camp Meeker, 22

Mar 1924, *Howell* 287 (CAS); Near Sonoma, Mar 1962, *Menzius s.n.* (CAS); 2 miles from juncture of Highway 12 and Trinita Road, 750', 27 Feb 1960, *Ruckert* 5 (CAS). Sonoma County, 10 Mar 1903, *Rattan s.n.* (DS); 0.5 mi. south of Calistoga, 400', 29 Mar 1953, *Raven* 5207 (CAS); Santa Rosa Creek Canyon, 8-10 miles east of Santa Rosa, 25 Mar 1937, *Robbins* 10 (UC); N. side of Vine Hill School Road ½ miles from Vine Hill Road, 250', 19 Apr 1965, *Thorne* 34319 (RSA); Parker Hill Rd. ca. 2 ½ mi. N of Santa Rosa and 1 mi. N of Sonoma Co. Hosp., 350', 20 Apr 1965, *Thorne* 34328 (RSA). Stanislaus County: Near head of Del Puerto Canyon, 20 Apr 1941, *Hoover* 4886 (UC). Trinity County: Vic. Dam at Ruth Reservoir on Mad River, 2700', 21 May 1979, *Mattoon* 121 (RSA, UC); Road along Coffee Creek, above Coffee Creek Ranch, 16 Jun 1956, *McClintock s. n.* (CAS); T6N, R6E, Sec. 34, Found in Grays Falls Campground, 21 Apr 1979, *Miller* 2-87 (RSA); Sec. 10, T4S, R7E, West slope of Salt Cr., 2400', 28 May 1933, *Sack & Iverson* 70393 (CAS); New River Trail from Grays Falls Campground on the North side of the Trinity River and west side of the New River, 800-1000', 7 Apr 1973, *Smith* 6006 (RSA); Under scattered yellow pine; along Van Duzen River, about 3 miles southeast of Kuntz, 20 Apr 1950, *Tracy* 18633 (RSA, UC). Ventura County: Las Turas Lake, Santa Monica Mts., 14 Feb 1931, *Ewan* 4027 (POM); Upper Ojai, Ojai Valley and vicinity, 7 Mar 1895, *Pettibone & Hubby s.n.* (CAS); Hills north of Ojai, Upper Ojai, Ventura River Basin, 16 Apr 1949, *Pollard s. n.* (CAS); Hills north of Ojai, Upper Ojai, Ventura River Basin, 21 Apr 1949, *Pollard s. n.* (CAS). County Unknown: Belmont (MSC); California, 1853-1854, *Bigelow s.n.* (DS); S. Oakland Hills, Mar 1900, *Carruth s.n.* (CAS); Mt. Hamilton, 3000', 3 Apr 1906, *Chaualer* 6014 (UC); Cuesta Summit, 2600', 2 Apr 1908, *Condit s.n.* (UC); California, *Coulter s.n.* (UC); Mt. St.

Helena, 1 May 1918, *Eastwood 6811* (CAS, UC); Near Woodville, May 1889, *Howell 1387* (ORE); Northern California, 7 Apr 1937, *Javete s.n.* (OSC); Napa River Basin, Trail to beaux's Cabin, 25 Apr 1893, *Jepson s.n.* (UC); Near San Jaun Hot Springs, 6 Mar 1913, *Perkins s.n.* (RSA); Oakland, 1903, *Rattan s.n.* (DS); California, 1889, *Wright s.n.* (UC). MEXICO: **Baja California**: Elev. Of peak with microwave towers at 1275m, 32°19'N-116°40'W, collections made from peak to base (ca. 600m)., *Thorne et al. 62130* (CAS, RSA).

Key:

Key to the two species, *Pedicularis densiflora* and *P. aurantiaca*, adapted in part from the Jepson Manual (Vorobik 1993): Key to *Pedicularis* by Linda Ann Vorobik. Steps 4' is directly transcribed from the Jepson Key. It is intended that 7,7', 7a, and 7b fit directly into the existing key;

4'. Corolla $\pm$ club-like, upper labium hooded, not beaked; lower labium not fan-like

7. Corolla deep red to red-purple (or yellow to orange, occasionally white), lower labium $< 1/2$ upper

7a. Lower labium $> 1/3^{\text{rd}}$ as long as the abaxial margin of galea. Bracts of the inflorescence with serrate margins. Tube exserted beyond the calyx lobes at anthesis. *Pedicularis densiflora*

7b. Lower labium $1/6^{\text{th}}$ as long as the abaxial margin of galea. Bracts of the inflorescence partially laciniate. Tube not exerted beyond the calyx lobes at anthesis*Pedicularis aurantiaca*

7' Corolla yellowish or purplish, lower labium $>1/2$ upper

Pedicularis densiflora and *P. aurantiaca* remain an interesting and dynamic group for the evolutionary study of character evolution, pollinator mediated selection, host specificity for parasitism, and habitat preference. Future research should focus on pollination of the two species, and the potential adaptation of floral morphology to different pollination regimes. Additional genetic work in the form of more informative sequence data (perhaps a low copy nuclear gene) or AFLPs would help resolve relationships among populations of *P. densiflora* and *P. aurantiaca*. The inferred phylogeny could be used to investigate the number of times floral morphs arose, relationships among populations in different localities, and the evolution of pollinator shifts. *Pedicularis densiflora* and *P. aurantiaca* could be used to investigate theories of speciation, pollinator mediated selection, and the rapid radiation of angiosperms.

CHAPTER 2

PHYLOGENY AND POLLEN EVOLUTION OF *CANTUA* (POLEMONIACEAE SUBFAMILY COBAEOIDEAE): EVIDENCE FROM CHLOROPLAST AND NUCLEAR DNA SEQUENCE DATA

INTRODUCTION

Cantua Juss. is a member of the Polemoniaceae subfamily Cobaeoideae. It has approximately ten species distributed at mid to high elevations in the Andes of Bolivia, Peru, and Ecuador. Most of the species of *Cantua* are narrow endemics. The relatively small genus has a tremendous amount of floral diversity, with flowers varying in size, form, and color, and a variety of pollination syndromes. Bee, bird, and moth pollination are known or suspected within the genus. *Cantua* is one of the few genera of the Polemoniaceae that includes woody species, and the only genus that includes species with a tree habit. The pollen exine of *Cantua* species is pantoporate, with large tectal insulae, and is distinct from all other pollen grains in the family. The genus is the only member of the Polemoniaceae endemic to South America. One taxon, *Cantua buxifolia*, has the distinction of being the national flower of both Bolivia and Peru and was cultivated by the Incas and used to adorn temples.

One or two species of *Cantua* have been included in several molecular phylogenetic analyses in an attempt to understand the relationships within the Polemoniaceae and elucidate the relationships among lineages within the angiosperms (*matK* phylogeny in Steele & Vilgalys 1994, *matK* phylogeny in Johnson et al. 1996, nrITS phylogeny in Porter 1997, *NAD1B* phylogeny in Porter and Johnson 1998, 18S phylogeny in Johnson et al. 1999, and *ndhF* phylogeny in Prather et al. 2000). These molecular analyses have resolved the Core Cobaeoideae (*Bonplandia*, *Cantua* and *Cobaea*) as a monophyletic clade distinct from the Polemoniaceae with the exception of two studies: the *matK* phylogeny in Steele & Vilgalys (1994) and the nrITS phylogeny in Porter (1997). The

matK phylogeny had an unresolved polytomy at the base of the Polemoniaceae that included members of the Cobaeoideae. This polytomy was resolved in a later phylogenetic analysis based on a longer region of the *matK* gene and more extensive taxonomic sampling (Johnson et al. 1996). Porter's (1997) nrITS phylogeny lacked support in the basal nodes of the Core Cobaeoideae and relationships among genera changed depending upon taxon inclusion, character weighting, and alignments. Porter (1997; pg 67) commented that "it is difficult to argue that the ITS phylogeny is error free" in the relationships among the taxa that make up the Core Cobaeoideae. Overall, the molecular analyses provide sufficient evidence to accept that *Cantua* is a member of the Core Cobaeoideae and has a recent shared ancestry with *Bonplandia* and *Cobaea*. However, the relationships among the species of *Cantua* have not been explored.

In the most recent classification of the Polemoniaceae, based on both morphology and molecular phylogenetics, *Cantua* was placed in its own tribe in the subfamily Cobaeoideae, Tribe Cantueae. The authors subsumed the small genus *Huthia* into *Cantua* (Porter & Johnson 2000). The two species previously in *Huthia* have been renamed *C. volcanica* (Brand.) J. M. Porter & Prather (= *Huthia coerulea* Brand), and *C. mediamnis* (Brand) J. M. Porter & Prather (= *H. longiflora* Brand). There have been no molecular phylogenetic analyses to test the monophyletic status of the genus.

Previous work on pollen exine sculpturing in the Polemoniaceae indicated a congruent relationship between pollen morphology and inferred evolutionary history (Stuchlik 1967a, 1967b, and Taylor and Levin 1975). Several studies have examined pollen across

the family Polemoniaceae, including the Core Cobaeoideae (Stuchlik 1967a, 1967b, and Taylor and Levin 1975). Additional generic level studies have been conducted on members of the Cobaeoideae: Day and Moran (1986) described the pollen in *Acanthogilia gloriosa* (Brand.) Day & Moran; Prather (1999) did an extensive review of pollen in *Cobaea*, and a review of *Bonplandia geminiflora* pollen exine sculpturing is underway (Dickman and Prather, unpublished data). Until now, few species of *Cantua* pollen have been described (Stuchlik 1967a, 1967b, and Taylor and Levin 1975).

Pollen grains in flowering plants give rise to pollen tubes, which grow through the transmitting tissue of the style and into the ovary. Once the pollen tube reaches the ovary, male gametes are released and fertilization takes place. Delpino (see Darwin 1896; 250) hypothesized pollen grain diameter is a product of the length of the style and the energy storage requirements of the pollen tube to reach the ovary. Several researchers have investigated this potential connection between style length and pollen diameter (Lee 1978, Baker & Baker 1979, Cruden and Lyon 1985, Elisens 1986, Lee 1989, Cruzan 1990, Stroo 2000, Aguilar et al 2002). Plitmann and Levin (1983) tested the correlation between pollen grain diameter and style length in the Polemoniaceae. They measured mean style length and pollen diameter for 140 species in 18 genera across the family. Using Pearson's pair-wise correlations, they found a strong significant correlation within and among genera across the family. However, these results could be an effect of non-independence due to shared phylogenetic history instead of independent evolution (Cruden and Lyon 1985, Felsenstein 1985).

Plitmann and Levin (1983) sampled five *Cantua* specimens in their analysis of the Polemoniaceae. While they found a strong correlation between pollen diameter and style length within the family, and within other genera, they did not find a significant correlation within the genus *Cantua* ($r = 0.39$, $p\text{-value} > 0.05$). A broader sampling of the genus, a morphological review of the pollen, and a comprehensive phylogenetic hypothesis would add insight into the potential correlation between pollen diameter and style length among species of *Cantua*.

This study had three primary goals: Estimate a phylogeny of the genus *Cantua*, examine the pollen exine sculpturing of the species, and investigate the relationship between pollen diameter and style length in *Cantua* in a phylogenetic context. Sequences from the nuclear ribosomal ITS gene and the chloroplast spacers *trnT-trnL*, *trnL-trnF*, and partial *ndhF* coding region were used to generate a phylogenetic hypothesis of the genus. A comprehensive review of pollen grains across *Cantua* completed the pollen grain sampling within the Core Cobaeids. The pollen grain study was combined with the phylogenetic analysis to address evolution of exine sculpturing within the genus and directly test the phylogenetic utility of pollen morphology. Comparative analyses were conducted to further test the potential correlation between pollen diameter and style length in *Cantua*. To our knowledge this was the first attempt to examine the correlation between pollen diameter and style length within a phylogenetic context.

MATERIALS AND METHODS

Herbarium Specimens and sampling - A total of 903 herbarium specimens of *Cantua* were examined from the following herbaria: AAU, BM, CAS, DAV, DES, DS, F, G, GB, GH,H, HUT, JEPS, K, LL, LPB, MO, MSB, MSC, PH, QCNE, S, TEX, U, UC, UPS, and US. Permission was requested and granted to sample herbarium material for DNA extraction and/or scanning electron microscopy (SEM) and light microscopy of pollen grains from the following herbaria: F, HUH, LL, MO, MSB, MSC, NY, UC, and US. Specimens were chosen to represent the morphological and geographical variation of the species.

Individuals were used in the phylogenetic and pollen analysis from the following nine species: *C. bicolor*, *C. buxifolia*, *C. candelilla*, *C. cuzcoensis*, *C. flexuosa*, *C. pyrifolia*, *C. quercifolia*, *C. volcanica*, and an as yet undescribed species (Table 4 & 5). The tenth species, *Cantua mediamnis*, is known from only one collection and the material was unavailable for sampling.

Phylogenetic Analysis -

Sampling –Fresh leaf or floral material from either field-collected or greenhouse-grown material was sampled whenever possible. When fresh samples were unavailable, tissue was sampled, with permission, from herbarium material. For species with broad

Table 4: Voucher information for material used in the molecular phylogenetic analyses of *Cantua*.

Species	Voucher	Location
<i>Bonplandia geminiflora</i> Cav.	Crespo 255 (MSC)	Mexico: Estado Morelos
<i>Bonplandia geminiflora</i>	Cultivated	San Francisco State Univ.
<i>Cantua bicolor</i> Lem.	Beck , Kiesling & Metzinger 22154 (MSC)	Bolivia: Tarija
<i>Cantua buxifolia</i> Lam. (A)	Weigand 214 (MSB)	unknown
<i>Cantua buxifolia</i> (B)	Porter 12228 (MSC)	Peru: Junin
<i>Cantua buxifolia</i> (C)	Weigand & Skrabal 5883 (MSC)	Peru: Lima
<i>Cantua candelilla</i> Brand (A)	Cultivated	San Francisco State Univ.
<i>Cantua candelilla</i> (B)	Porter 12192 (RSA)	Peru: Arequipa
<i>Cantua cuzcoensis</i> Infantes	Porter 12227 (MSC)	Peru: Junin
<i>Cantua flexuosa</i> Pers. (A)	Porter 12224 (MSC)	Peru: Huancavelica
<i>Cantua flexuosa</i> (B)	Weigand & Skrabal 5862 (MSB)	Peru: Huancavelica
<i>Cantua n. sp.</i>	Weigand, Rodriguez, Förther & Dostert 915 (MSC)	Peru: Amazonas
<i>Cantua pyrifolia</i> Juss.	Porter 12168 (MSC)	Peru: Amazonas
<i>Cantua quercifolia</i> Juss (A)	Boeke 2206 (MSC)	Ecuador: Azuay
<i>Cantua quercifolia</i> (B)	Wrigley 2 (MSC)	Ecuador: Loja
<i>Cantua quercifolia</i> (C)	Weigand 808 (MSC)	Peru: La Libertad
<i>Cantua volcanica</i> (Brand) J. M. Porter & Prather (A)	Hodgson 7924 (F)	Peru: Arequipa
<i>Cantua volcanica</i> (B)	Porter 12199 (MSC)	Peru: Arequipa
<i>Cobaea minor</i> M. Martens & Galeotti	Prather 1575 (TEX)	Panama: Chiriqui
<i>Cobaea pachysepalala</i> Standl.	Prather 1522 (TEX)	Guatemala: Quezaltenango

Table 5. Voucher information for material used in palynological study.

analysis. In voucher column, * denotes specimens examined with SEM, † denotes specimens examined using light microscopy.

Species	Voucher	Location	Figure
<i>Cantua bicolor</i> Lem.	Cardenas 5479 (HUH)*†	Bolivia: Cochabamba	Fig. 16 F
<i>Cantua bicolor</i> †	Beck, Kiesling & Metzger 22154 (MSC)*†	Bolivia: Tarija	Fig. 16 E
<i>Cantua buxifolia</i> Lam.	Gentry, Smith & Tredwell 37515 (MO)*†	Peru: Pasco	
<i>Cantua buxifolia</i>	Lopez & Sagastegui 8023 (LL)*†	Peru: La Libertad	
<i>Cantua buxifolia</i>	Plowman & Davis 4653 (HUH)*†	Peru: Ayacucho	
<i>Cantua buxifolia</i> †	Porter 12228 (MSC)*	Peru: Junin	
<i>Cantua buxifolia</i>	Bols 2053A(HUH)*†	Bolivia: La Paz	Fig. 17 A & B
<i>Cantua candelilla</i> Brand	Hutchison 1252 (UC)*†	Peru: Ayacucho	
<i>Cantua candelilla</i>	Hutchison & Wright 7235 (UC)*†	Peru: Arequipa	Fig. 16 D & E
<i>Cantua cuzcoensis</i> Infantes	Vargas 9785 (MO)*†	Peru: Cuzco	
<i>Cantua cuzcoensis</i> †	Porter 12227 (MSC)*	Peru: Junin	Fig. 16 C & D
<i>Cantua cuzcoensis</i>	Balls B6903 (UC)*†	Peru: Apurimac	
<i>Cantua flexuosa</i> Pers.	Gentry, Smith & Tredwell 37518 (NY)*†	Peru: Pasco	
<i>Cantua flexuosa</i> †	Porter 12224 (MSC)*	Peru: Huancavelica	Fig. 16 A
<i>Cantua flexuosa</i>	Beck 1349 (MSC)*†	Bolivia: La Paz	Fig. 16 B
<i>Cantua n. sp.</i>	Knapp & Alcorn 7556 (NY)*†	Peru: Amazonas	
<i>Cantua n. sp.</i>	Leiva, Chuna & Cadle 1419 (F)*†	Peru: Cajamarca	Fig. 17 E & F
<i>Cantua pyriformis</i> Juss.	Hitchcock 21580 (HUH)*†	Ecuador: Azuay	
<i>Cantua pyriformis</i>	Sagastegui & Cabanillas 8560 (MO)*†	Peru: Piura	
<i>Cantua pyriformis</i>	Van der Werff & Palacios 8891 (NY)*†	Ecuador: Loja	Fig. 17 C & D
<i>Cantua pyriformis</i>	Woytkowski 7670 (HUH)*†	Peru: Amazonas	
<i>Cantua pyriformis</i> †	Porter 12168 (MSC)*	Peru: Amazonas	
<i>Cantua pyriformis</i>	Camp 4280 (NY)*†	Ecuador: Azuay	
<i>Cantua quercifolia</i> Juss. †	Wrigley 2 (MSC)*†	Ecuador: Loja	Fig. 18 C
<i>Cantua quercifolia</i>	Hutchison & Wright 3482 (HUH)*†	Peru: Lambayaque	Fig. 18 D
<i>Cantua volcanica</i> (Brand) J. M. Porter & Prather	West 7139 (MO)*†	Peru: Arequipa	
<i>Cantua volcanica</i>	Vargas 19918 (US)*†	Peru: Arequipa	
<i>Cantua volcanica</i> †	Porter 12199 (MSC)*	Peru: Arequipa	Fig. 18 A & B

distributions and/or high levels of intraspecific morphological variation, several geographically and/or morphologically distinct individuals were sampled (Table 4). Nineteen samples were included in the phylogenetic analyses. I used two sequences of the internal transcribed spacer region of nuclear ribosomal DNA (ITS) from outgroup species that were previously published. The taxa and their GenBank accession numbers are as follows: *Cobaea minor* (AH005678) and *Cobaea pachysepala* (AH005690). Additional sequences were made available for *Bonplandia geminiflora*, *Cantua volcanica*, *Cobaea minor*, and *Cobaea pachysepala* by David C. Jarrell and L. Alan Prather (unpublished data).

Outgroup - *Bonplandia geminiflora* and two species of *Cobaea*: *C. minor* and *C. pachysepala* were chosen as outgroups based on the *ndhF* phylogeny of Prather et al. (2000).

Phylogenetic Analysis - DNA was extracted using the techniques of Loockerman and Jansen (1996) and purified using the Schleicher & Schuell Elu-quick DNA Purification Kit (Keene, NH). Three sets of chloroplast primers were used: *trnT* - *trnL* 5' primers from Fujii et al. (1997), *trnL* 3' - *trnF* primers from Taberlet et al. (1991), and primers for a partial *ndhF* coding region using the 1201 forward primer of Jansen (1992) and a reverse primer designed for this analysis. The sequence of the *ndhF* reverse primer is as follows: 5'-GTAGTAAATTACTAAAAAGATTRATAC-3'. Additional internal primers were designed to amplify the *trnT* - *trnL* intergenic spacer. The forward primer was 5'-AGCTAAGCGGGCTCACATAA-3', and the reverse primer sequence was 5'-

TGTGATGTCCTTTCCCCTTT-3'. ITS1, ITS2, and the 5.8S regions of nuclear ribosomal DNA were amplified using ITS-4 primers of White et al (1990) and the modified ITS-5 primer of Sang et al. (1995).

Standard amplification protocols were used, including reaction mixture components and the PCR profile (Prather et al. 2002), and amplifications were performed on a MJ Research PTC-100 thermalcycler. PCR products were gel purified using the Schleicher & Schuell Elu-quick DNA Purification Kit, (Keene, NH) and then sequenced in both directions using an ABI-373 automated sequencer. Sequencing reactions were conducted using the AmpliTaq DNA Dye Terminator Cycle Sequencing reagents (PE Applied Biosystems, Norwalk, CT).

Edited sequences were aligned using Sequencher 3.0 (Gene Codes Corporation, Ann Arbor, MI). Termini of the *trnT-trnL* intergenic spacer region and *trnL-trnF* intergenic spacer region were determined from Fujii et al. (1995) and Morrell et al. (1998), respectively. Termini of ITS1, ITS2, and the 5.8S regions of nuclear ribosomal DNA were determined by comparison with published sequences of Prather and Jansen (1998). The segment of *ndhF* used for the analysis began at the 1244th base pair of tobacco (Olmstead et al. 1993).

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simony methods were implemented using PAUP* (Version 4.0b4; Swofford 2000).
Heuristic searches were performed using the TREE BISECTION RECONNECTION, and
MULTREES options. All insertion/deletion events, displayed as gaps in the data set,

were treated as characters using the “Simple Indel Coding” method outlined by Simmons and Ochoterena (2000). Bootstrap analyses were conducted using 10,000 replicates with 200 random addition-sequence replicates per bootstrap replicate. A partition homogeneity test, using 10,000 replicates, was conducted to test for homogeneity in the distribution of phylogenetic information between the nuclear and chloroplast data sets.

A second analysis was conducted to determine branch lengths for the independent contrast of pollen grain diameter and style length. This analysis included only one sample of each taxon. The sample was chosen by selecting the species with the most complete sequences for both the chloroplast and nuclear molecular data sets. All insertion/deletion events, displayed as gaps in the data set, were treated as missing data. Branch lengths were determined using the MinF option in PAUP* (version 4.0b4; Swofford 2000, Swofford and Maddison 1987). Sequence termini, parsimony methods, heuristic searches, and bootstrap analysis were identical to the analysis described above.

Pollen Analysis -

Pollen Grain Morphology and Style Length - For the SEM study, I examined the pollen morphology of 28 individuals of nine species of *Cantua*. For each taxon, at least two individuals were sampled from different parts of their geographical range (Table 5).

Pollen preparation for the SEM was conducted using the methods of Prather (1999).

Unopened anthers were removed from herbarium specimens, boiled in water until the

pollen was released, and acetolyzed using the methods of Adams and Morton (1972).

Macerations and critical drying point were omitted. Specimens were mounted on stubs,

coated with 60% palladium and 40% gold, and examined using a JEOL 6400V scanning electron microscope at the Center for Electron Optics at Michigan State University.

Light microscopy was used to measure pollen diameter and style length on a minimum of two populations for each species. Twenty three populations were sampled for a total of 555 pollen grains and 90 individual styles (Table 5, Appendix I). Whenever possible, 30 pollen grains from each population were sampled. Number of styles measured per collection varied from 1-8.

Pollen grains were removed from two dehiscing anthers on herbarium specimens and stained in Cotton-blue with lactophenol for at least 24 hours prior to measurement. This assured that all pollen grains had absorbed the stain and were fully hydrated. Pollen grains were measured with a calibrated eyepiece micrometer under 400X magnification. Only fully stained, intact pollen grains were measured. All available styles, from fully developed, non-senescing flowers were measured on all duplicates of the same collection number. Measurements were made using digital calipers and recorded to the nearest 0.01 mm.

Style Length and Pollen Diameter Correlation—Traits in related species are not independent. Closely related species may share common traits due to shared ancestry rather than independent evolution. To remove the issue of non-independence in data sets comparative methods have been developed to examine relationships among pairs of continuous traits while accounting for potential effects of shared evolutionary history. To

assess the relationship between style length and pollen diameter, the independent contrasts method of Felsenstein (1985) was implemented using the Comparative Analysis of Independent Contrasts (CAIC; Purvis and Rambaut 1995). CAIC is suitable for analyzing comparative data on continuous characters and can accept polytomies in a phylogeny.

Mean values were calculated for pollen diameter and style length for each species, and log-transformed before analysis. In the independent contrasts analysis, two types of data were used. The raw data set assumed every branch in the phylogeny was of equal length indicating equal amounts of evolutionary change between speciation events. The raw data analysis assumed a punctuational view of evolution with evolutionary change occurring only at the nodes. The transformed data set utilized branch lengths from the phylogenetic analysis as expected units of evolutionary change between speciation events; this data analysis assumed a gradualistic view of evolution with evolutionary change occurring along the branches between speciation events. CAIC does not accept branch lengths less than 2, so all branch lengths were multiplied by 2 to fulfill the program requirements (Purvis and Rambaut 1995). Both the raw and transformed data sets were checked to assure they conformed to the assumptions of regression models: that the residual variation around the regression line has equal mean and variance at all points on the line.

In the output, CAIC computes the standardized linear contrasts for the traits in the analysis and forces the regression of the standardized linear contrasts through the origin. CAIC computes a slope and the significance of the linear contrasts. The value of the

slope describes the relationship between pollen diameter and style length based on independent contrasts (Purvis and Rambaut 1995). An additional analysis of the correlation of standardized linear contrasts was computed using the JMP statistical package (SAS Institute Inc., Cary, NC) for a direct comparison to the results reported by Plitmann and Levin (1983) who performed a Pearson pair-wise correlations correlation on non-independent data. The resultant correlation, like the slope in the regression analysis, is representative of the relationship between pollen grain diameter and style length minus phylogenetic effects (Pagel 1993).

RESULTS

Phylogenetic Analysis – In the data set excluding insertion/deletion events (indels), the aligned ITS sequences were 660 bp long, with a total of 201 potentially phylogenetically informative characters. Phylogenetic analyses of the nucleotide data resulted in 15 most parsimonious trees with a length of 437, C.I.^c = 0.7889, and R.I. = 0.8783. Forty-five indels were scored and appended to the ITS nucleotide data, 25 of those characters were potentially phylogenetically informative. The analysis of the data set including indels resulted in 15 most parsimonious trees with a length of 489, C.I.^c = 0.7882, and R.I. = 0.8783 (Figure 12). Tree topologies were identical for the analyses including and excluding the indel characters.

A clade comprising all members of the genus (Clade A, Fig. 12), including *C. volcanica* (formerly *Huthia*), had strong (100%) bootstrap support. Likewise, two major clades within *Cantua* were strongly supported: One clade consisting of *Cantua volcanica* and *C. quercifolia* (96%) and a second clade which encompasses the remaining *Cantua* species (100% bootstrap support). Relationships within the second clade had weak bootstrap support with the exception of the *Cantua pyrifolia* / *C. n. sp.* clade which had strong bootstrap support (100%).

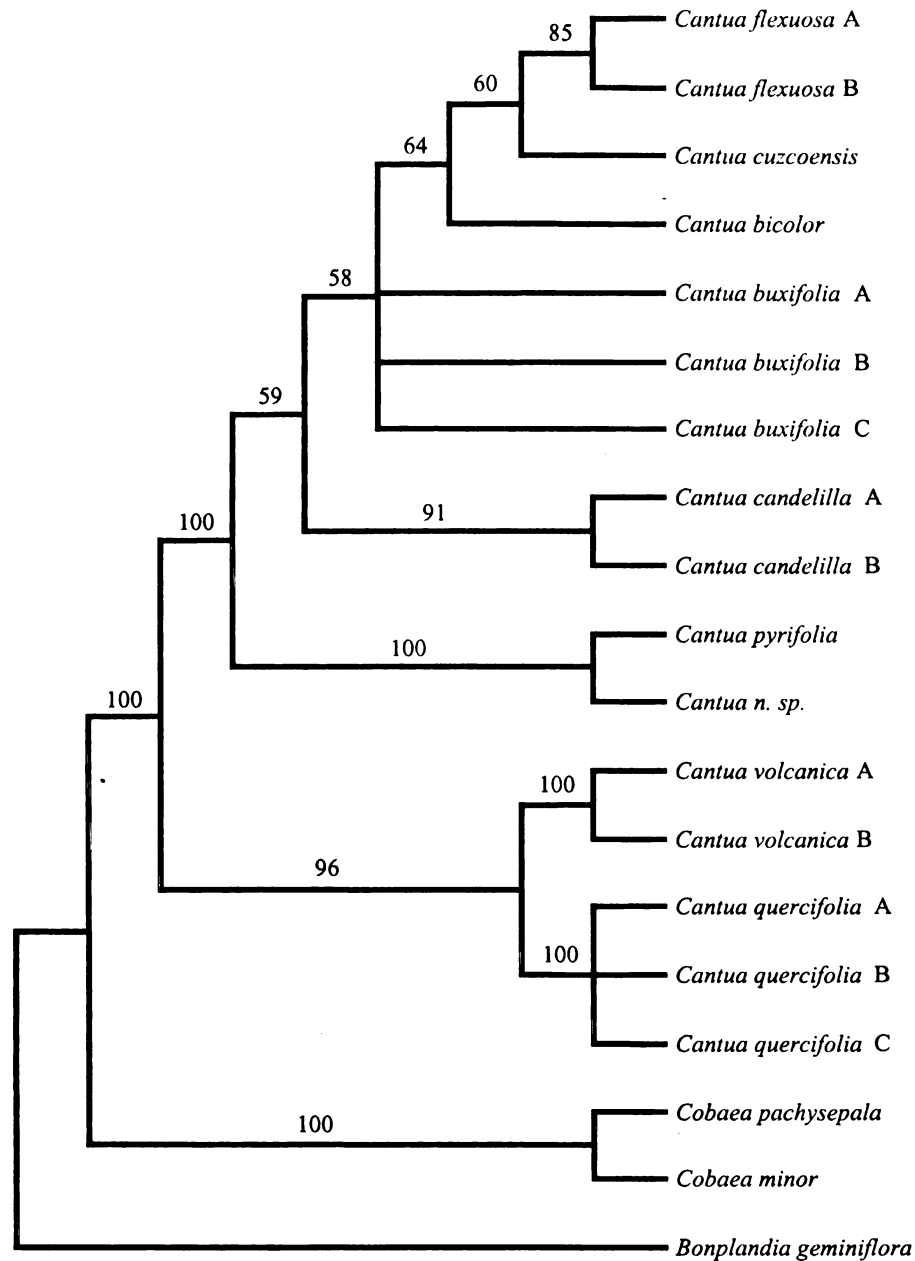


Figure 12: Strict consensus of 15 most parsimonious trees based on the *Cantua* total ITS data set including nucleotide substitutions and indels. Tree length = 489, with a C.I.^c = 0.7882 and R.I. = 0.8783. Numbers above the branches represent bootstrap support based on 10,000 replicates. Location and voucher information for each sample is available in Table 4.

Multiple taxa from the same species were in exclusive clades with strong bootstrap support (*C. flexuosa* 85%, *C. candelilla* 91%, *C. volcanica* 100%, and *C. quercifolia* 100%) with the exception of the three individuals of *C. buxifolia*, which had unresolved relationships at the base of a clade including *C. bicolor*, *C. cuzcoensis* and *C. flexuosa*.

In the data set excluding indels, the aligned sequences from the *trnT-trnL* intergenic spacer were 642 bp long with 18 potentially phylogenetically informative characters. Parsimony analysis resulted in 207 most parsimonious trees with a length of 63, a C.I.^c = 0.9524, and a R.I. = 0.9697. The data set had five insertion-deletion events, one of which was potentially phylogenetically informative. Phylogenetic analysis of the data set including indels resulted in 441 most parsimonious trees with a length of 68, a C.I.^c = 0.9545 and a R.I. = 0.9714. I was unable to amplify *Cantua flexuosa* B (Weigand 5862, see Table 4) and it was not included in *trnT-trnL* analyses. Analyses of the data, both including and excluding the indels, yielded a consensus trees with no resolution among the species of *Cantua*.

In the data set excluding indels, the *trnL-trnF* intergenic spacer was 448 bp long with 13 potentially phylogenetically informative characters. The parsimony analysis of the nucleotide data set resulted in three most parsimonious trees, with a length of 48, a C.I.^c = 1.0, and a R.I. = 1.0. There were 14 insertion-deletion events, 9 of which were potentially phylogenetically informative. Analyses of the data set including indels found ten most parsimonious trees, with a length of 65, C.I.^c = 0.8846 and a R.I. = 0.9348. Analyses of the data set both including and excluding indels, had some resolution and

concordant topologies. The analysis of the data set including indels had more resolution within *Cantua*.

The aligned sequences from the partial *ndhF*-coding region were 938 bp long, with 59 potentially phylogenetically informative characters. Two most parsimonious trees resulted from the analysis and each had a length of 119, a C.I.^e = 0.9444 and a R. I. = 0.9690. No indels were present and the strict consensus tree showed some inter- and intraspecific resolution.

The chloroplast data sets including indels were combined for a total of 2047 bp and 19 indels with 100 parsimony informative characters (Figure 13). Two most parsimonious trees were generated, with a length of 256, a C.I.^e = 0.9032, and a R.I. = 0.9429. The monophyly of *Cantua*, including *C. volcanica*, had strong support (100%). *Cantua volcanica* and *C. quercifolia* were strongly supported (97%) as sister taxa, and together they were sister to the remainder of the genus (96% bootstrap support). A clade comprising *Cantua buxifolia* (A & B), *C. pyrifolia* and *C. n. sp.* had weak bootstrap support (73%). The clade containing *C. buxifolia* A & B was moderately supported (75%) and sister to a well supported clade containing *C. pyrifolia* and *C. n.sp.* (97%). *Cantua flexuosa* A & B, *C. buxifolia* C, both samples of *C. candelilla* A & B, *C. cuzcoensis*, and *C. bicolor* had strong bootstrap support (84%). The clade including *C. buxifolia* and *C. candelilla* A & B had moderate bootstrap support

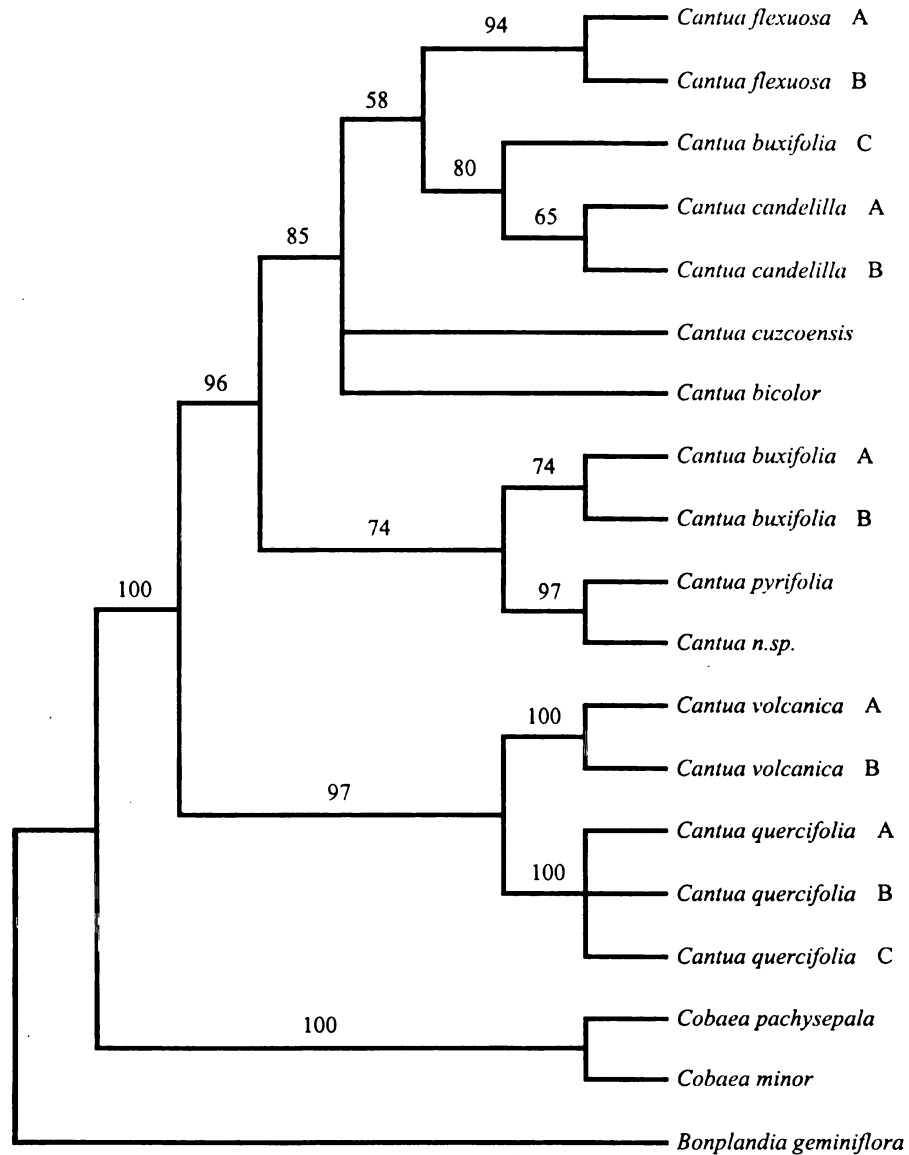


Figure 13: Strict consensus of two most parsimonious trees based on the *Cantua* combined chloroplast sequences (*trnT-trnL*, *trnL-trnF*, partial *ndhF*) for the data sets including indels. Tree length = 256, C.I.^c = 0.9032 and a R.I. = 0.9429. Numbers above the branches represent bootstrap support based on 10,000 replicates.

(81%). With the exception of *C. buxifolia* which is paraphyletic in the phylogeny, multiple taxa from the same species were in exclusive clades with strong bootstrap support (*C. flexuosa* 77%, *C. candelilla* 66%, *C. volcanica* 100%, and *C. quercifolia* 100%).

When the data sets including indels from the nuclear and chloroplast genomes were combined, the null hypothesis of homogeneity in distribution of phylogenetic information between the data sets based on the partition homogeneity test was rejected ($p = 0.0127$). The data set was reviewed and the relationships of *C. buxifolia* in the nuclear and chloroplast phylogenies were not concordant. In the ITS phylogeny (Fig 12), *Cantua buxifolia* was part of an unresolved polytomy at the base of a clade including *C. bicolor*, *C. cuzcoensis* and *C. flexuosa*. In the chloroplast phylogeny (Fig. 13), *C. buxifolia* C was sister to a clade with *C. candelilla*, but *C. buxifolia* A & B were sister to the clade containing *C. pyrifolia* and the *C. n. sp.* *Cantua buxifolia* has a high level of intraspecific morphological variation and has been cultivated throughout much of Andean South America for centuries. The likelihood of hybridization is high, and is a likely explanation for the lack of congruence between the chloroplast and nuclear phylogenies. The specimen of *C. buxifolia* C had different relationships within *Cantua* in the chloroplast DNA and nuclear DNA phylogenies. This sample was removed from both data sets and a second partition homogeneity test was run. This test did not reject the null hypothesis of homogeneity among data sets ($p = 0.2529$).

The total combined data set including indels had 2752 total characters: 2688 nucleotides and 64 indels. The data set had 324 potentially phylogenetically informative characters. Four most parsimonious trees resulted from the analysis, each with a tree length of 741, a C.I.^c = 0.8133, and a R.I. = 0.8903. A strict consensus tree was generated (Figure 14). The monophyly of *Cantua* was strongly supported (100%). The sister relationship between *C. quercifolia* and *C. volcanica* had strong bootstrap support (99%). All remaining *Cantua* taxa are included in a strongly supported clade (100% bootstrap support). *Cantua pyrifolia* and *C. n. sp.* are strongly supported as sister taxa (100% bootstrap support) in a polytomy at the base of the clade including the remaining *Cantua* species. *Cantua candelilla*, *C. bicolor*, and *C. cuzcoensis*, had weak bootstrap support (71%). A monophyletic group of *Cantua bicolor*, *C. cuzcoensis*, and *C. flexuosa*, had moderate support (81%). In this phylogenetic analysis, with the removal of *C. buxifolia* C, multiple taxa from the same species were in exclusive clades with strong bootstrap support (*C. quercifolia* 100%, *C. volcanica* 100%, *C. buxifolia* 79%, *C. candelilla* 100%, and *C. flexuosa* 97%).

The tree estimated for the independent contrasts, with only one sample per species, had 2688 total characters (Figure 15). The data set had 210 potentially phylogenetically informative characters. A single most parsimonious tree resulted from the analysis, with a length of 650, a C.I.^c = 0.7771, and a R.I. = 0.7869. The tree topology did not conflict between the tree from the total combined data set and the tree estimated for the comparative analysis, with one exception, in the tree estimated for the comparative analysis a sister relationship was resolved between *C.*

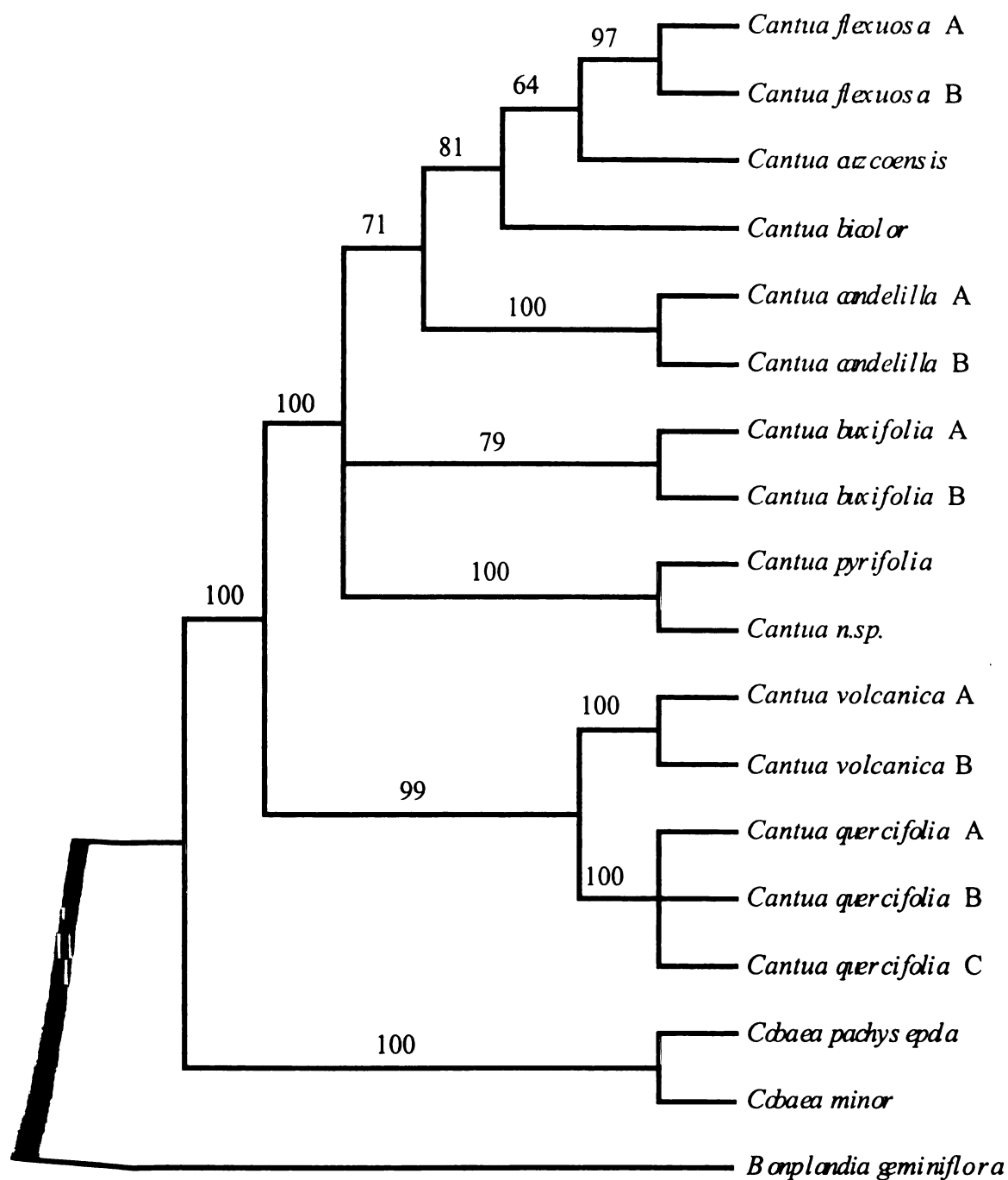


Figure 14: Strict consensus of four most parsimonious trees based on the *Cantua* combined chloroplast (*trnT-trnL*, *trnL-trnF*, and partial *ndhF*) and nuclear ITS sequences for the data set including indels. Tree length = 747, C.I.^e = 0.8133 and a R.I. = 0.8903. Numbers above the branches represent bootstrap support based on 10,000 replicates.

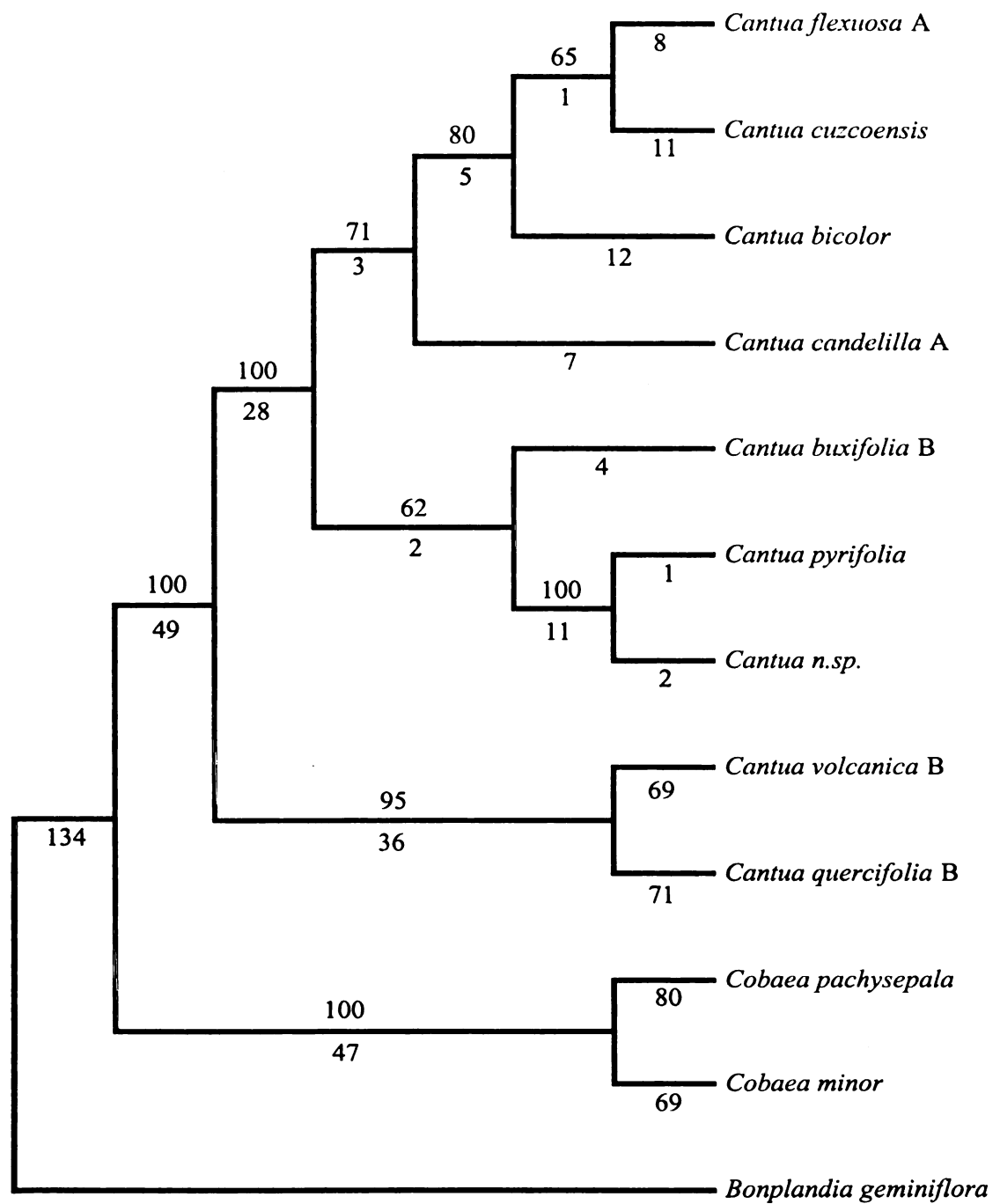


Figure 15: *Cantua* tree estimated for comparative analysis. Single most parsimonious tree based on the modified data set of chloroplast (*trnT-trnL*, *trnL-trnF*, partial *ndhF*) and nuclear ITS sequences excluding indels. Tree length is 650, with a C.I. = 0.7771 and a R.I. = 0.7869. Numbers above the branches represent bootstrap support based on 10,000 replicates, numbers below the branches indicate branch lengths based on the MINF option in Paup*.

buxifolia and *C. pyrifolia*/*C. n.sp.* This relationship, however, was weakly supported (bootstrap support of 62%).

Pollen Morphology

Description of Cantua Pollen – *Cantua* grains were large (49-93µm), spheroidal and pantoporate with mean pore size ranging from 3.78-14.4µm. The sexine was semitectate with irregularly shaped insulae, and insulae were evenly distributed over the surface of the pollen grain, with the exception of *C. flexuosa* where they were more sparsely and haphazardly distributed. Bacula were reticulate and the supratectal surfaces striated in all species. *Cantua quercifolia* and *C. volcanica* shared a synapomorphy of supratectal verrucae. A pollen diagnosis for each of the species of *Cantua* is given below (Figures 16, 17, & 18).

Cantua flexuosa (Figure 16, A & B). Pantoporate. Pollen grain spheroidal, 58 – 83 µm in diameter. Pores circular, 4.66-6.29 µm in diameter. Sexine semitectate (insulous). Insulae irregular in shape, haphazardly distributed with considerable, irregular intratectal space. Bacula reticulate. Supratectal surface deeply striated.

Cantua cuzcoensis (Figure 16, C & D). Pantoporate. Pollen grain spheroidal, 63-81 µm in diameter. Pores circular, 4.62-7.94 µm in diameter. Sexine semitectate (insulous). Insulae irregular in shape, evenly distributed. Bacula reticulate. Supratectal surface deeply striated.

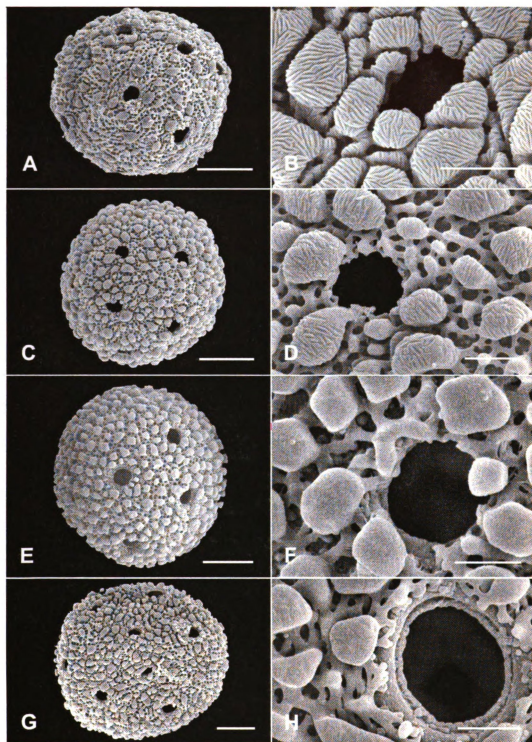


Figure 16. (A-H) SEM photographs of pollen grains of *Cantua* species (Polemoniaceae): (A & B) *C. flexuosa*; (C & D) *C. cuzcoensis*; (E & F) *C. bicolor*; (G & H) *C. candelilla*. Scale bars = 25 µm (A, C, E, & G) & 5 µm (B, D, F, & H). Voucher information available in Table 5.

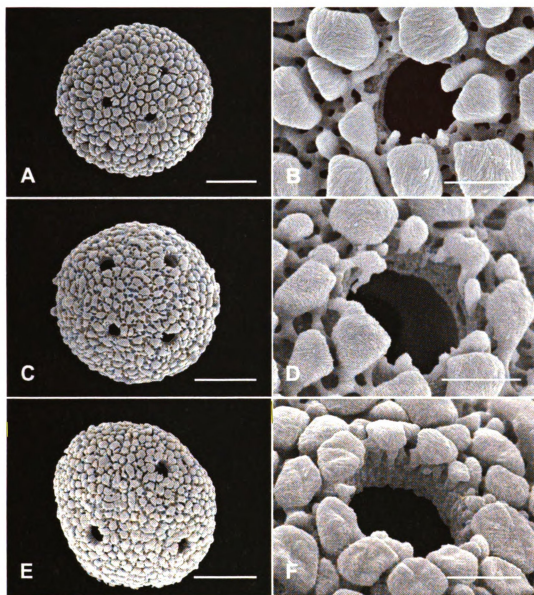


Figure 17. (A-F) SEM photographs of pollen grains of *Cantua* species (Polemoniaceae): (A & B) *C. buxifolia*; (C & D) *C. pyrifolia*; (E & F) *C. n. sp.*. Scale bars = 25 μ m (A, C, & E) & 5 μ m (B, D, & F).

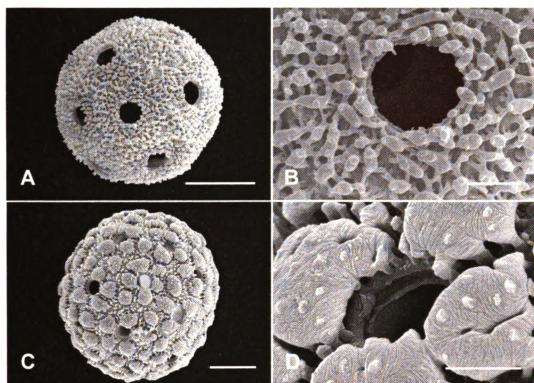


Figure 18. (A-D) SEM photographs of pollen grains of *Cantua* species (Polemoniaceae): (A & B) *C. volcanica* (C & D) *C. quercifolia*. Scale bars = 25 μm (A & C) & 5 μm (B & D).

Cantua bicolor (Figure 16, D & E). Pantoporate. Pollen grain spheroidal, 51.5-78.5 μm in diameter. Pores circular, 7.40-9.32 μm in diameter. Sexine semitectate (insulose). Insulae irregular in shape, evenly distributed. Bacula reticulate. Supratergal surface faintly striated.

Cantua candelilla (Figure 16, F & G). Pantoporate. Pollen grain spheroidal, 75.5-90.5 μm in diameter. Pores circular, 3.90-9.00 μm in diameter. Sexine semitectate (insulose). Insulae irregular in shape, evenly distributed. Bacula reticulate. Supratergal surface faintly striated.

Cantua buxifolia (Figure 17, A & B). Pantoporate. Pollen grain spheroidal, 49-89 μm in diameter. Pores circular, 3.78-11.11 μm in diameter. Sexine semitectate (insulose). Insulae irregular in shape, evenly distributed to randomly distributed with considerable, irregular intratergal spaces. Bacula reticulate. Supratergal surface faintly striated.

Cantua pyrifolia (Figure 17, C & D). Pantoporate. Pollen grain spheroidal, 64-86 μm in diameter. Pores circular, 4.86-14.4 μm in diameter, considerable variation in pore size among individual samples. Sexine semitectate (insulose). Insulae irregular in shape, evenly distributed. Bacula reticulate, density of bacula variable among individuals sampled. Supratergal surface faintly striated.

Cantua n. sp. (Figure 17, E & F). Pantoporate. Pollen grain spheroidal, 67-81 μm in diameter. Pores circular, 6.30-7.56 μm in diameter. Sexine semitectate (insulose).

Insulae irregular in shape, evenly distributed. Bacula reticulate with occasional stray free bacula. Supratectal surface faintly striated.

Cantua volcanica (Figure 18, A & B). Pantoporate. Pollen grain spheroidal, 54-69 μm in diameter. Pores circular, 4.10-8.22 μm in diameter, considerable variation in pore size among individual samples. Sexine semitectate (insulose). Insulae elongated, evenly distributed. Bacula reticulate with occasional stray free bacula. Supratectal surface faintly striated with supratectal verrucae.

Cantua quercifolia (Figure 18, C & D). Pantoporate. Pollen grain spheroidal, 78.5-93 μm in diameter. Pores circular, 5.38-8.62 μm in diameter, considerable variation in pore size among individual samples. Sexine semitectate (insulose). Insulae circular, evenly distributed. Stray free bacula. Supratectal surface faintly striated with supratectal verrucae.

Pollen Trait Evolution-Pollen grains in *Cobaea* have been extensively reviewed (Prather 1999) and an analysis of pollen in *Bonplandia geminiflora* is currently underway (Dickman and Prather, unpublished data). *Cobaea* pollen grains are pantoporate and spheroidal. The grains are large (112-195 μm) and have a reticulate sexine. The grains of the monotypic genus *Bonplandia* are also spheroidal and pantoporate. The grains are smaller in *Bonplandia* (60 μm) and the sexine is striato reticulate.

Cantua grains were large (49-93 μ m), spheroidal and pantoporate, these traits are shared with the two outgroup taxa (*Cobaea* and *Bonplandia*). *Cantua* pollen grains share synapomorphic characters not present in the outgroup taxa: semitectate sexine with irregularly shaped insulae and reticulate bacula. *Cantua quercifolia* and *C. volcanica* shared a synapomorphy of supratectal verrucae (Figure 19).

Style Length and Pollen Grain Diameter Correlation—Raw data (Table 6) did not conform to the assumption for regression analysis of equal variance of residuals (p-value < 0.05). When the data were transformed, and branch length data were utilized, data conformed to all the assumptions of the analysis. The transformed analyses did not suggest a significant relationship between pollen grain diameter and style length based on the regression of standardized linear contrasts through the origin ($r^2 = 0.07$, slope = -0.05, p-value = 0.48). Standardized linear contrasts were analyzed on the transformed data using Pearson pair-wise correlations and the resultant correlation values were insignificant (-0.23 Pearson's pair-wise correlation, p-value = 0.58).

Table 6. Pollen diameter and style length of *Cantua* taxa included in the analysis. Whenever possible, 30 pollen grains from each population were sampled. Total number of styles per collection varied from 1-10.

Species	Number of populations measured	<u>Style length (mm)</u>		<u>Pollen diameter (μm)</u>	
		Mean	Range	Mean	Range
<i>Cantua bicolor</i>	2	39.24	35.21-42.69	67.31	51.45-78.40
<i>Cantua buxifolia</i>	4	68.98	35.02-80.30	74.31	49.00-85.75
<i>Cantua candelilla</i>	2	65.69	56.86-73.95	81.96	73.50-90.65
<i>Cantua cuzcoensis</i>	2	53.54	48.50-57.96	72.80	63.70-80.85
<i>Cantua flexuosa</i>	2	34.10	30.92-39.67	71.34	58.80-83.30
<i>Cantua n. sp.</i>	2	42.78	38.27-45.95	75.91	68.60-80.85
<i>Cantua pyrifolia</i>	5	32.98	24.96-46.77	77.23	63.70-85.75
<i>Cantua quercifolia</i>	2	42.49	39.87-52.13	85.94	78.40-93.10
<i>Cantua volcanica</i>	2	21.16	16.42-24.62	62.45	53.90-68.60

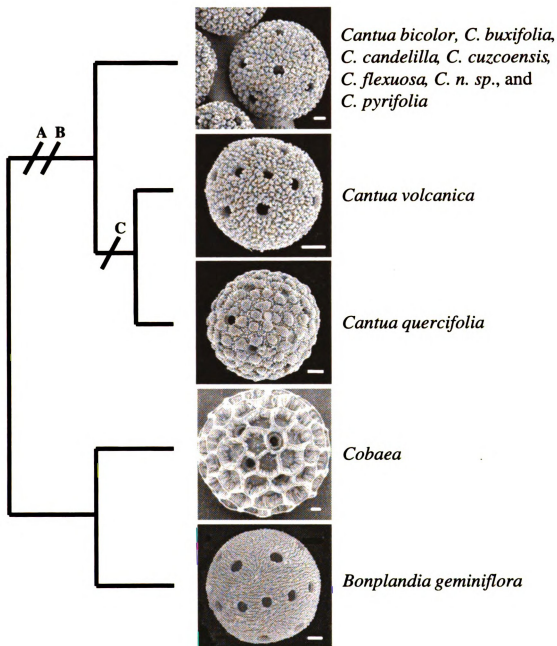


Figure 19. Diagram representing phylogenetic relationships found in the analysis of the *Cantua* combined chloroplast (*trnT-trnL*, *trnL-trnF*, partial *ndhF*) and nuclear ITS sequences and represented in Figure 14. Slash marks on the tree branches represent synapomorphic characters: A. semitectate sexine with irregularly shaped insulae, B. reticulate bacula, C. supratectal verrucae. Representative pollen grains are shown at the tree tips: *Bonplandia geminiflora* (Rzedowski 18144), *Cobaea* (*C. trianae*; Panero & Clark 3044), *Cantua quercifolia* (Wrigley 2), *Cantua volcanica* (West 7139), and seven remaining *Cantua* (*Cantua bicolor*; Cardenas 5479). Scale bar = 10 μ m

CONCLUSIONS

The phylogenetic analysis of the nuclear ribosomal ITS and chloroplast *trnT-trnL*, *trnL-trnF* and *ndhF* regions in *Cantua* strongly supported the inclusion of the two species formerly placed in *Huthia* and verified the monophyly of the genus *Cantua*. *Cantua volcanica* (= *Huthia coerulea*) was most closely related to *C. quercifolia*. These two species were the sister group to the rest of *Cantua*. *Cantua flexuosa*, *C. cuzcoensis*, *C. bicolor*, *C. candelilla*, *C. buxifolia*, *C. pyrifolia* and *C. n. sp* were closely related and *C. pyrifolia* was sister to *C. n. sp*. Relationships between *C. buxifolia* and the other species in the clade were unresolved. The monophyly of *C. buxifolia* and its relationship to the other members of the genus *Cantua* could be investigated further with additional sampling within *C. buxifolia* and more informative molecular sequences. The work outlined here is an important link into research on the evolution of the Cobaeoideae and part of a large ongoing project to monograph the subfamily.

Pollen morphological work in *Cantua* supported the findings from the molecular phylogenetic analysis. Pollen characteristics within *Cantua* were highly conserved, pollen morphology examined was consistent within populations and among species. All nine species of *Cantua* have spheroidal pantoporate pollen with a semitectate sexine and insulae. This is a shared derived characteristic in the Polemoniaceae, giving further support to the subsumption of *Huthia* and the monophyly of the genus. The relationship between *C. quercifolia* and *C. volcanica* was supported by the synapomorphy of supratectal verrucae on the sexine of the pollen grains. The pollen work in *Cantua* confirms that pollen grain morphology is highly conserved and a valuable morphological

character for cladistic analysis. In addition, this research completes a comprehensive review of pollen grain morphology within the subfamily Cobaeoideae.

Plitmann and Levin (1983) addressed the potential relationship between pollen diameter and style length in a correlation analysis across the Polemoniaceae. They found a strong significant correlation between the traits within and among genera in the family. The results from their analysis supported the hypothesis of Delpino (Darwin 1896); pollen grain diameter is functionally integrated with style length. Lack of independence in the data set may have confounded the results of Plitmann and Levin's research. Data were collected from several groups of related species within the Polemoniaceae, and could be affected by non-independence due to shared evolutionary history (Cruden and Lyon 1985, Felsenstein 1985, and Harvey and Pagel 1991).

Plitmann & Levin (1983) found a non-significant correlation between pollen diameter and style length in five of the ten species of *Cantua*. My research was designed to address the correlation question using a comprehensive sample of the *Cantua* species and pairwise independent comparisons of the traits. I almost doubled the representative species used in the previous study, included the recently subsumed *C. volcanica*, and used independent contrasts to control for the effects of shared ancestry. Independent contrasts would not result in a correlation which was not present in the non-independent data. However, the increased, more inclusive sampling could result in a correlation and the independent contrasts would be necessary to address the non-independence of data in the *Cantua* data set. The results from my analysis of *Cantua* and the analysis of Plitmann

and Levin (1983) are consistent. Neither significant regression nor correlation was found in the genus *Cantua*, which failed to find a relationship between the diameter of the pollen grain and the length of the style in *Cantua*.

This comprehensive phylogenetic analysis of *Cantua* provided insight into relationships within the genus and confirmed the monophyly of the group. The investigation into pollen grain morphology substantiated the subsumption of *Huthia* into *Cantua* and provided further evidence for the monophyly of the genus. Both the pollen grain morphology and the phylogenetic analyses supported the relationship between *C. volcanica* and *C. quercifolia*. This pollen work also confirmed that pollen grain morphology is highly conserved and a valuable morphological character for cladistic analysis in *Cantua*. Despite comprehensive sampling and a well-supported phylogenetic hypothesis, pollen diameter and style length were found to be unrelated in *Cantua*. The work on pollen grain diameter and style length is the first step in a family-wide comparison of this correlation using independent contrasts to control for the effects of shared ancestry. The study outlined here is an important link into research on the evolution of the Cobaeoideae, molecular analysis using the same chloroplast and nuclear sequences and identical pollen grain preparation for SEM and light microscopy will be used in a large ongoing project to monograph this sub-family.

CHAPTER 3

EVOLUTION OF VARIANCE-COVARIANCE STRUCTURE OF FLORAL MORPHOLOGY AMONG MEMBERS OF THE MUSTARD FAMILY (BRASSICACEAE)

INTRODUCTION

Individual floral traits may not evolve independently. Flowers are complex structures made up of several functionally integrated traits which work together to aid in successful plant reproduction (Darwin 1862). Often groups of traits will evolve together due to genetically, developmentally, and functionally integrated constraints (Arnold 1992). Consequently, how diverse floral traits evolve as a unit is of tremendous interest to botanists and evolutionists alike.

The matrix of genetic variance and covariance (G-matrix) represents the amount of heritable variation in a trait and its genetic covariation with other traits. It is an important concept because selective forces acting on one trait will cause evolution of a second trait even if the change infers no specific selective advantage. The G-matrix represents the type and quantity of genetic variation available to natural selection. While the G-matrix may confer a selective advantage, over time the amount of genetic variation and covariation in a population could constrain the direction of genetic drift and dictate response to selection. Genetic variation-covariation can affect both the rate and direction of evolutionary change (Lande 1976, 1979, Lande and Arnold 1983, Conner and Via 1993, Steppan 1997a, 1997b, Arnold and Phillips 1999, Phillips and Arnold 1999, Badyaev and Hill 2000, Arnold et al. 2001, and Steppan et al. 2002).

The potential constraint imposed by the G-matrix has been an issue under intense scrutiny. Futuyma (1995) studied the evolution of the host affiliation in the leaf beetle genus *Ophraella* and found that evolution of ecologically important traits were

influenced by genetic constraints. Schluter (1996) examined several vertebrate taxa to determine the long term effects of genetic variation on morphological divergence. He found that among the species he studied, morphological variation had been biased in the multivariate direction of greatest additive genetic variance for the last four million years. Both studies support the theory that quantitative genetic variance and covariance can constrain evolution over time.

The degree to which the G-matrix is conserved is an important unsolved problem in evolutionary biology. Lande (1979) pointed out how consistency in the G-matrix would allow us to make inferences about patterns of selection. Lande (1979) developed an important equation for the measuring changes in traits in evolutionary time:

$$\Delta\bar{\mathbf{z}} = \mathbf{G}\boldsymbol{\beta}$$

$\Delta\bar{\mathbf{z}}$ is the change in phenotypic traits across one generation. $\mathbf{G}$ is the matrix of genetic variances and covariances among traits. $\boldsymbol{\beta}$ is the selection gradient. So the rate of $\Delta\bar{\mathbf{z}}$ is the product of additive genetic variance-covariance and the strength of selection and can be used to predict the response to selection over time, including the effects on correlated traits. Lande (1979) predicted that G-matrices would remain constant over time and could therefore be used to predict the response of natural populations to selection and drift. If the G-matrix is stable over time, then scientists can predict the response of a population to selection and reconstruct ancestral events that have lead to speciation (Arnold 1992, Arnold et al. 2001, and Steppan et al. 2002).

Several empirical studies have been conducted using both selection and drift experiments and comparative analyses to investigate the stability and evolution of the G-matrix (Arnold and Phillips 1999, Phillips and Arnold 1999, Roff and Mousseau 1999, Roff 2000, and Stepan et al. 2002 and references therein). Both matrix similarity and dissimilarity have been found when comparing G-matrices between populations, subspecies and species and the closer the taxonomic relationship the more stable the G-matrixes have been. Additional studies, with similar results, have been conducted using the phenotypic variance-covariance matrix (P-matrix; Stepan 1997a, 1997b, Badayaev & Hill 2000, Ackermann and Cheverud 2000, Dodd et al. 2000, and Baker and Wilkinson 2003). While the P-matrix is not equivalent to the G-matrix, phenotypic variance-covariance has genetic variance-covariance as a component and can give insight into the heritable genetic variation-covariation available (Lofsvold 1986, Cheverud 1988, Arnold 1992, Stepan 1997a, 1997b, Wait and Levin 1988, Badayaev & Hill 2000, Arnold et al. 2001, and Stepan et al. 2002).

Baker and Wilkinson (2003) and was the first to look at the evolution of the P-matrix using a phylogenetic hypothesis at the species level or higher. This study showed equality of the P-matrices among three species of *Diasemopsis* (stalk-eyed flies).

In reviewing the findings from studies of G and P-matrices, only the Baker and Wilkinson (2003) study found proportionality or equality in the shared structure among matrices when comparing taxa at the subspecies or higher taxonomic level (see review in Stepan et al. 2002).

The evolution of G-matrix structure is still not well understood, particularly in an historical context (Badyaev and Hill 2000). The question of whether the G-matrix remains stable over evolutionary time remains an unresolved issue (Arnold et al. 2001, Stepan et al. 2002). Additional investigations into the nature, stability, and historical pattern of change in the G-matrix are required. Understanding how variance-covariance structures evolve over time will provide insight into how populations evolve and species diverge (Lande 1979, 1985; Price and Grant 1985, Grant and Grant 1995, Cheverud 1996, Arnold and Phillips 1999, Camara and Pigliucci 1999, Roff et al. 1999, Badyaev and Foresman 2000, Badyaev and Hill 2000, Arnold et al. 2001, and Stepan et al. 2002).

This study examined the relationship among P-matrices across the family Brassicaceae using a strong phylogenetic hypothesis. The Brassicaceae study system was chosen for several practical reasons: investigative work on G-matrices, genetic correlations, and phenotypic correlations have already been conducted in several members of the family (Conner and Via 1993, Conner and Sterling 1995, 1996, Kercher and Conner 1996, and Conner 2003 and references therein), preliminary research on phylogenetic relationships in the Brassicaceae had been conducted by Galloway et al. (1998) and were available for analysis, species in the family were widely distributed and easily collectable, and the floral characters were conserved and straightforward to measure across the family.

The Brassicaceae includes several economically and agronomically important plants, most notably several *Brassica* species, which include such diverse crops as canola

(*Brassica napus*), broccoli (*Brassica oleraceae* var. *italica*), cabbage (*Brassica oleraceae* var. *capitata*), and turnips (*Brassica rapa* var. *rapa*). Several species are cultivated as ornamentals including *Lobularia maritima* (sweet alyssum), *Iberis* (candy tuft), and *Matthiola* (stock). The Brassicaceae also contains the model species *Arabidopsis thaliana* and the problematic invasive plant *Alliaria petiolata* (garlic mustard). The family has approximately 340 genera and as many as 3350 species (Al-Shehbaz 1984). Brassicaceae are widely distributed, grow predominantly in the temperate northern hemisphere, and are most prevalent in arid regions. The largest concentrations of Brassicaceae species occur in southwestern/central Asia and the Mediterranean (Al-Shehbaz 1984).

In 1998 the Angiosperm Phylogeny Group advocated lumping the Capparaceae and Brassicaceae sensu stricto into one family, the Brassicaceae. This nomenclatural change was based on the paraphyly of the Capparaceae in the morphological cladistic analysis of Judd et al. (1994) and the chloroplast *rbcl* molecular phylogenetic analysis of Rodman et al (1996). Recent nuclear 18S molecular phylogenetic analysis (Rodman et al 1998) and chloroplast *ndhF* and *trnL-trnF* molecular phylogenetic analyses (Hall et al. 2002) have revisited the issue of relationship and monophyly in the Capparaceae and Brassicaceae sensu stricto. Hall et al. (2002) advocated the recognition of the three families: Capparaceae, Cleomaceae, and Brassicaceae, with the Cleomaceae most closely related to the Brassicaceae. The most recent update by the Angiosperm Phylogeny Group (2003), recognizes these studies, and advocates dissolving the Brassicaceae sensu APG 1998, and recognizing the three families as suggested by Hall et al. (2002). In addition to the

molecular phylogenetic evidence for the narrowly, and traditionally, circumscribed Brassicaceae, the family has some distinct floral characteristics that distinguish the flowers from its close relatives in the Capparaceae and Cleomaceae (Hall et al. 2002). These features include four alternating clawed petals arranged in the form of a cross and tetradynamous stamens.

Several attempts have been made to establish a tribal classification of the Brassicaceae (Hayek 1911, Schulz 1936, Janchen 1942, and Al-Shehbaz 1984). Most of this work has been based on morphological characters, most notably fruit morphology, pubescence, and cotyledon orientation (Al-Shehbaz 1984). In his morphological treatment of the Brassicaceae in the southeastern United States, Al-Shehbaz (1984), used a modification of the Janchen (1942) system and recognized seven major tribes, though he suspected that not all seven tribes were naturally monophyletic (Al-Shehbaz 1984, Price et al. 1994, Galloway et al. 1998). Koch et al. (2001) did the most comprehensive molecular systematic analysis of the *Brassicaceae* to date, using chloroplast *matK* and nuclear *Chs* sequences, and reviewed the tribal classification systems of Hayek (1911), Schulz (1936), and Janchen (1942). The study concluded that many of the tribal and subtribal classifications were artificial and “a new classification of crucifers based on molecular data would be desirable” (Koch et al. 2001; 541). No consensus has been reached on relationships among the major clades within the Brassicaceae and only a handful of studies have been conducted to investigate relationships across the family (Price et al. 1994, Galloway et al. 1998, Koch et al. 2001, and Hall et al. 2002).

This study incorporates a phylogenetic hypothesis of the family Brassicaceae and a study of floral morphological traits to test Lande's (1979) theories about stability in variance - covariance structure over time. The goal of this research was to test the hypothesis that P-matrix stability within the Brassicaceae followed a stepwise pattern of decrease in similarity with decreased relatedness corresponding to taxonomic rank within the phylogeny. This was the first attempt to investigate P-matrix relationships across a family-level phylogeny.

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MATERIALS AND METHODS

Phylogenetic Analysis-

Sampling – Fresh leaf or floral material from field collections or greenhouse material was collected, dried on silica gel, and stored at -80 degrees. A total of 25 individual specimens were used in the phylogenetic analysis. Eight DNA sequences of the partial *ndhF* coding region were previously published in Galloway et al. (1998) and available on GENBANK (Table 7).

Outgroup – *Cleome spinosa* was chosen as the outgroup based on the *ndhF* phylogeny of Galloway et al. (1998) and evidence from the chloroplast *ndhF* gene and *trnL-trnF* spacer sequences of Hall et al. (2002).

Analysis - DNA was extracted using the techniques of Loockerman and Jansen (1996) and purified using the Schleicher & Schuell Elu-quick DNA Purification Kit (Keene, NH). The *ndhF* coding region was amplified using the forward primer *ndhF* 1318 and the reverse primer *ndhF* 2110R of Olmstead and Sweere (1994).

Standard amplification protocols were used, including reaction mixture components and the PCR profile (Prather et al. 2002), and amplifications were performed on a MJ Research PTC-100 thermalcycler. PCR products were gel purified using the Schleicher & Schuell Elu-quick DNA Purification Kit, (Keene, NH) and then sequenced in both directions using an ABI-373 automated sequencer. Sequencing reactions were conducted

Table 7. Voucher and location information for material used in the *ndhF* sequencing analysis of Brassicaceae. In location column, * denotes specimens grown in greenhouses at Michigan State University.

Species	DNA	Location
<i>Aethionema arabicum</i> (L.) Rothm.	Monfils & Conner 66 (MSC)	Cultivated seed from Jardin Botanique de Nancy (France)*
<i>Alliaria petiolata</i> Cavara & Grande	Conner, Sahli & Fant 15 May 2002 (MSC)	Michigan: Gull Lake, Kellogg Biological Station
<i>Arabidopsis lyrata</i> (L.) O'Kane & AL-Shehbaz	Monfils & Conner 68 (MSC)	Michigan: Saugatuk Dunes State Park
<i>Arabidopsis thaliana</i> (L.) Heynh.	AF064654	GenBank submission from Galloway et al. 1998
<i>Arabis hirsuta</i> DC.	Conner & Stewart May 2000 (MSC)	Cultivated seed from Munster Botanical Garden*
<i>Barbarea verna</i> (Mill.) Asch.	Conner, Monfils & Stewart summer 2000 (MSC)	Michigan: Gull Lake, Kellogg Biological Station
<i>Barbarea vulgaris</i> R.Br.	AF064652	GenBank submission from Galloway et al. 1998
<i>Brassica napus</i> L.	Monfils et al. 70 (MSC)	Cultivated from Cascade Rape Seed *
<i>Brassica nigra</i> (L.) Koch	Monfils & Conner 56 (MSC)	Illinois: Urbana Junkyard*
<i>Brassica oleracea</i> L.	AF064647	GenBank submission from Galloway et al. 1998
<i>Brassica rapa</i> L.	Monfils & Conner 82 (MSC)	Crucifer Genetics Cooperative*
<i>Cakile edentula</i> (Bigelow) Hook.	Conner & Stewart Aug 2000 (MSC)	Michigan: Saugatuk Dunes State Park
<i>Capsella bursa-pastoris</i> (L.) Medik.	AF2064653	GenBank submission from Galloway et al. 1998
<i>Cardamine concatenata</i> (Michx.) O. Schwarz	Conner, Sahli & Fant 24 Apr 2002 (MSC)	Michigan: East Lansing, Hudson Woodlot, MSU
<i>Cleome spinosa</i> Jacq.	Monfils & Conner 67 (MSC)	Cultivated seed from Thompson & Morgan *
<i>Hesperis matronalis</i> L.	Monfils & Conner 48 (MSC)	Michigan: Gull Lake, Kellogg Biological Station
<i>Iberis</i> L.	Monfils & Conner 61 (MSC)	Cultivated seed from Thompson & Morgan *
<i>Lobularia maritima</i> (L.) Desv.	Monfils & Conner 71 (MSC)	Cultivated seed from Thompson & Morgan *
<i>Matthiola</i> R.Br.	Monfils & Conner 54 (MSC)	Cultivated seed from Thompson & Morgan *
<i>Nasturtium officinale</i> R.Br.	AF064659	GenBank submission from Galloway et al. 1998
<i>Raphanus raphanistrum</i> L.	Conner & Stewart 15 May 2002 (MSC)	New York: Binghamton *
<i>Raphanus sativus</i> L.	Monfils & Conner 49 (MSC)	California*
<i>Sisymbrium altissimum</i> L.	AF064648	GenBank submission from Galloway et al. 1998
<i>Stanleya pinnata</i> Britton	AF064655	GenBank submission from Galloway et al. 1998

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using the AmpliTaq DNA Dye Terminator Cycle Sequencing reagents (PE Applied Biosystems, Norwalk, CT).

Edited sequences were aligned using Sequencher 3.0 (Gene Codes Corporation, Ann Arbor, MI). Insertion deletion events were treated as missing data. Parsimony methods were implemented using PAUP* (Version 4.0b4; Swofford 2000). Heuristic searches were performed using the TREE BISECTION RECONNECTION, and MULTREES options. Bootstrap analysis was conducted using 10,000 replicates with 200 random addition-sequence replicates per bootstrap replicate.

Floral Morphological Trait Measurements-

Sampling- Floral morphological measurements were made on populations from twenty-four species within the Brassicaceae and one species from the Cleomaceae. Taxon selection was based on the phylogeny of Galloway et al. (1997) and discussions with Robert Price (personal communication). Two species, *Brassica nigra* and *Raphanus raphanistrum*, were sampled from two populations each. Study populations were selected based on availability of seeds and natural populations (Table 8).

Floral measurements- Flowers were measured from wild populations whenever possible. When wild populations were unavailable, seeds from wild populations, research collections, or commercial seed companies were acquired and grown to flowering. If

Table 8. Brassicaceae species measured for floral morphological characters, with sample locality, cultivation site, sample size and year measured. Species measured on cultivated seed are noted in sample locality column. Species with no cultivation information were measured in the field on natural populations.

Species	Sample Locality	Cultivation Site	N	Year
<i>Aethionema arabicum</i> (L.) Rothm.	France: Jardin Botanique de Nancy	Greenhouse - Michigan State U.	50	2000
<i>Alliaria petiolata</i> Cavara & Grande	Michigan: Kellogg Biological Station	-	50	2002
<i>Arabis lyrata</i> (L.) O'Kane & AL-Shehbaz	Michigan: Saugatuck Dunes State Park	-	48	1997
<i>Arabis thaliana</i> (L.) Heynh.	Michigan: Kellogg Biological Station	-	47	1997
<i>Arabis hirsuta</i> DC.	Munster Botanical Gardens	Greenhouse - Michigan State U.	21	1999
<i>Barbarea verna</i> (Mill.) Asch.	Michigan: Kellogg Biological Station	-	50	2000
<i>Barbarea vulgaris</i> R.Br.	Michigan: Kellogg Biological Station	-	49	1997
<i>Brassica napus</i> L.	Commercial Seed - Cascade Rape Seed	Phillips Tract - U. of Illinois	50	1991
<i>Brassica nigra</i> (L.) Koch	Illinois: Urbana, Junkyard	-	50	1991
<i>Brassica nigra</i> (L.) Koch	Illinois: Urbana, Yard Waste Disposal Site	-	48	1992
<i>Brassica oleracea</i> L.	Crucifer Genetics Cooperative	Greenhouse - Michigan State U.	50	1999
<i>Brassica rapa</i> L.	Crucifer Genetics Cooperative	Greenhouse - Michigan State U.	50	1999
<i>Cakile edentula</i> (Bigelow) Hook.	Michigan: Saugatuck Dunes State Park	-	50	1998
<i>Capsella bursa-pastoris</i> (L.) Medik.	Michigan: Kellogg Biological Station	-	50	1997
<i>Cardamine concatenata</i> (Michx.) O. Schwarz	Michigan: Michigan State University	-	45	2002
<i>Cleome spinosa</i> Jacq.	Commercial Seed - Thompson & Morgan	Greenhouse - Michigan State U.	22	1997
<i>Hesperis matronalis</i> L.	Illinois: Urbana, Phillips Tract	-	50	1991
<i>Iberis</i> L.	Commercial Seed - Thompson & Morgan	Greenhouse - Michigan State U.	44	1997
<i>Lobularia maritima</i> (L.) Desv.	Commercial Seed - Thompson & Morgan	Greenhouse - Michigan State U.	40	1997
<i>Matthiola</i> R.Br.	Commercial Seed - Thompson & Morgan	Greenhouse - Michigan State U.	41	1997
<i>Nasturtium officinale</i> R.Br.	Michigan: Kalamazoo Nature Center	-	50	1998
<i>Raphanus raphanistrum</i> L.	New York: Binghamton	Greenhouse - U. of Illinois	340	1989
<i>Raphanus raphanistrum</i> L.	New York: Binghamton	Phillips Tract - U. of Illinois	65	1992
<i>Raphanus sativus</i> L.	California:	Greenhouse - Michigan State U.	28	1998
<i>Sisymbrium altissimum</i> L.	Michigan: Mackinac City	-	41	1998
<i>Stanleya pinnata</i> Britton	Utah: Lake Powell	Greenhouse - Michigan State U.	35	1999

available, measurements were made on a minimum of 50 plants per population. A range of 22-340 plants per population were measured for a total of 1539 plants. One to three flowers per plant were measured. If more than one flower per plant was measured, the mean value was calculated and used in the analysis. Measurements were made using digital calipers and recorded to the nearest 0.01 mm. Six quantitative characters were measured: claw length, limb length, limb width, short filament length, long filament length, and pistil length (Figure 20 and 21)

Populations of *Raphanus raphanistrum*, *Brassica napus*, *B. nigra*, and *Hesperis matronalis* were measured according to the methods outlined in Conner & Sterling (1995). For all other populations, measurements were taken on the most apical, fully developed, intact flower. Only flowers that had not begun to senesce were measured. In wild populations, plants and seeds were sampled at set intervals along transects encompassing the population range. In the greenhouse, when the number of flowering plants exceeded 50, plants were selected for measurement using a random number table.

P-matrix construction – The Phenotypic variance-covariance matrix was constructed from the morphological data sets of six floral measurements recorded for the plants measured in the 26 populations. Data was imported into the JMP statistical package (SAS Institute Inc., Cary, NC) to construct a variance-covariance matrix using Multivariate Analysis-Covariance Matrix. The resultant matrix has variances for the six variables on the diagonal and covariances among the six variable above and below the diagonal (Table 9).

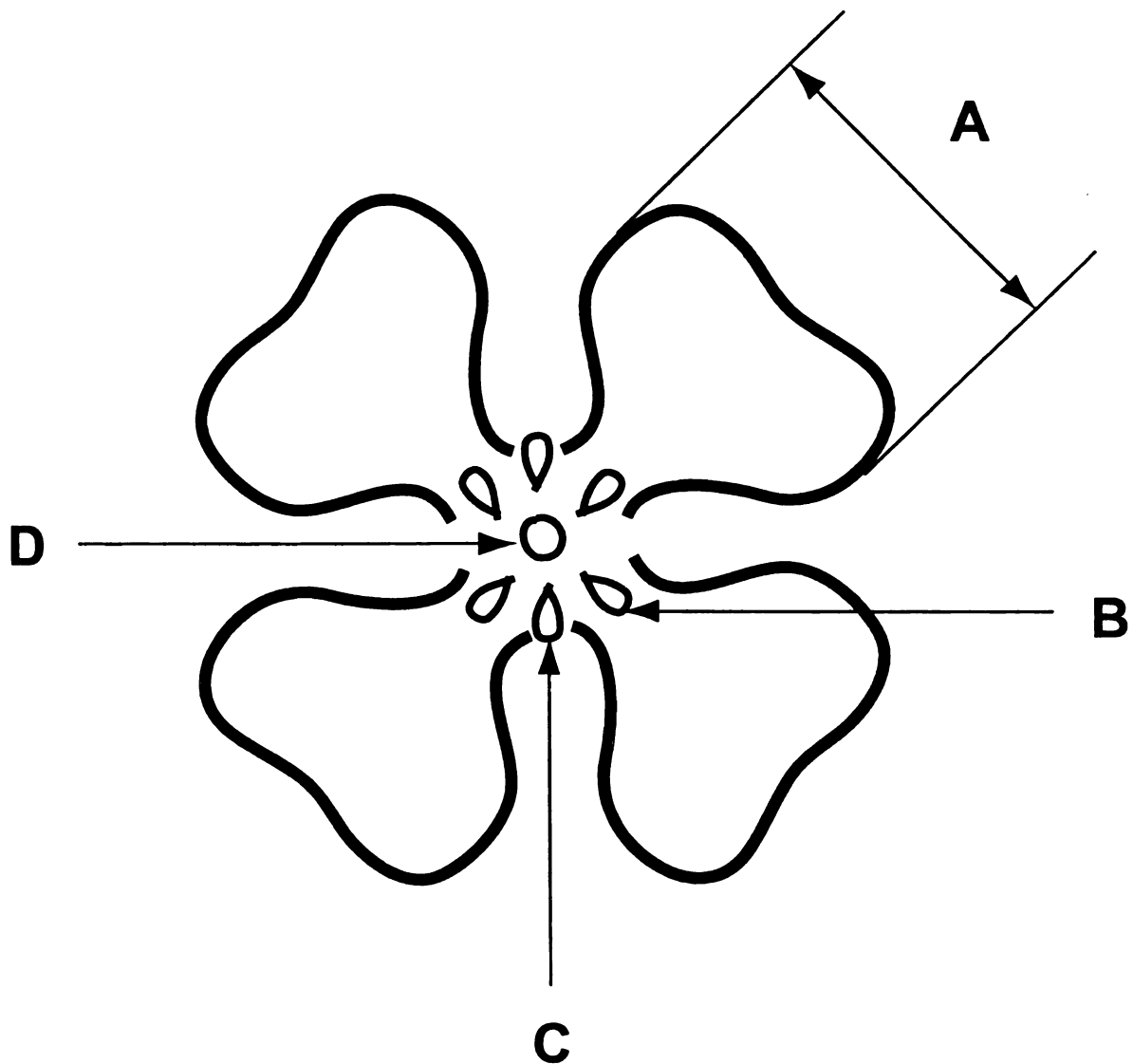


Figure 20. Schematic of generic Brassicaceae flower viewed from the top. Figure illustrates the cruciform petal arrangement. Letter A shows the floral measurement for limb width. The six tetradynamous stamens are shown: B shows one of four long antepetalous stamens located opposite each petal, C shows one of two outer short stamens borne between the petals. Letter D shows the central location of the pistil.

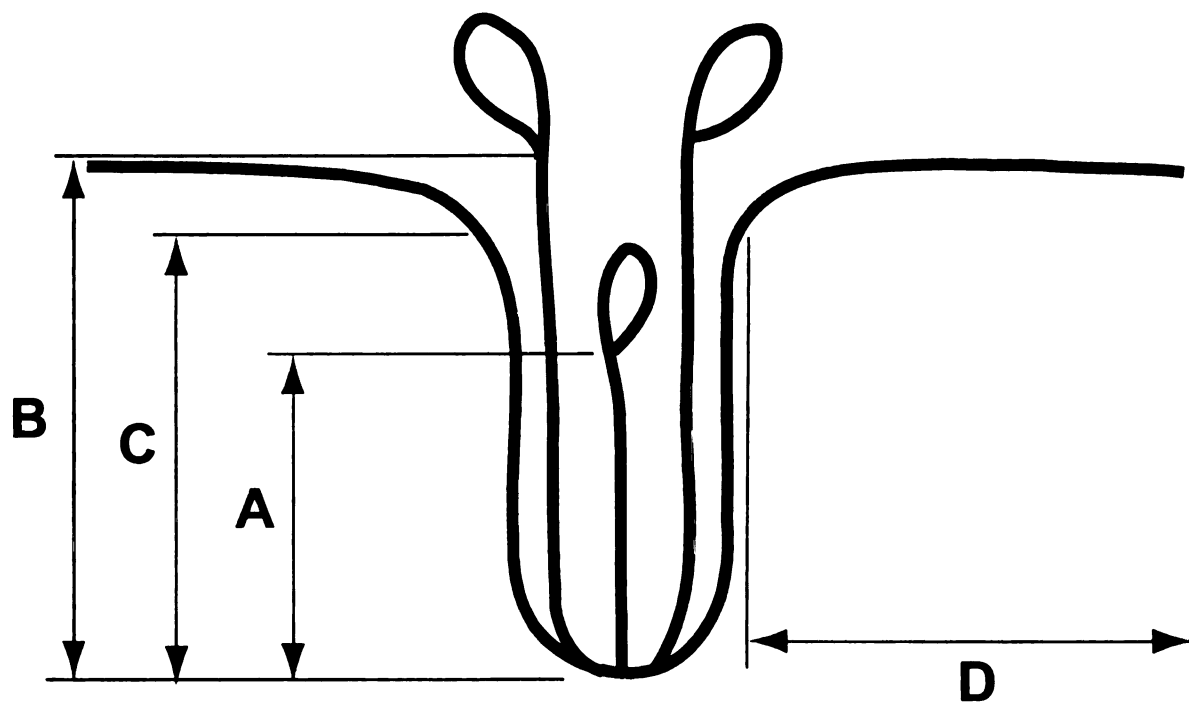


Figure 21. Schematic representation of a generic Brassicaceae flower in lateral cross-section. Pistil is not shown and would be located in the flower center. Only three stamens are shown (two long and one short) to illustrate the tetradynamous stamens. Letters in the figure refer to floral measurements: A=short filament, B=long filament, C=claw length of the petal, D=Limb length.

Table 9. Example of the Phenotypic variance-covariance matrix for the six variables in the *Nasturtium officinale* data set. The variance for each variable is along the diagonal and the covariances are on the upper and lower triangle off the diagonal.

	Limb length	Limb Width	Claw length	Short filament	Long filament	Pistil
Limb length	0.11440	0.06869	0.07314	0.03818	0.05610	0.06642
Limb Width	0.06869	0.06361	0.05202	0.02987	0.04101	0.05925
Claw length	0.07314	0.05202	0.13396	0.06672	0.06858	0.07521
Short filament	0.03818	0.02987	0.06672	0.12914	0.06953	0.06974
Long filament	0.05610	0.04101	0.06858	0.06953	0.08878	0.06358
Pistil	0.06642	0.05925	0.07521	0.06974	0.06358	0.16584

Hierarchical Matrix Comparisons - Comparisons of phenotypic variance-covariance matrices were made using the common principal component (CPC) analysis described by Flury (1988) and implemented using CPCRand (Phillips 1998, Phillips and Arnold 1999). CPCRand allows the simultaneous comparison of multiple matrices and uses randomization procedures to circumvent problems in the data set associated with the assumption of multivariate normality and degrees of freedom. Matrices were compared among related taxa in progressively more inclusive clades based on the phylogeny of the Brassicaceae. CPCRand could not accommodate comparisons of more than ten matrices and clades including more than ten populations were not included in this analysis. A total of sixteen matrix comparisons were made.

The Flury hierarchy (1988) goes beyond the determination of whether matrices are equal or unequal. The “Jump-Up” approach described by Phillips and Arnold (1999) starts by testing the matrices for related structure in the partial common principal components (PCPC) and then the common principal components for all the eigenvectors (CPC). If related structure in all the eigenvectors is not rejected, then the matrices are compared for proportional eigenvalues (proportional). The final step in the hierarchy is equality of eigenvectors and eigenvalues (equality). Each level in the hierarchy is inclusive of all the lower levels and each level is tested against the model of unrelated structure. Significance testing starts at the level of PCPC1 and proceeds up the hierarchy until a significant p-value is obtained. Once a significant p-value is determined, that level of the hierarchy is rejected, and the next lower level is accepted (Figure 22; Phillips & Arnold 1999).

The “Jump Up” approach is dependent on acceptance of PCPC1 in order to test any higher level in the hierarchy. In the analysis using CPCRand, eigenvectors are initially ordered by decreasing eigenvalues. A significant P-value for the first eigenvector discontinues the analysis and may preclude any investigation into matrix similarity among other eigenvectors with smaller eigenvalues. The CPCRand program has a reordering option which allows the user to change the order of the PCPCs and analyze additional eigenvectors for similarity. Houle et al. (2002) recommend reordering PCPCs to examine the possible similarity among the eigenvectors and this method was used by Baker and Wilkinson (2003) when comparing stalk-eyed flies.

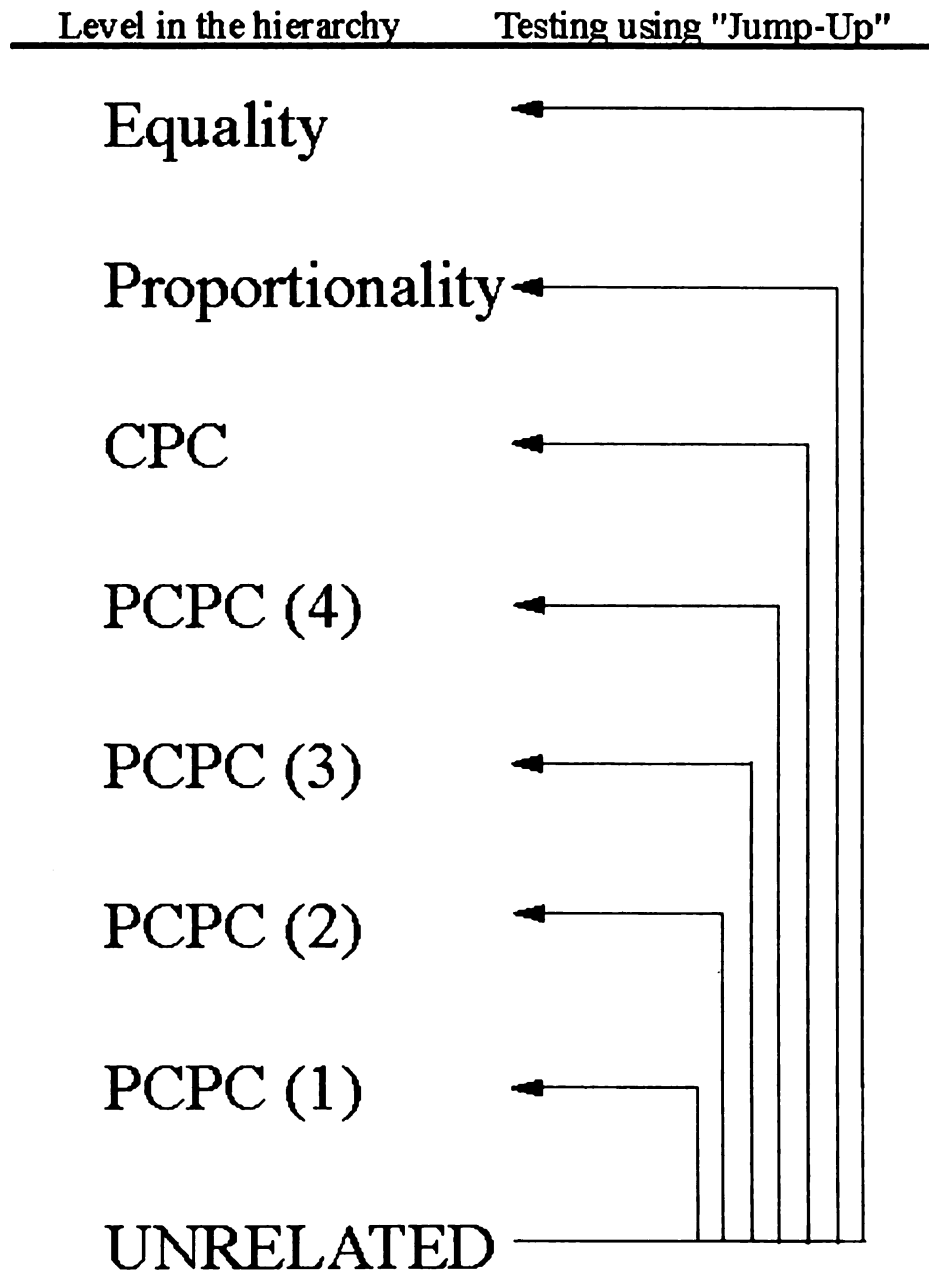


Figure 22. A representation of the “Jump Up” approach to matrix comparisons using the Flury hierarchy. This hierarchy represents the steps in the Brassicaceae six trait by six trait matrix comparison. Each level in the hierarchy is inclusive of all the lower levels and each level is measured against the model of unrelated structure. Testing starts with PCPC1 and moves up the hierarchy. PCPC is the partial common principal component model for successively higher numbers of eigenvectors from one to four, CPC is common principal components for all six eigenvectors, proportionality indicates that the eigenvectors are identical and the eigenvalues are proportional, and equality has equal eigenvectors and eigenvalues (Phillips & Arnold 1999).

Reordering of the PCPC was done on all sixteen matrix comparisons in the Brassicaceae data set. In the reordered analysis, instead of proceeding through the PC in the order of highest eigenvalue to lowest, the hierarchy of matrix comparisons skipped the first PC (the PC with the largest eigenvalue) started with the 2nd PC (the PC with the second largest eigenvalue) and proceeded through the remaining smaller PCs in order of largest to smallest eigenvalue. The first PC was the final component and included in the CPC level in the hierarchy. PCA analysis was completed for each individual population and eigenvectors were compared among populations where reordering had considerable effect on the matrix comparisons in the CPC analysis.

In phenotypic matrix comparisons the first PC is most often associated with size. In this analysis there was a great disparity in overall flower size across the Brassicaceae. To investigate the potential size disparity I ran a principal component analysis on the data set including all measurements in each population. The average first principal component was tabulated for each population based on the individual first PC values for measured flowers in each population. These values can be compared to examine the overall size difference among flowers assuming the first principal component is size.

RESULTS

Phylogenetic hypothesis –The aligned *ndhF* region was 771 bp long, with 113 parsimony informative-characters. The analysis resulted in 12 most parsimonious trees with a length of 362, C.I.^c = 0.5975, and a R.I. = 0.7328 (Figure 23). The *Aethionema* clade was strongly supported (100%) and basal to the well supported clade of the remaining Brassicaceae (99%). Three additional clades of interest were resolved in the strict consensus tree: *Hesperis matronalis* - *Matthiola* (87% bootstrap support), *Arabidopsis lyrata* – *Cardamine concatenata* (63% bootstrap support), and *Brassica nigra* - *Stanleya pinnata* (99% bootstrap support).

Within the *Arabidopsis lyrata* – *Cardamine concatenata* clade, *Arabidopsis lyrata* was sister to *A. thaliana* (95%) and these taxa formed a clade sister to *C. bursa-pastoris* (99% bootstrap support). The clade containing *Barbarea verna* and *B. vulgaris* was strongly supported (96%) and the clade of *N. officinale* and *C. concatenata* had moderate support (78%). Support for the clade including *B. verna*, *B. vulgaris*, *N. officinale* and *C. concatenata* was strong (89%).

The clade of *Brassica nigra* - *Stanleya pinnata* was comprised of two smaller clades: The *S. altissimum* and *S. pinnata* clade had strong support (95%), and the Brassicaceae clade (*Brassica nigra* - *Brassica rapa*) had weak support (71%). The *B. nigra* and *C. edentula* clade had weak bootstrap support (52%). The clade of the two *Raphanus* species had moderate support (83 %) and the clade containing, *B. oleraceae*, *B. napus*, and *B. rapa*, was unresolved and strongly supported (94%). The clade consisting of *Raphanus* and the unresolved *Brassica* was strongly supported (93%).

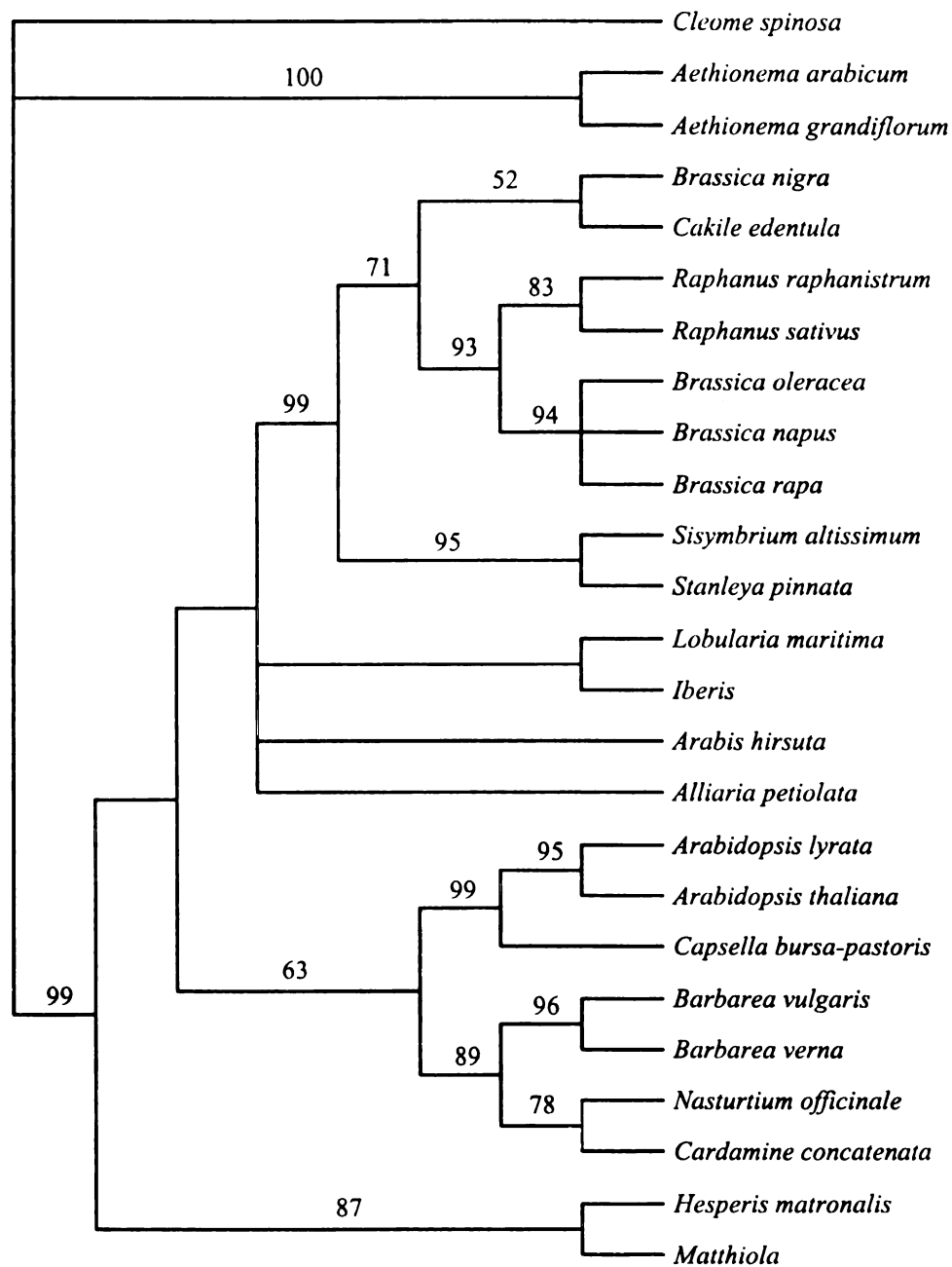


Figure 23. Strict consensus of 12 most parsimonious trees from the Brassicaceae based on parsimony analyses of 771 base pairs of *ndhF* coding region. Phylogeny has a tree length of 362, a C.I.^c = 0.732, and a R.I. = 0.733. Numbers above the branches represent bootstrap percentages based on 10,000 replicates.

Matrix comparisons –Sixteen comparisons were made among matrices. Nine comparisons showed some level of matrix similarity without reordering. After reordering the first principal component, all 16 matrix comparisons had common structure at some level in the hierarchy of matrix association. Comparisons of matrix similarity were equal for two intraspecific assessments, and two of the four within genera comparisons had equal or proportional matrices. One of seven pair-wise comparisons among genera had a level of shared structure above CPC. Of the three comparisons done among more than two genera, two were proportional and one shared a common structure for only one PC (Table 10 and Figure 24).

The two populations of *Brassica nigra*, Junkyard and Yard Waste Disposal Site, shared two principal components in common in the unordered analysis. The hypothesis of three PC in common was rejected ($P=0.014$). The trait loadings from the first PCs from the individual population level analysis were reviewed; *Brassica nigra* – Junkyard had a lower claw length weight (0.28599) on the first PC than *B. nigra* - Yard Waste Disposal Site (0.38854; Table 11). Principal components were reordered in the analysis and equality was found between the two P-matrices. When both populations of *Raphanus raphanistrum* were compared the matrices were found to be equal matrices whether the principal components were reordered or not.

Table 10. The P-value results of the CPCRand analysis in the Brassicaceae. P-value indicated without reordering principal components, followed by the value with reordering. Species correspond to populations listed in Table 8.

Matrices compared	Partial Common Principal Component (1)	Partial Common Principal Component (2)	Partial Common Principal Component (3)	Partial Common Principal Component (4)	Common Principal component	Proportional	Equal
<i>Brassica nigra</i> – two populations Junkyard and Yard Waste Disposal Site	0.10560/ 0.24000	0.16620/ 0.44670	0.01400/ 0.46050	0.04520/ 0.06860	0.06390	0.20870	0.25150
<i>B. nigra</i> populations and <i>Cakile edentula</i>	0.00010/ 0.21320	0.00010/ 0.15750	0.00010/ 0.05320	0.00060/ 0.01120	0.00080	0.01060	0.00000
<i>Raphanus raphanistrum</i> – two populations Greenhouse and Field	0.37740/ 0.55440	0.61210/ 0.71290	0.66000/ 0.88360	0.78340/ 0.75030	0.80970	0.36140	0.10230
<i>R. raphanistrum</i> populations and <i>Raphanus sativus</i>	0.05070/ 0.79320	0.17650/ 0.93450	0.33800/ 0.99270	0.54240/ 0.88860	0.56400	0.33690	0.00020
<i>Brassica oleracea</i> , <i>Brassica napus</i> , and <i>Brassica rapa</i>	0.35190/ 0.39930	0.05300/ 0.00050	0.00310/ 0.01000	0.00360/ 0.00150	0.00680	0.00000	0.00000
<i>B. oleracea</i> , <i>B. napus</i> , <i>B. rapa</i> , <i>R. raphanistrum</i> , and <i>R. sativus</i>	0.00900/ 0.27890	0.00300/ 0.01130	0.00070/ 0.01000	0.00080/ 0.00440	0.00180	0.00000	0.00000
<i>B. oleracea</i> , <i>B. napus</i> , <i>B. rapa</i> , <i>R. raphanistrum</i> , <i>R. sativus</i> , <i>B. nigra</i> populations, and <i>C. edentula</i>	0.08600/ 0.01070/ 0.13270	0.00000/ 0.02100/ 0.64970	0.00000/ 0.00010/ 0.08930	0.00000/ 0.00000/ 0.12650	0.00000	0.00000	0.00000
<i>Sisymbrium albidum</i> and <i>Stanleya pinnata</i>	0.00000/ 0.30450	0.00000/ 0.18100	0.00000/ 0.15820	0.00000/ 0.02690	0.00000	0.00000	0.00000
<i>Lobularia maritima</i> and <i>Iberis</i>	0.11000/ 0.18680	0.11570/ 0.25290	0.06110/ 0.02580	0.02480/ 0.01640	0.03000	0.02230	0.00210
<i>Arabidopsis lyrata</i> and <i>Arabidopsis thaliana</i>	0.01240/ 0.06760	0.02010/ 0.07320	0.02700/ 0.00400	0.02390/ 0.00410	0.00920	0.00160	0.00000
<i>A. lyrata</i> , <i>A. thaliana</i> , and <i>Capsella bursa-pastoris</i>							

Table 10 (cont'd)

Matrixes compared	Partial Common Principal Component (1)	Partial Common Principal Component (2)	Partial Common Principal Component (3)	Partial Common Principal Component (4)	Common Principal component	Proportional	Equal
<i>Barbarea vulgaris</i> and <i>Barbarea verna</i>	0.25830/ 0.53490	0.09820/ 0.50880	0.24020/ 0.59780	0.28450/ 0.39700	0.30760	0.22660	0.10610
<i>Nasturtium officinale</i> and <i>Cardamine concatenata</i>	0.18860/ 0.67100	0.37410/ 0.06290	0.69460/ 0.11970	0.56340/ 0.04840	0.06760	0.36980	0.00000
<i>B. vulgaris</i> , <i>B. verna</i> , <i>N. officinale</i> and <i>C. concatenata</i>	0.29780/ 0.96120	0.64470/ 0.60460	0.74630/ 0.71630	0.85240/ 0.46640	0.54000	0.76710	0.00000
<i>A. lyrata</i> , <i>A. thaliana</i> , <i>C. bursa-pastoris</i> , <i>B. vulgaris</i> , <i>B. verna</i> , <i>N. officinale</i> and <i>C. concatenata</i>	0.35220/ 0.61420	0.40440/ 0.35930	0.55600/ 0.30040	0.58010/ 0.25690	0.36890	0.33730	0.00000
<i>Hesperis matronalis</i> and <i>Matthiola</i>	0.00000/ 0.11830	0.00010/ 0.24930	0.00060/ 0.37300	0.00100/ 0.00140	0.00190	0.00000	0.00000

Figure 24. Strict consensus of tree for the Brassicaceae (see figure 23) Numbers above the branches represent bootstrap percentages based on 10,000 replicates. Notations below the branches indicate level of matrix similarity among species in the clade above the node. Matrix similarity is indicated without reordering principal components, followed by the value with reordering. Notations for similarity among matrices are as follows: U = unrelated matrix structure, PCPC # = partial common principal component followed by the number of principal components in common between the matrices, CPC = all principal components have shared structure among matrices, P = matrices are proportional and E = equality among matrices.

Table 11. Results from the principal component analysis of populations in the Brassicaceae. Eigenvalues with percent variation explained, and eigenvectors are given. Principal components are denoted as “PC” and ordered by decreasing eigenvalues.

Aethionema arabicum						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	2.4429	1.4401	0.8811	0.6824	0.3579	0.0955
Percent	40.7150	24.0022	14.6849	11.3738	5.9654	3.2587
Eigenvectors						
Claw Length	0.42235	-0.51436	0.30469	-0.09881	0.19075	0.64658
Limb Width	0.29559	0.37414	0.69189	-0.45631	-0.16321	-0.24308
Limb Length	0.12228	0.77109	-0.10780	0.18014	0.20898	0.55021
Anther (S)	0.48071	0.02203	-0.51354	-0.26786	-0.65086	0.09659
Anther (L)	0.54013	0.01448	-0.32011	-0.14104	0.65011	-0.40379
Pistil	0.44325	-0.01364	0.22503	0.81113	-0.21689	-0.21849
Alliaria petiolata						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	4.5930	0.6266	0.2830	0.2303	0.1464	0.1208
Percent	76.5497	10.4438	4.7159	3.8379	2.4402	2.0126
Eigenvectors						
Claw Length	0.35009	0.75867	0.46052	0.19729	0.22509	0.01405
Limb Width	0.42932	-0.15763	0.37834	-0.28156	-0.63868	-0.40064
Limb Length	0.41948	-0.36886	0.27756	-0.29492	0.23880	0.68333
Anther (S)	0.41641	0.25999	-0.60996	0.18511	-0.46159	0.37367
Anther (L)	0.42726	0.05789	-0.44232	-0.46369	0.47783	-0.41848
Pistil	0.40151	-0.43883	0.00723	0.73861	0.20742	-0.2399
Arabidopsis lyrata						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.3577	0.9194	0.8266	0.4163	0.3097	0.1704
Percent	55.9611	15.3239	13.7759	6.9375	5.1617	2.8399
Eigenvectors						
Claw Length	0.32558	0.66184	0.46898	0.26566	0.11861	0.38906
Limb Width	0.36274	-0.50309	0.53501	0.21701	0.39048	-0.35988
Limb Length	0.44662	-0.47636	0.00780	-0.18331	-0.33439	0.65432
Anther (S)	0.38146	0.01362	-0.68088	0.28295	0.54191	0.11564
Anther (L)	0.47243	0.13370	-0.17244	0.34133	-0.63800	-0.45349
Pistil	0.44073	0.25272	-0.02054	-0.80533	0.14469	-0.26825
Arabidopsis thaliana						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.5445	1.2464	0.5987	0.2588	0.2013	0.1503
Percent	59.0754	20.7731	9.9778	4.3138	3.3557	2.5043
Eigenvectors						
Claw Length	0.23853	0.71138	0.42324	0.39072	0.31381	0.08235
Limb Width	0.46103	0.28745	0.01912	0.21490	-0.79829	0.14494
Limb Length	0.47159	-0.14632	0.33119	-0.42528	0.22512	-0.64418
Anther (S)	0.33116	-0.59067	0.33680	0.62752	-0.16839	0.07663
Anther (L)	0.48235	-0.17037	-0.14102	-0.30868	0.41846	0.66935
Pistil	0.4073	0.10949	-0.75993	0.36225	0.10052	-0.32148
Arabis hirsuta						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	2.6684	1.2457	0.8039	0.7038	0.3268	0.2515
Percent	44.4728	20.7622	13.3975	11.7294	5.4465	4.1916

Table 11 (cont'd)

Arabis hirsuta cont'd						
Eigenvectors						
Claw Length	0.14121	0.73464	-0.46897	0.27006	0.35058	-0.15680
	PC1	PC2	PC3	PC4	PC5	PC6
Limb Width	0.52667	0.06326	-0.17691	0.27672	-0.54323	0.56182
Limb Length	0.39905	-0.29906	0.38128	0.62981	0.44672	-0.09862
Anther (S)	0.47523	0.04191	0.09237	-0.62766	0.48935	0.36118
Anther (L)	0.52018	0.16940	0.23565	-0.23544	-0.36911	-0.67343
Pistil	-0.21682	0.58000	0.73439	0.06662	-0.08202	0.25707
Babarea verna						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.4760	0.9761	0.7508	0.3925	0.2710	0.13335
Percent	57.9335	16.2684	12.5137	6.5406	4.5174	2.2254
Eigenvectors						
Claw Length	0.44198	-0.05373	0.41064	-0.60976	-0.27918	0.42825
Limb Width	0.46317	0.29467	-0.26014	-0.36491	0.00868	-0.70551
Limb Length	0.3885	0.32583	-0.65083	0.20300	-0.04192	0.52565
Anther (S)	0.41543	-0.46225	0.04606	0.49431	-0.57207	-0.20003
Anther (L)	0.39980	-0.55370	-0.04178	0.01202	0.72750	0.04934
Pistil	0.32670	0.53278	0.57987	0.45754	0.25240	-0.01035
Barbarea vulgaris						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.0987	1.2526	0.7133	0.5854	0.2286	0.1214
Percent	51.6453	20.8764	11.8882	9.7559	3.8105	2.0234
Eigenvectors						
Claw Length	0.43446	-0.33843	-0.18349	0.54073	0.54165	0.27798
Limb Width	0.31173	0.60337	-0.20610	0.52709	-0.46739	-0.00327
Limb Length	0.35518	0.51354	-0.25860	-0.56948	0.36962	0.28694
Anther (S)	0.45779	-0.39822	0.13570	-0.25660	-0.56134	0.48217
Anther (L)	0.50496	-0.23057	-0.26557	-0.19257	-0.05559	-0.76233
Pistil	0.35122	0.21436	0.87638	0.05051	0.18262	-0.16357
Brassica napus						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	2.6892	1.3756	0.7998	0.4569	0.3619	0.3165
Percent	44.8198	22.9264	13.3306	7.6157	6.0319	5.2755
Eigenvectors						
Claw Length	0.47275	-0.31788	-0.01312	-0.50249	0.48427	-0.43390
Limb Width	0.24031	0.70726	-0.07985	-0.01004	0.54740	0.36867
Limb Length	0.44321	0.38054	-0.29018	0.36107	-0.33322	-0.57719
Anther (S)	0.44157	-0.234662	-0.56018	-0.20321	-0.33446	0.53198
Anther (L)	0.41348	-0.39778	0.28482	0.69704	0.24921	0.20422
Pistil	0.39544	0.20163	0.71716	-0.29977	-0.42525	0.13400
Brassica nigra - Junkyard						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	2.7011	1.0437	0.9392	0.6106	0.3987	0.3067
Percent	45.0183	17.3947	15.6528	10.1773	6.6450	5.1119
Eigenvectors						
Claw Length	0.28599	0.28913	0.78873	0.35446	-0.21382	0.20286
Limb Width	0.36572	-0.59929	0.33171	-0.12069	0.61091	-0.09634
Limb Length	0.44748	-0.45553	-0.20449	-0.13935	-0.55719	0.46964
Anther (S)	0.42440	0.47458	-0.34215	0.04140	0.48311	0.49242

Table 11 (cont'd)

Brassica nigra – Junkyard cont'd						
	PC1	PC2	PC3	PC4	PC5	PC6
Anther (L)	0.43565	0.35152	0.08586	-0.68018	-0.16555	-0.43499
Pistil	0.46294	-0.03073	-0.31878	0.61320	-0.09904	-0.54526
Brassica nigra – Yard Waste Disposal Site						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.3141	1.0112	0.5855	0.4439	0.3658	0.2796
Percent	55.2344	16.8527	9.7585	7.3983	6.0962	4.6599
Eigenvectors						
Claw Length	0.38854	0.11397	0.90879	0.02315	-0.02752	0.09413
Limb Width	0.34617	0.63997	-0.28826	0.41597	-0.19557	0.41980
Limb Length	0.41096	0.43530	-0.16308	-0.52524	0.42846	-0.39442
Anther (S)	0.41653	-0.47873	-0.16687	-0.17933	0.38034	0.62663
Anther (L)	0.43425	-0.31595	-0.10518	0.64494	0.19970	-0.49468
Pistil	0.44524	-0.24281	-0.15972	-0.32007	-0.76999	-0.14824
Brassica napus						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	2.6892	1.3756	0.7998	0.4569	0.3619	0.3165
Percent	44.8198	22.9264	13.3306	7.6157	6.0319	5.2755
Eigenvectors						
Claw Length	0.47275	-0.31788	-0.01312	-0.50249	0.48427	-0.43390
Limb Width	0.24031	0.070726	-0.07985	-0.01004	0.54740	0.36867
Limb Length	0.44321	0.38054	-0.29018	0.36107	-0.33322	-0.57719
Anther (S)	0.44157	-0.23462	-0.56018	-0.20321	-0.33446	0.53198
Anther (L)	0.41348	-0.39778	0.28482	0.69704	0.24921	0.20422
Pistil	0.39544	0.20163	0.71716	-0.2997	-0.42525	0.13400
Barbarea oleracea						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	4.1835	0.9090	.4340	0.2404	.1604	0.0726
Percent	69.7250	15.1512	7.2329	4.0073	2.6732	1.2103
Eigenvectors						
Claw Length	0.43622	-0.10026	-0.51300	-0.02993	0.68741	0.25113
Limb Width	0.34290	0.64996	0.27229	0.61234	0.10386	0.00880
Limb Length	0.39056	0.48987	0.08736	-0.74889	-0.17634	0.08907
Anther (S)	0.44262	-0.28520	-0.17312	0.23054	-0.62427	0.49991
Anther (L)	0.46392	-0.16488	-0.21505	0.05252	-0.17591	-0.82319
Pistil	0.35842	-0.46797	0.76081	-0.08604	0.25481	0.03702
Brassica rapa						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.1750	0.9990	0.8323	0.4101	0.3296	0.2540
Percent	52.9163	16.6498	13.8721	6.8350	5.4927	4.2341
Eigenvectors						
Claw Length	0.31273	0.41859	0.73278	0.28260	0.29946	0.14308
Limb Width	0.41588	-0.50822	0.28734	-0.00759	-0.089849	-0.69147
Limb Length	0.40253	-0.60106	-0.00059	-0.08143	0.18229	0.66093
Anther (S)	0.40653	0.17204	-0.58846	0.34037	0.54994	-0.20139
Anther (L)	0.46660	0.20465	-0.17225	0.34775	-0.75274	0.15224
Pistil	0.42922	0.36570	-0.06716	-0.82260	-0.00501	-0.02886
Cakile edentula						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	2.7187	1.3946	0.7914	0.5300	0.3270	0.2383

Table 11 (cont'd)

Cakile edentula cont'd						
	PC1	PC2	PC3	PC4	PC5	PC6
Percent	45.3109	23.2440	13.1899	8.8339	5.4495	3.9718
Eigenvectors						
Claw Length	0.43903	-0.34189	-0.07112	0.69218	-0.25749	-0.37401
Limb Width	0.24453	0.62036	-0.46854	0.29079	0.50126	0.00213
Limb Length	0.41320	0.47387	-0.10425	-0.31329	-0.70365	-0.02370
Anther (S)	0.49178	-0.22837	0.03065	-0.54749	0.39113	-0.50232
Anther (L)	0.48425	-0.36785	-0.19795	-0.07067	0.07176	0.76214
Pistil	0.31682	0.29365	0.85113	0.18283	0.17084	0.16235
Capsella bursa-pastoris						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.0733	1.0457	0.7345	0.5918	0.3327	0.2220
Percent	51.2210	17.4283	12.2422	9.8629	5.5452	3.7004
Eigenvectors						
Claw Length	0.44290	-0.13394	-0.43139	0.54102	0.05110	0.55181
Limb Width	0.47978	-0.09174	0.29296	0.34603	0.48889	-0.56286
Limb Length	0.43523	-0.13384	0.46441	-0.53915	0.21513	0.48993
Anther (S)	0.05346	0.94966	0.18169	0.15589	0.09947	0.16758
Anther (L)	0.37709	0.22618	-0.66730	-0.52092	0.12931	-0.27069
Pistil	0.48905	0.05220	0.18465	0.03500	-0.82794	-0.19315
Cardamine concatenata						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	2.5952	1.1680	0.9131	0.6576	0.5127	0.1534
Percent	43.2542	19.4660	15.2189	10.9594	8.5445	2.5570
Eigenvectors						
Claw Length	0.47256	-0.01118	-0.54336	-0.18276	0.408880	-0.52992
Limb Width	0.45417	-0.55907	-0.12199	-0.15391	0.08420	0.65993
Limb Length	0.36976	-0.33704	0.53540	0.58789	0.12343	-0.31966
Anther (S)	0.32369	0.29743	0.61720	-0.63702	0.13962	-0.02308
Anther (L)	0.31974	0.68100	-0.08764	0.43747	0.25911	0.40964
Pistil	0.47612	0.14661	-0.12088	0.01093	-0.85084	-0.11471
Cleome spinosa						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	4.9859	0.5018	0.2854	0.1667	0.0457	0.0146
Percent	83.0977	8.3637	4.7564	2.7780	0.7612	0.2431
Eigenvectors						
Claw Length	0.39963	0.16972	-0.75731	0.34991	0.33711	0.04353
Limb Width	0.38354	0.51141	0.55650	0.53054	-0.01172	-0.00723
Limb Length	0.39152	0.53792	-0.07493	-0.71591	-0.15404	0.03278
Anther (S)	0.42794	-0.35529	0.16720	-0.14591	0.29477	-0.74465
Anther (L)	0.41997	-0.41523	0.25266	-0.15159	0.35032	0.66458
Pistil	0.42473	-0.34880	-0.13921	0.15773	-0.80801	0.02850
Hesperis matronalis						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.6211	1.0398	0.7011	0.2753	0.2133	0.1494
Percent	60.3512	17.3300	11.6853	4.5887	3.5550	2.4898
Eigenvectors						
Claw Length	0.28425	0.65318	0.57058	-0.01086	0.40681	0.03714
Limb Width	0.35238	-0.44962	0.62727	0.30532	-0.40882	0.14087
Limb Length	0.43914	-0.32499	0.02773	-0.82205	0.15632	-0.02392

Table 11 (cont'd)

Hesperis matronalis cont'd						
	PC1	PC2	PC3	PC4	PC5	PC6
Anther (S)	0.45043	0.24117	-0.40684	0.07313	-0.19583	0.72782
Anther (L)	0.45463	0.32402	-0.21086	0.03446	-0.48282	-0.63997
Pistil	0.43887	-0.32003	-0.26497	0.47367	0.60949	-0.19728
Iberis						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.7128	1.0840	0.4946	0.3817	0.2274	0.0994
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvectors						
Claw Length	0.44567	0.23196	-0.28428	-0.29278	-0.75919	0.06836
Limb Width	0.41338	-0.52935	0.13132	0.02447	-0.04319	-0.72746
Limb Length	0.38609	-0.59096	0.02085	0.25203	0.00067	0.66162
Anther (S)	0.35526	0.45835	0.67535	0.44912	-0.07666	0.00987
Anther (L)	0.40220	0.29397	-0.64070	0.41534	0.39571	-0.11055
Pistil	0.43992	0.14227	0.18684	-0.68989	0.50922	0.12675
Lobularia maritima						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.3567	0.9711	0.8468	0.3443	0.3105	0.1706
Percent	55.9444	16.1858	14.1128	5.7390	5.1745	2.8435
Eigenvectors						
Claw Length	0.37676	-0.00471	0.68480	0.44200	-0.43194	-0.08452
Limb Width	0.40421	0.47083	0.25824	-0.70473	-0.00871	0.22701
Limb Length	0.35009	0.62958	-0.29076	0.51517	0.36181	0.01479
Anther (S)	0.47148	-0.13317	-0.37219	-0.18774	-0.22638	-0.73141
Anther (L)	0.43532	-0.33120	-0.42386	0.08245	-0.32898	0.63727
Pistil	0.40038	-0.50448	0.24828	-0.02349	0.72316	0.00581
Matthiola						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	2.4225	1.3719	0.8461	0.5957	0.4628	0.3010
Percent	40.3750	22.8656	14.1017	9.9282	7.7127	5.0168
Eigenvectors						
Claw Length	0.46963	-0.20275	-0.48369	-0.41711	0.22627	0.52840
Limb Width	0.33143	-0.52353	0.34559	0.59416	-0.14275	0.35104
Limb Length	0.47950	-0.39637	0.17814	-0.27302	0.15142	-0.69554
Anther (S)	0.38200	0.47353	-0.18816	0.52911	0.54189	-0.14442
Anther (L)	0.46220	0.33204	-0.23010	0.05210	-0.77858	-0.11947
Pistil	0.28309	0.43957	0.72563	-0.34027	0.07527	0.28045
Nasturtium officinale						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.6993	0.8981	0.5373	0.3954	0.2890	0.1810
Percent	61.6547	14.9679	8.9544	6.5906	4.8159	3.0166
Eigenvectors						
Claw Length	0.42110	0.05808	-0.36783	-0.81852	0.08776	-0.07950
Limb Width	0.42713	-0.47130	0.06193	0.24630	0.17950	-0.70620
Limb Length	0.41962	-0.48572	-0.21338	0.22875	0.16382	0.68067
Anther (S)	0.35307	0.67307	-0.02982	0.30304	0.57395	0.01332
Anther (L)	0.43186	0.28871	-0.25496	0.28019	-0.76426	-0.05037
Pistil	0.39115	0.04689	0.86570	-0.21606	-0.14049	0.17013

Table 11 (cont'd)

Raphanus raphanistrum Field						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.4581	0.9490	0.7675	0.3710	0.3204	0.1341
Percent	57.6351	15.8161	12.7917	6.1828	5.3400	2.2343
Eigenvectors						
Claw Length	0.45968	-0.18612	-0.23824	0.02283	-0.72975	0.40526
Limb Width	0.33444	0.68345	-0.20880	0.59998	0.05708	-0.11923
Limb Length	0.39374	0.50443	0.11157	-0.75095	0.09736	0.06826
Anther (S)	0.44456	-0.34563	-0.19896	0.09729	0.67268	0.42585
Anther (L)	0.47764	-0.34439	-0.12325	-0.07345	-0.01499	-0.79526
Pistil	0.30989	-0.07577	0.91237	0.24640	-0.04473	0.05562
Raphanus raphanistrum Greenhouse						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.5331	1.0431	0.6983	0.3916	0.2424	0.0917
Percent	58.884	17.3842	11.6379	6.5263	4.0395	1.5277
Eigenvectors						
Claw Length	0.45013	-0.34368	-0.11313	0.10218	0.76324	0.27111
Limb Width	0.31601	0.62771	-0.35510	0.61443	-0.02284	-0.04438
Limb Length	0.36638	0.53812	-0.03202	-0.74964	0.10669	0.04269
Anther (S)	0.47064	-0.28173	-0.14683	-0.02268	-0.61666	0.54477
Anther (L)	0.48205	-0.31726	-0.11705	-0.05442	-0.15620	-0.79115
Pistil	0.33076	0.13516	0.90820	0.21586	-0.02993	0.00403
Raphanus sativus						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.8613	0.8472	0.6630	0.3836	0.1853	0.0595
Percent	64.3557	14.1206	11.0507	6.3936	3.0885	0.9910
Eigenvectors						
Claw Length	0.45994	-0.00215	-0.28430	0.14226	-0.80194	-0.21043
Limb Width	0.32226	-0.67762	0.41630	0.49126	0.09617	0.11446
Limb Length	0.38139	0.07085	0.63053	-0.66139	-0.12022	-0.00799
Anther (S)	0.46508	-0.11848	-0.33148	-0.14733	0.51800	-0.60807
Anther (L)	0.46909	0.03430	-0.39107	-0.14125	0.18407	0.75631
Pistil	0.32064	0.72153	0.29236	0.50925	0.17603	-0.02815
Sisymbrium altissimum						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.2417	0.9487	1.6088	0.4861	0.4446	0.2700
Percent	54.0284	15.8117	10.1475	8.1022	7.4102	4.5001
Eigenvectors						
Claw Length	0.42668	0.26772	0.20615	0.30022	-0.78087	-0.06240
Limb Width	0.41056	-0.54283	0.28431	0.05238	0.08001	0.66843
Limb Length	0.43123	-0.46600	0.14554	-0.32248	0.04507	-0.68533
Anther (S)	0.36577	0.53586	0.47000	0.15638	0.57339	-0.07028
Anther (L)	0.40556	0.35236	-0.38379	-0.70236	-0.04983	0.26130
Pistil	0.40642	-0.07212	-0.69807	0.53420	0.22483	-0.08005
Stanleya pinnata						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	3.6190	0.8382	0.6331	0.5579	0.2883	0.0635
Percent	60.3159	13.9697	10.5515	9.2987	4.8058	1.0584
Eigenvectors						
Claw Length	0.41849	0.05914	-0.30768	0.59016	-0.61482	-0.02014

Table 11 (cont'd)

Stanleya pinnata cont'd						
	PC1	PC2	PC3	PC4	PC5	PC6
Limb Width	0.33750	0.76137	0.05573	0.22972	0.49268	0.08831
Limb Length	0.39069	0.27976	0.46484	-0.56540	-0.48107	-0.04384
Anther (S)	0.46912	-0.19875	-0.36687	-0.24951	0.26681	-0.68731
Anther (L)	0.46874	-0.29893	-0.28838	-0.25679	0.16462	0.71743
Pistil	0.34428	-0.45792	0.68439	0.38867	0.22260	-0.05260

Four matrix comparisons were made between among species within a genus. The analysis of *Barbarea vulgaris* and *B. verna* showed equality of matrices and comparison *R raphanistrum* to the *R. sativus* found proportionality among matrices. The comparison of *Brassica oleraceae*, *B. napus*, and *B. rapa* found matrices with two PC in common. *Arabidopsis lyrata* and *A. thaliana* shared a common structure in the first three PC. Reordering reduced the number of PC with shared structure by one in both the *Arabidopsis* clade and the *Brassica* polytomy (PCPC2 and PCPC1 respectively).

The matrices in the clade including *A. lyrata*, *A. thaliana*, and *Capsella bursa-pastoris* were unrelated without reordering the PCs. Reordering showed a related structure in two PC. In the first PC for the individual population analysis of PCA, *C. bursa-pastoris* had an extremely low weight (0.05346) for the short anther length. This could explain why related structure in the first eigenvector was rejected.

Nasturtium officinale and *Cardamine concatenata* had proportional matrices and, when included in an analysis with the *Barbarea* species, all four matrices were proportional. An even more inclusive clade of *A. lyrata* / *Cardamine concatenata* also was proportional. None of these values were affected by reordering PCs.

Several pair-wise comparisons showed significant structure only after reordering.

Sisymbrium altissimum and *Stanleya pinnata* had shared structure among all their principal components. *Lobularia maritima* and *Iberis*, *Hesperis matronalis* and *Matthiola*, and *B. nigra* and *Cakile edentula* had shared structure in three PCPC.

The PCA analysis for the combined data from all populations had a first PC, which when averaged within populations, was closely associated with overall size of the populations' flowers (Table 12). The first PC explained over 85% of the variation in the data set. Larger flowers had larger average PCs and the inverse was true for smaller flowers.

Table 12. Results of a Principal Component Analysis incorporating measurements from all 26 populations measured in the Brassicaceae and Cleomaceae including eignvalues with percent variation explained, and eigenvectors. Principal components are denoted as "PC" and ordered by decreasing eigenvalues. Species listed correspond to species listed in Table 8 followed by the average first principal component for individuals in the population.

Principal Component Analysis of combined data from 26 populations in the family Brassicaceae and Cleomaceae						
	PC1	PC2	PC3	PC4	PC5	PC6
Eigenvalue	5.0142	0.7472	0.1095	0.0928	0.0314	0.0050
Percent	85.5698	12.4531	1.8253	1.5460	0.5233	0.0825
	<u>Eigenvectors</u>					
Claw Length	0.39230	0.47053	0.67419	-0.36030	-0.18095	0.08726
Limb Width	0.39454	0.46965	-0.08967	0.75023	0.22438	-0.05044
Limb Length	0.41376	0.29390	-0.71195	-0.48161	-0.00344	0.05998
Anther (S)	0.40872	-0.45219	0.10880	-0.00816	0.44415	0.64753
Anther (L)	0.42242	-0.35926	0.11803	-0.12671	0.31094	-0.75222
Pistil	0.41683	-0.37163	-0.06923	0.24347	-0.78927	0.03344
	<u>Species</u>	<u>Average first principal component for individuals in each population</u>				
	Aethionema arabicum L. Rothm.	-2.599				
	Alliaria petiolata Cavara & Grande	-1.581				
	Arabidopsis lyrata (L.) O'Kane & AL-Shehbaz	-1.371				
	Arabidopsis thaliana (L.) Heynh.	-2.3208				
	Arabis hirsuta DC.	-1.855				
	Barbarea verna (Mill.) Asch.	-1.393				
	Barbarea vulgaris R.Br.	-1.443				
	Brassica napus L.	-0.421				
	Brassica nigra (L.) Koch JUNK	-0.928				
	Brassica nigra (L.) Koch YWLG	-0.974				
	Brassica oleraceae L.	1.699				
	Brassica rapa L.	-1.074				
	Cakile edentula (Bigelow) Hook.	-1.758				
	Capsella bursa-pastoris (L.) Medik.	-2.570				
	Cardamine concatenata (Michx.) O. Schwarz	0.257				
	Cleome spinosa Jacq.	12.361				
	Hesperis matronalis L.	0.737				
	Iberis L.	-1.871				
	Lobularia maritima (L.) Desv.	-2.429				
	Matthiola R.Br.	0.422				
	Nasturtium officinale R.Br.	-1.918				
	Raphanus raphanistrum L. FLD92	0.996				
	Raphanus raphanistrum L. SA1	1.896				
	Raphanus sativus L.	1.481				
	Sisymbrium altissimum L.	-1.425				
	Stanleya pinnata Britton	1.062				

CONCLUSION

The phylogenetic analysis of the *ndhF* coding region was consistent with other molecular phylogenetic analyses within the family Brassicaceae (*rbcL*, Price et al. 1994; *ndhF* and *Adc*, Galloway et al. 1998; ITS, Mitchell & Heenan 2000; *matK* and *Chs*, Koch et al. 2001; and *ndhF* and *trnL-trnF*, Hall et al. 2002). The genus *Aethionema* was basal within the family Brassicaceae and a clade including *Hesperis matronalis* and *Matthiola* was basal to the remainder of the genera sampled. Good support existed for the *Arabidopsis lyrata* – *Cardamine concatenata* clade and relationships within the clade were resolved; this was the first molecular support for a clade including *Nasturtium officinale* and *Cardamine concatenata*. *S. altissimum* and *S. pinnata* were in a clade sister to the tribe Brassiceae.

The Brassiceae tribe is one of the few natural tribes described in the Brassicaceae (Al-Shehbaz 1984, Warwick & Black 1997, Gomez-Campo 1999, Koch et al 2001). Previous phylogenetic and phenetic analyses of RFLP data have been conducted in the Brassiceae (Pradham et al 1992, Thorman et al. 1994, Song et al. 1988, 1990, 1992, Warwick & Black 1991, 1993, 1997 and references therein) and a few molecular phylogenetic analyses have studied relationships in this group (Yang et al. 1999, Wroblewski et al. 2000, and Inaba & Nishio 2002). The findings of the *ndhF* phylogenetic study were consistent with the previous investigations in finding two lineages of *Brassica*: one including *B. oleraceae*, *B. napus*, and *B. rapa*, and second including *B. nigra*.

The comparisons of the P-matrix across the Brassicaceae found matrix proportionality at higher taxonomic levels than any study conducted to date (Steppan et al. 2002 and references therein, Baker and Wilkinson 2003). Equality in matrices between different species was found between *Barbarea verna* and *B. vulgaris* and proportional matrices were not rejected between *Raphanus raphanistrum* and *R. sativus*, and *Nasturtium officinale* and *Cardamine concatenata*. Proportionality among matrices in five genera was found in the *A. lyrata* – *Cardamine concatenata* clade. The presence of matrix similarity at such high taxonomic levels was noteworthy. The study tested the hypothesis that matrix structure deteriorates at the sub-species level and higher (Steppan et al. 2002), and found evidence for shared matrix structure among different genera in Brassicaceae. The results indicate, that in at least some cases, the P-matrix remains proportional (eigenvectors are equal and the eigenvalues change proportionally among matrixes) over long spans of evolutionary time and if the P-matrix is a good proxy for the G-matrix, the G-matrix can be a useful tool for reconstructing past evolutionary events (Lande 1979). This supports the findings of Schluter (1996) and Futuyma (1995) regarding the potential for long term, sustained constraints of the G-matrix.

Within *Brassica*, species had low levels of shared structure. In the Brassicaceae clade and its sister clade *Sisymbrium altissimum* / *Stanleya pinnata* low levels of matrix stability were found among genera. This was also true of the *Hesperis matronalis* / *Matthiola* and the *Lobularia* / *Iberis* clades. This supports the premise of Steppan (1997a, 1997b, and 2002 and references therein) that variance-covariance matrix structure is not always constant.

The results of this study confirm that the stability of the P-matrix, and potentially the G-matrix, varies among lineages. Assumptions can not be made about either the stability or lack of stability in covariance structure at different taxonomic levels within a family. Within the Brassicaceae matrices were proportional among distantly related taxa, and completely unrelated among other closely related taxa. In this study the phylogenetic level of the matrix comparison did not dictate the level of stability found among matrices. More empirical studies of matrix structure are needed to investigate variance-covariance stability within a phylogenetic context.

An important caveat - Measurements of the G-matrix in multiple species are not practical. Phenotypic measurements are much easier to obtain when taxa are sampled across a phylogeny. Phenotypic matrices are not identical to genetic matrices, though they may shed light on their genetic counterparts. Several studies have found that homogeneity in P-matrices may imply homogeneity in G-matrices (Cheverud 1988, Arnold 1992, Waitt & Levin 1998, Arnold et al. 2001, and Steppan et al. 2002). The P-matrix can be a conservative estimator of G-matrix stability. P-matrices, when directly compared to G-matrices, tend to deviate more readily from shared matrix structure among more closely related taxa (Steppan et al. 2002). Both Cheverud (1988) and Waitt & Levin (1998) reviewed the literature and found phenotypic correlations were good indicators of genetic correlations. Willis et al (1991) questioned the findings of Cheverud (1988) and refuted the utility of phenotypic variation in determining genetic variation (for a review of the P-matrix / G-matrix debate see Steppan et al. 2002).

In the reordering process, the first PC was moved to the end of the PC hierarchy, and the five PCs with smaller eigenvalues were assessed for eigenvector similarity. In several cases, reordering the principal components increased the level of matrix similarity among taxa. Even though the first principal component was responsible for a large portion of the variation in the individual data sets (average 55.45%, range 40.38-83.10), the remaining PCs still account for approximately half the variance. The remaining PCs could account for significant shape differences between the populations and represent important principal components affecting floral morphology. It makes intuitive sense that even though populations have a high proportion of variation in their first vector the remaining vectors may share commonalities of biological significance (Houle 2002, Steppan et al. 2002, Baker and Wilkinson 2003).

Analysis of the first PC for the combined data set of all 26 populations showed a strong relationship between the first factor and overall flower size. In addition, in the individual PC analysis of the populations – most populations had positive, relatively equally weighted variables. It is likely that the first vector is predominantly a size factor. If size was the only biological explanation of the first PC, and the only variance found between the populations was proportional, all the first PCs eigenvectors would be identical among populations. There were, however subtle differences in the weighting of the variables in the first eigenvector which resulted in a finding of unrelated matrix structure in the Flury Hierarchy. These subtle differences in the variable weights could be attributed to differences unrelated to proportionality, but rather shape differences in the floral morphology. This is particularly important since small differences in flower structure can

have a large impact on pollen deposit, pollinator attraction, and pollen removal, all key factors in reproductive success (Conner 1997).

Empirical studies of patterns of P- and G-matrix similarity are important. The G-matrix plays a key role in understanding evolutionary processes (Lande 1988). Understanding how the G-matrix changes through evolutionary time helps to explain multivariate evolution (Phillips and Arnold 1999). Selection can only act on the amount of genetic variation-covariation available in a population. How this G-matrix changes dictates the potential response of the population to selection and drift. An understanding of how matrix stability changes over the course of evolutionary time may help us to understand the potential constraints caused by the G-matrix and the factors that can overcome these constraints. In understanding the leap from microevolutionary processes to macroevolutionary events, the G-matrix serves as the key component of change and evolution.

SUMMARY

This dissertation examined phenotypic diversity at several different hierarchical levels. In all studies, a phylogeny was used as the framework to interpret floral morphology. Floral traits were measured on individuals across the species *Pedicularis densiflora* and *Pedicularis aurantiaca*, within the tropical genus *Cantua*, and throughout the family Brassicaceae.

The species *Pedicularis densiflora* and *P. aurantiaca* were previously described as sub-species of *Pedicularis densiflora* s.l. A close examination of floral traits among populations revealed two distinct morphologies among the populations. This morphological variation was examined intensively using ANOVA tests, principal component analysis, UPGMA cluster analysis and a comprehensive review of over 1000 herbarium specimens. Phylogenetic analysis of the two species confirmed they were closely related taxa, sister to a clade containing *Pedicularis semibarbata*, but the relationships among taxa within the *P. densiflora* / *P. aurantiaca* clade were unresolved. Without resolution phylogenetic information can sometimes be of limited help. Lack of resolution within the phylogeny prevented conclusions regarding the number of times the different floral morphs arose, relationships among populations in different localities, and potential pollinator shifts.

Past research on diversity in pollen morphology showed that pollen exine sculpturing was helpful in exploring phylogenetic relationships in the Polemoniaceae (Stuchlik 1967a, 1967b, Taylor and Levin 1965). Additional work examined the potential functional relationship between pollen grain size and style length (Plitmann and Levin 1983). While

past research had been restricted to phenotypic data, this *Cantua* research was able to integrate pollen and floral morphological data and a molecular phylogeny. Pollen grain morphology was highly conserved in *Cantua*, which supported the subsumption of *Huthia* into *Cantua*. The synapomorphy of supratectal verrucae united the *C. volcanica* / *C. quercifolia* clade and provided additional support for the hypothesized relationship. The molecular phylogeny of *Cantua* allowed me to confirm the phylogenetic utility of pollen morphological characters and remove the issue of non-independence when examining the relationship between pollen diameter and style length. Neither a significant regression slope nor correlation was found using independent contrasts of pollen diameter and style length in *Cantua* and the hypothesis for a morphological integration of these two traits in *Cantua* was not supported.

The evolution of phenotypic variance-covariance structure is still not well understood, particularly in an historical context (Badyaev and Hill 2000). The question of whether the P-matrix remains stable over evolutionary time remains an unresolved issue (Arnold et al. 2001, Stepan et al. 2002). I studied six floral traits in the Brassicaceae to examine P-matrix stability within a phylogenetic context. The comparisons of the P-matrix across the Brassicaceae found matrix equality and proportionality at higher taxonomic levels than any study conducted to date (Stepan 2001 and references therein, Baker and Wilkinson 2003). Unrelated matrix structure also was found among species and genera in the family. The phylogenetic level of the matrix comparison did not appear to affect the level of stability found among matrices. A phylogenetic hypothesis in the Brassicaceae

was used to conclude that P-matrix stability does not follow a stepwise pattern of similarity corresponding to taxonomic rank within the phylogeny.

Biological diversity is created by evolution. When attempting to explore biodiversity and examine processes in evolution, we need perspective on past evolutionary events. At present one of the most effective methods to investigate past evolutionary events is phylogenetics. My work on floral diversity and phenotypes in the genus *Cantua* and the family Brassicaceae exemplifies how phylogenetic history can clarify our understanding of biological phenomena. In contrast, phylogenetic relationships in the *Pedicularis* study were unresolved and consequently I was unable to add insight into past evolutionary events. Investigations of evolution benefit from the perspective of an historical context.

APPENDICES

APPENDIX A

Aligned sequences of *Pedicularis*:
Nuclear ribosomal internal transcribed spacer regions and 5.8S ribosomal RNA gene

Table 13. Aligned sequences of the nuclear ribosomal internal transcribed spacer regions and the 5.8S subunit of ribosomal RNA from the taxa sampled in *Pedicularis*. Names correspond to vouchers listed in Table 1. Gaps indicated with ":", Ambiguities indicated with "N", missing data indicated with "-".

VITS 1

1

4

8

P._cystopteridifolia_A	AAA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	ATG	GGA	TCG	CGG	GTC	TTG	GGG	GAG
P._cystopteridifolia_B	AAA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	ATG	GGA	TCG	CGG	GTC	TTG	GGG	GAG
P._bracteosa_A	AGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	GGG	GTG
P._bracteosa_B	AGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	GGG	GTG
P._semibarbata_A	AGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	GGG	GTG
P._semibarbata_B	AGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	GGG	GTG
McBride_Springs	GGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	TGG	GTG
Pinehurst	GGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	TGG	GTG
Hobo_Gulch	GGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	TGG	GTG
Inskip	GGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	TGG	GTG
Weaver_Camp	GGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	TGG	GTG
Hurles_Circle	GGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	TGG	GTG
Briceland	GGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	TGG	GTG
Mount_Diablo	GGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	TGG	GTG
Missouri_Flat	GGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	TGG	GTG
Round_Valley	GGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	TGG	GTG
Paradise	GGA	CCG	SGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	TGG	GTG
San_Marcos_Pass	GGA	CCG	CGA	ACA	CGT	TAA	ATC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	TGG	GTG
Pinnacles	GGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	TGG	GTG
Bear_Valley	GGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	TGG	GTG
Auberry_Road	GGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	TGG	GTG
Lake_Santa_Margarita	GGA	CCG	CGA	ACA	CGT	TAA	ACC	ACA	TTG	GGA	TCG	CGG	GTC	TTG	TGG	GTG

Table 13 (cont'd)

P._cystopteridifolia_A	ACC	CTT	TGC	CCG	CTC	CCA	CCT	CTC	GCA	CAG	CGT	GCG	CCT	AGG	CGC	GCG	9
P._cystopteridifolia_B	ACC	CTT	TGC	CCG	CTC	CCA	CCT	CTC	GCA	CAG	CGT	GCG	CCT	AGG	CGC	GCG	6
P._bracteosa_A	ACC	CTA	TGA	CCC	CGC	CCA	ACT	CTC	GCA	CGG	CGT	GTG	CCT	AGG	CGC	GCG	
P._bracteosa_B	ACC	CTA	TGA	CCC	CGC	CCA	ACT	CTC	GCA	TGG	CGT	GTG	CCT	AGG	CGC	GCG	
P._semibarbata_A	ACC	CTT	TGC	CCG	CGC	CCA	CCT	CTC	GCA	CGG	CGT	GCG	CCT	AGG	CGC	TCT	
P._semibarbata_B	ACC	CTT	TGC	CCG	CGC	CCA	CCT	CTC	GCA	CGG	CGT	GCG	CCT	AGG	CGC	GCT	
McBride_Springs	ACC	CTT	TGC	CCG	CGC	CCA	ACT	CCC	GCA	CGG	CGT	GCG	CCT	AGG	CGT	GCA	
Pinehurst	ACC	CTT	TGC	CCG	CGC	CCA	ACT	CCC	GCA	CGG	CGT	GCG	CCT	AGG	CGT	GCA	
Hobo_Gulch	ACC	CTT	TGC	CCG	CGC	CCA	ACT	CCC	GCA	CGG	CGT	GCG	CCT	AGG	CGT	GCA	
Inskip	ACC	CTT	TGC	CCG	CGC	CCA	ACT	CCC	GCA	CGG	CGT	GCG	CCT	AGG	CGT	GCA	
Weaver_Camp	ACC	CTT	TGC	CCG	CGC	CCA	ACT	CCC	GCA	CGG	CGT	GTG	CCT	AGG	CGT	GCA	
Hurles_Circle	ACC	CTT	TGC	CCG	CGC	CCA	ACT	CCC	GCA	CGG	CGT	GCG	CCT	AGG	CGT	GCA	
Briceland	ACC	CTT	TGC	CCG	CGC	CCA	ACT	CCC	GCA	CGG	CGT	GCG	CCT	AGG	CGT	GCA	
Mount_Diablo	ACC	CTT	TGC	CCG	CGC	CCA	ACT	CTC	GCA	CGG	CGT	GCG	CCT	AGG	CGC	GCG	
Missouri_Flat	ACC	CTT	TGC	CCG	CGC	CCA	ACT	CTC	GCA	CGG	CGT	GCG	CCT	AGG	CGC	GCG	
Round_Valley	ACC	CTT	TGC	CCG	CGC	CCA	ACT	CTC	GCA	CGG	CGT	GCG	CCT	AGG	CGC	GCG	
Paradise	ACC	CTT	TGC	CCG	CGC	CCA	ACT	CTC	GCA	CGG	CGT	GCG	CCT	AGG	CGC	GCG	
San_Marcos_Pass	ACC	CTT	TGC	CCG	CGC	CCA	ACT	CTC	GCA	CGG	CGT	GCG	CCT	AGG	CGC	GCG	
Pinnacles	ACC	CTT	TGC	CCG	CGC	CCA	ACT	CTC	GCA	CGG	CGT	GCG	CCT	AGG	CGC	GCG	
Bear_Valley	ACC	CTT	TGC	CCG	CGC	CCA	ACT	CTC	GCA	CGG	CGT	GCG	CCT	AGG	CGC	GCG	
Auberry_Road	ACC	CTT	TGC	CCG	CGC	CCA	ACT	CTC	GCA	CGG	CGT	GCG	CCT	AGG	CGC	GCG	
Lake_Santa_Margarita	ACC	CTT	TGC	CCG	CGC	CCA	ACT	CTC	GCA	CGG	CGT	GCG	CCT	AGG	CGC	GCG	

Table 13 (cont'd)

P._cystopteridifolia_A	TTG	TGC	GGG	:CT	AAC	GAA	CCC	CGG	CGC	GGC	ATG	CGC	CAA	GGA	AAA	CTC	1
P._cystopteridifolia_B	TTG	TGC	GGG	:CT	AAC	GAA	CCC	CGG	CGC	GGC	ATG	CGC	CAA	GGA	AAA	CTC	4
P._bracteosa_A	TTG	TGC	GGG	:CT	AAC	GAA	CCC	CGG	CGC	GGC	CTG	CGT	CAA	GGA	AAA	CTC	4
P._bracteosa_B	TTG	TGC	GGG	:CT	AAC	GAA	CCC	CGG	CGC	GGC	CTG	CGT	CAA	GGA	AAA	CTC	
P._semibarbata_A	TTG	TGC	GGG	GCT	AAC	GAA	CCC	CGG	CGC	GGC	ATG	CGC	CAA	GGA	AAA	CTC	
P._semibarbata_B	TTG	TGC	GGG	GCT	AAC	GAA	CCC	CGG	CGC	GGC	ATG	CGC	CAA	GGA	AAA	CTC	
McBride_Springs	TTG	TGC	GGG	CCT	AAC	GAA	CCC	CGG	CGT	GGC	ATG	CGC	CAA	GGA	AAA	CTC	
Pinehurst	TTG	TGC	GGG	CCT	AAC	GAA	CCC	CGG	CGT	GGC	ATG	CGC	CAA	GGA	AAA	CTC	
Hobo_Gulch	TTG	TGC	GGG	CCT	AAC	GAA	CCC	CGG	CGT	GGC	ATG	CGC	CAA	GGA	AAA	CTC	
Inskip	TTG	TGC	GGG	CCT	AAC	GAA	CCC	CGG	CGT	GGC	ATG	CGC	CAA	GGA	AAA	CTC	
Weaver_Camp	TTG	TGC	GGG	CCT	AAC	GAA	CCC	CGG	CGT	GGC	ATG	CGC	CAA	GGA	AAA	CTC	
Hurles_Circle	TTG	TGC	GGG	CCT	AAC	GAA	CCC	CGG	CGT	GGC	ATG	CGC	CAA	GGA	AAA	CTC	
Briceland	TTG	TGC	GGG	CCT	AAC	GAA	CCC	CGG	CGT	GGC	ATG	CGC	CAA	GGA	AAA	CTC	
Mount_Diablo	TTG	TGC	GGG	CCT	AAC	GAA	CCC	CGG	CGT	GGC	ATG	CGC	CAA	GGA	AAA	CTC	
Missouri_Flat	TTG	TGC	GGG	CCT	AAC	GAA	CCC	CGG	CGT	GGC	ATG	CGC	CAA	GGA	AAA	CTC	
Round_Valley	TTG	TGC	GGG	CCT	AAC	GAA	CCC	CGG	CGT	GGC	ATG	CGC	CAA	GGA	AAA	CTC	
Paradise	TTG	TGC	GGG	CCT	AAC	GAA	CCC	CGG	CGT	GGC	ATG	CGC	CAA	GGA	AAA	CTC	
San_Marcos_Pass	TTG	TGC	GGG	CCT	AAC	GAA	CCC	CGG	CGT	GGC	ATG	CGC	CAA	GGA	AAA	CTC	
Pinnacles	TTG	TGC	GGG	CCT	AAC	GAA	CCC	CGG	CGT	GGC	ATG	CGC	CAA	GGA	AAA	CTC	
Bear_Valley	TTG	TGC	GGG	CCT	AAC	GAA	CCC	CGG	CGT	GGC	ATG	CGC	CAA	GGA	AAA	CTC	
Auberry_Road	TTG	TGC	GGG	CCT	AAC	GAA	CCC	CGG	CGT	GGC	ATG	CGC	CAA	GGA	AAA	CTC	
Lake_Santa_Margarita	TTG	TGC	GGG	CCT	AAC	GAA	CCC	CGG	CGT	GGC	ATG	CGC	CAA	GGA	AAA	CTC	

1	1
4	9
5	2

166

Table 13 (cont'd)

V5.8S Ribosomal DNA																			2
1																			2
9																			4
3																			0
	P._cystopteridifolia_A	GAA	CTG	ACG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	P._cystopteridifolia_B	GAA	CTG	ACG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	P._bracteosa_A	GAC	CTG	ACG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	P._bracteosa_B	GAC	CTG	ACG	TCT	CTC	CAA	TGT	CAT	AAM	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	P._semibarbata_A	GAC	CTG	ACG	GCT	CTA	TAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	P._semibarbata_B	GAC	CYG	ACG	TCT	CTA	TAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	McBride_Springs	GAC	CTG	GCG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	Pinehurst	GAC	CTG	GCG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	Hobo_Gulch	GAC	CTG	GCG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	Inskip	GAC	CTG	GCG	TCT	CTY	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	Weaver_Camp	GAC	CTG	GCG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	Hurles_Circle	GAC	CTG	GCG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	Briceland	GAC	CTG	ACG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	Mount_Diablo	GAC	CTG	ACG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	Missouri_Flat	GAC	CTG	ACG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	Round_Valley	GAC	CTG	ACG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	Paradise	GAC	CTG	ACG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	San_Marcos_Pass	GAC	CTG	ACG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	Pinnacles	GAC	CTG	ACG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	Bear_Valley	GAC	CTG	ACG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	Auberry_Road	GAC	CTG	ACG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		
	Lake_Santa_Margarita	GAC	CTG	ACG	TCT	CTC	CAA	TGT	CAT	AAC	GAC	TCT	CGG	CAA	CGG	ATA	TCT		

Table 13 (cont'd)

P._cystopteridifolia_A	CGG	TTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	2
P._cystopteridifolia_B	CGG	TTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	8
P._bracteosa_A	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	8
P._bracteosa_B	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	8
P._semibarbata_A	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	
P._semibarbata_B	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	
McBride_Springs	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	
Pinehurst	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	
Hobo_Gulch	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	
Inskip	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	
Weaver_Camp	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	
Hurles_Circle	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	
Briceland	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	
Mount_Diablo	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	
Missouri_Flat	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	
Round_Valley	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	
Paradise	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	
San_Marcos_Pass	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	
Pinnacles	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	
Bear_Valley	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	
Auberry_Road	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	
Lake_Santa_Margarita	CGG	CTC	TCG	CAT	CGA	TGA	AGA	ACG	TAG	CGA	AAT	GCG	ATA	CTT	GGT	GTG	

Table 13 (cont'd)

P._cystopteridifolia_A	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	3
P._cystopteridifolia_B	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	3
P._bracteosa_A	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	6
P._bracteosa_B	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
P._semibarbata_A	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
P._semibarbata_B	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
McBride_Springs	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
Pinehurst	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
Hobo_Gulch	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
Inskip	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
Weaver_Camp	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
Hurles_Circle	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
Briceland	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
Mount_Diablo	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
Missouri_Flat	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
Round_Valley	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
Paradise	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
San_Marcos_Pass	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
Pinnacles	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
Bear_Valley	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
Auberry_Road	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	
Lake_Santa_Margarita	AAT	TGC	AGA	ATC	CCG	TGA	ACC	ATC	GAG	TCT	TTG	AAC	GCA	AGT	TGC	GCC	

Table 13 (cont'd)

		VITS2																	
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
		7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
P._cystopteridifolia_A	CGA AGC CAT TCG GCC GAG GGC ACG TCT GCC TGG GCG TCA CGC ATC GCG																		
P._cystopteridifolia_B	CGA AGC CAT TCG GCC GAG GGC ACG TCT GCC TGG GCG TCA CGC ATC GCG																		
P._bracteosa_A	CKA AGC CAT TCG GCC GAG GGC ACG TCT GCC TGG GCG TCA CGC ATC GCG																		
P._bracteosa_B	CGA AGC CAT TCG GCC GAG GGC ACG TCT GCC TGG GCG TCA CGC ATC GCG																		
P._semibarbata_A	CGA AGC CAT TCG GCC AAG GGC ACG TCT GCC TGG GCG TCA CGC ATC GCG																		
P._semibarbata_B	CGA MGC CAT TCG GCC AAG GGC ACG TCT GCC TGG GCG TCA CGC CTC GCG																		
McBride_Springs	CGA AGC CAT TCG GCC AAG GGC ACG CCT GCC TGG GCG TCA CGC ATC GCG																		
Pinehurst	CGA AGC CAT TCG GCC AAG GGC ACG CCT GCC TGG GCG TCA CGC ATC GCG																		
Hobo_Gulch	CGA AGC CAT TCG GCC AAG GGC ACG CCT GCC TGG GCG TCA CGC ATC GCG																		
Inskip	CGA AGC CAT TCG GCC AAG GGC ACG CCT GCC TGG GCG TCA CGC ATC GCG																		
Weaver_Camp	CGA AGC CAT TCG GCC AAG GGC ACG CCT GCC TGG GCG TCA CGC ATC GCG																		
Hurles_Circle	CGA AGC CAT TCG GCC AAG GGC ACG CCT GCC TGG GCG TCA CGC ATC GCG																		
Briceland	CGA AGC CAT TCG GCC AAG GGC ACG CCT GCC TGG GCG TCA CGC ATC GCG																		
Mount_Diablo	CGA AGC CAT TCG GCC AAG GGC ACG CCT GCC TGG GCG TCA CGC ATC GCG																		
Missouri_Flat	CGA AGC CAT TCG GCC AAG GGC ACG CCT GCC TGG GCG TCA CGC ATC GCG																		
Round_Valley	CGA AGC CAT TCG GCC AAG GGC ACG CCT GCC TGG GCG TCA CGC ATC GCG																		
Paradise	CGA AGC CAT TCG GCC AAG GGC ACG CCT GCC TGG GCG TCA CGC ATC GCG																		
San_Marcos_Pass	CGA AGC CAT TCG GCC AAG GGC ACG CCT GCC TGG GCG TCA CGC ATC GCG																		
Pinnacles	CGA AGC CAT TCG GCC AAG GGC ACG CCT GCC TGG GCG TCA CGC ATC GCG																		
Bear_Valley	CGA AGC CAT TCG GCC AAG GGC ACG CCT GCC TGG GCG TCA CGC ATC GCG																		
Auberry_Road	CGA AGC CAT TCG GCC AAG GGC ACG CCT GCC TGG GCG TCA CGC ATC GCG																		
Lake_Santa_Margarita	CGA AGC CAT TCG GCC AAG GGC ACG CCT GCC TGG GCG TCA CGC ATC GCG																		

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Table 13 (cont'd)

P._cystopteridifolia_A	AAA	TTG	GCC	CCC	CGT	GCG	CTA	AGT	CGC	GCG	GCC	GGC	GGC	TTA	AAT	GAA	AAC	4
P._cystopteridifolia_B	AAA	TTG	GCC	CCC	CGT	GCG	CTA	AGT	CGC	GCG	GCC	GGC	GGC	TTA	AAT	GAA	AAC	8
P._bracteosa_A	AAA	TTG	GCC	CCC	CGT	GYG	CTA	ACT	CGC	GCG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	0
P._bracteosa_B	AAA	TTG	GCC	CCC	CGT	GCG	CTA	ACT	CGC	GCG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	
P._semibarbata_A	AAA	TTG	GCC	CCC	CGT	GCT	CTA	AAT	TGC	GCG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	
P._semibarbata_B	AAA	TTG	GCC	CCC	CGT	GCT	CTA	ATT	TGC	GCG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	
McBride_Springs	AAA	TTG	GCC	CCC	CGT	GCG	CTA	AAC	CGC	GCG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	
Pinehurst	AAA	TTG	GCC	CCC	CGT	GCG	CTA	AAC	CGC	GCG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	
Hobo_Gulch	AAA	TTG	GCC	CCC	CGT	GCG	CTA	AAC	CGC	GCG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	
Inskip	AAA	TTG	GCC	CCC	CGT	GCG	CTA	AAC	CGC	GCG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	
Weaver_Camp	AAA	TTG	GCC	CCC	CGT	GCG	CTA	AAC	CGC	GCG	GCC	GGC	GGC	CTT	AAT	GAG	AAC	
Hurles_Circle	AAA	TTG	GCC	CCC	CGT	GCG	CTA	AAC	CGC	GYG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	
Briceland	AAA	TTG	GAC	CCC	CGT	GCG	CTG	AAC	CGA	NGG	GCG	GGC	GGC	CTA	AAT	TAG	AAC	
Mount_Diablo	AAA	TTG	GCC	CCC	CGT	GCG	CTG	AAC	CGC	GTG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	
Missouri_Flat	AAA	TTG	GCC	CCC	CGT	GCG	CTG	AAC	CGC	GTG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	
Round_Valley	AAA	TTG	GCC	CCC	CGT	GCG	CTG	AAC	CGC	GTG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	
Paradise	AAA	TTG	GCC	CCC	CGT	GCG	CTG	AAC	CGC	GTG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	
San_Marcos_Pass	AAA	TTG	GCC	CCC	CGT	GCG	CTA	AAC	CGC	GCG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	
Pinnacles	AAA	TTG	GCC	CCC	CGT	GCG	CTG	AAC	CGC	GTG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	
Bear_Valley	AAA	TTG	GCC	CCC	CGT	GCG	CTG	AAC	CGC	GTG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	
Auberry_Road	AAA	TTG	GCC	CCC	CGT	GCG	CTA	AAC	CGC	GCG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	
Lake_Santa_Margarita	AAA	TTG	GCC	CCC	CGT	GCG	CTG	AAC	CGC	GTG	GCC	GGC	GGC	CTA	AAT	GAG	AAC	

Table 13 (cont'd)

P._cystopteridifolia_A	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CTC	TCA	ACT	CTC	5
P._cystopteridifolia_B	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CTC	TCA	ACT	CTC	2
P._bracteosa_A	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	8
P._bracteosa_B	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	
P._semibarbata_A	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	
P._semibarbata_B	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	
McBride_Springs	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	
Pinehurst	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	
Hobo_Gulch	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	
Inskip	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	
Weaver_Camp	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	
Hurles_Circle	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	
Briceland	CCG	TGG	CGA	CTC	GCG	TCA	CGA	ACA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	
Mount_Diablo	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	
Missouri_Flat	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	
Round_Valley	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	
Paradise	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	
San_Marcos_Pass	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	
Pinnacles	CCG	TGG	CGA	CTC	GCG	TCA	CGA	NCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	
Bear_Valley	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	CCA	ACT	CTC	
Auberry_Road	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	
Lake_Santa_Margarita	CCG	TGG	CGA	CTC	GCG	TCA	CGA	CCA	GTG	GTG	GTT	GAA	CAC	TCA	ACT	CTC	

Table 13 (cont'd)

P._cystopteridifolia_A	GTG	CTG	TCG	TGC	CGT	TTA	GAG	TGC	GCC	ATC	GTG	CTT	CAT	TGC	AGA	CCC	5
P._cystopteridifolia_B	GTG	CTG	TCG	TGC	CGT	TTA	GAG	TGC	GCC	ATC	GTG	CTT	CAT	TGC	AGA	CCC	7
P._bracteosa_A	GTG	CTG	TCG	TGC	CGT	TCC	GAG	CCG	CCC	GTC	GGG	CTT	CGT	CGC	AGA	CCC	6
P._bracteosa_B	GTG	CTG	TCG	TGC	CGT	TCC	GAG	CCG	CCC	GTC	GGG	CTT	CGT	CGC	AGA	CCC	
P._semibarbata_A	GTG	CTG	TCG	TGC	CGG	TCC	GAG	TCG	CCT	GCC	GGG	CTT	CGT	CCC	AGA	CCC	
P._semibarbata_B	GTG	CTG	TCG	TGC	CGG	TCC	GAG	TTG	CCT	GCC	GGG	CTT	CGT	CCC	AGA	CCC	
McBride_Springs	GTG	CTG	TCG	TGC	CGT	TCC	GAG	TCG	CCT	ATC	GGG	CTT	CGT	CGC	AGA	CCC	
Pinehurst	GTG	CTG	TCG	TGC	CGT	TCC	GAG	TCG	CCT	ATC	GGG	CTT	CGT	CGC	AGA	CCC	
Hobo_Gulch	GTG	CTG	TCG	TGC	CGT	TCC	GAG	TCG	CCT	ATC	GGG	CTT	CGT	CGC	AGA	CCC	
Inskip	GTG	CTG	TCG	TGC	CGT	TCC	GAG	TCG	CCT	ATC	GGG	CTT	CGT	CGC	AGA	CCC	
Weaver_Camp	GTG	CTG	TCG	TGC	CGT	TCC	GAG	TCG	CCT	ATC	GGG	CTT	MGT	CGC	AGA	CCC	
Hurles_Circle	GTG	CTG	TCG	TGC	CGT	TCC	GAG	TCG	CCT	GTC	GGG	CTT	CAT	CGC	AGA	CCC	
Briceland	GTG	CTG	TCG	TGC	CGT	NCC	GAG	TCG	CCT	GTC	GGG	CTT	CGT	CCC	AGA	CCA	
Mount_Diablo	GTG	CTG	TCG	TGC	CGT	TCC	GAG	TCG	CCT	GTC	GGG	CTT	CGT	CCC	AGA	CCC	
Missouri_Flat	GTG	CTG	TCG	TGC	CGT	TCC	GAG	TCG	CCT	GTC	GGG	CTT	CGT	CCC	AGA	ACC	
Round_Valley	GTG	CTG	TCG	TGC	CGT	TCC	GAG	TCG	CCT	GTC	GGG	CTT	CGT	CCC	AGA	CCC	
Paradise	KTG	CTG	TCG	TGC	CGT	TCC	GAG	TCG	CCT	GTC	GGG	CTT	CGT	CCC	AGA	---	
San_Marcos_Pass	GTG	CTG	TCG	TGC	CGT	TCC	GAG	TCG	CCT	GTC	GGG	CTT	CGT	CCC	AGA	NCC	
Pinnacles	GTG	CTG	TCG	TGC	CGT	TCC	GAG	TCG	CCT	GTC	GGG	CTT	CGT	CCC	AGA	CCC	
Bear_Valley	GTG	CTG	TCG	TGC	CGT	TCC	GAG	TCG	CCT	GTC	GGG	CTT	CGT	CCC	AGA	CCC	
Auberry_Road	GTG	CTG	TCG	TGC	CGT	TCC	GAG	TCG	CCT	GTC	GGG	CTT	CGT	CCC	AGA	CCC	
Lake_Santa_Margarita	GTG	CTG	TCG	TGC	CGT	TCC	GAG	TCG	CCT	GTC	GGG	CTT	CGT	CCC	AGA	CCC	

Table 13 (cont'd)

	5	6
	7	0
	7	3
P._cystopteridifolia_A	ATC GGC GCG ATC CTA TCG CGC CTT CGA	
P._cystopteridifolia_B	ATC GGC GCG ATC CTA TCG CGC CTT CGA	
P._bracteosa_A	AAC GGC GCG ATC CTA TCG TGC CTT CGA	
P._bracteosa_B	AAC GGC GCG ATC CTA TCG TGC CTT CGA	
P._semibarbata_A	AAT GGC GCG ATC CCA TCG CGC CTT CGA	
P._semibarbata_B	AAT GGC GCG ATC CCA TCG CGC CTT CGA	
McBride_Springs	AAC GGC GCG ATC CTA TGG CGC CTT CGA	
Pinehurst	AAC GGC GCG ATC CTA TGG CGC CTT CGA	
Hobo_Gulch	AAC GGC GCG ATC CTA TGG CGC CTT CGA	
Inskip	AAC GGC GCG ATC CTA TGG CGC CTT CGA	
Weaver_Camp	AAC GGC GCG ATC CTA TGG CGC CTT TGA	
Hurles_Circle	AAC GGC GCG ATC CTA TGG CGC CTT CGA	
Briceland	ACG GGC GCG ATC CTA TTG GNG CTT CGA	
Mount_Diablo	AAC GGC GCG ATC CTA TGG CGC CTT CGA	
Missouri_Flat	AAC GGC GCG ATC CTA TGG CGC CTT CGA	
Round_Valley	AAC GGC GCG ATC CTA TGG CGC CTT CGA	
Paradise	---	---
San_Marcos_Pass	AAC GGC GCG ATC CTA TGG CGC CTT CGA	
Pinnacles	AAC GGC GCG ATC CTA TGG CGC CTT CGA	
Bear_Valley	AAC GGC GCG ATC CTA TGG CGC CTT CGA	
Auberry_Road	AAC GGC GCG ATC CTA TGG CGC CTT CGA	
Lake_Santa_Margarita	AAC GGC GCG ATC --- --- --- ---	---

APPENDIX B

Aligned sequences of *Pedicularis*:
intergenic region between *trnL*3' and *trnF* coding regions

Table 14. Aligned sequences of intergenic region between *trnI3'* and *trnF* coding regions from the *taxa* sequences listed in Table 1.

Table 14. Aligned sequences of intergenic region between trnL3' and trnF coding regions from the taxa sampled in *Pedicularis*. Names correspond to vouchers listed in Table 1. Gaps indicated with ":"; Ambiguities indicated with "N", Midding data indicated with "-".

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P._cystopteridifolia_A	AAA	AGT	CTT	ATT	TGA	CTC	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
P._cystopteridifolia_B	AAA	AGT	CTT	ATT	TGA	CTC	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
P._bracteosa_A	AAA	AGC	CTT	ATT	TGA	CTC	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
P._bracteosa_B	AAA	AGC	CTT	ATT	TGA	CTC	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
P._semibarbata_A	AAA	AGC	CTT	ATT	TGA	CTA	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
P._semibarbata_B	AAA	AGC	CTT	ATT	TGA	CTA	CCC	AAA	TAT	TTA	TCC	TAT	TCC	CCC	CTT	TCG
McBride_Springs	AAA	AGC	CTT	ATT	TGA	CTA	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
Pinehurst	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Hobo_Gulch	AAA	AGC	CTT	ATT	TGA	CTA	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
Inskip	AAA	AGC	CTT	ATT	TGA	CTA	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
Weaver_Camp	AAA	AGC	CTT	ATT	TGA	CTA	CCA	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
Hurles_Circle	AAA	AGC	CTT	ATT	TGA	CTA	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
Briceland	AAA	AGC	CTT	ATT	TGA	CTA	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
Mount_Diablo	AAA	AGC	CTT	ATT	TGA	CTA	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
Missouri_Flat	AAA	AGC	CTT	ATT	TGA	CTA	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
Round_Valley	AAA	AGC	CTT	ATT	TGA	CTA	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
Paradise	---	---	---	---	TGA	CTA	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
San_Marcos_Pass	AAA	AGC	CTT	ATT	TGA	CTA	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
Pinnacles	AAA	AGC	CTT	ATT	TGA	CTA	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
Bear_Valley	AAA	AGC	CTT	ATT	TGA	CTA	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::
Auberry_Road	---	---	---	---	---	---	---	---	--T	TTA	TCC	TAT	T::	:::	:::	:::
Lake_Santa_Margarita	AAA	AGC	CTT	ATT	TGA	CTA	CCC	AAA	TAT	TTA	TCC	TAT	T::	:::	:::	:::

Table 14 (cont'd)

P._cystopteridifolia_A	4	9
P._cystopteridifolia_B	9	6
P._bracteosa_A		
P._bracteosa_B		
P._semibarbata_A		
P._semibarbata_B		
McBride_Springs		
Pinehurst		
Hobo_Gulch		
Inskip		
Weaver_Camp		
Hurles_Circle		
Briceland		
Mount_Diablo		
Missouri_Flat		
Round_Valley		
Paradise		
San_Marcos_Pass		
Pinnacles		
Bear_Valley		
Auberry_Road		
Lake_Santa_Margarita		

Table 14 (cont'd)

P._cystopteridifolia_A	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGC	GGC	ATA	AAT	GCC	CTT	CTC	1
P._cystopteridifolia_B	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGC	GGC	ATA	AAT	GCC	CTT	CTC	4
P._bracteosa_A	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGC	GGC	ATA	AAT	GCC	CTT	CTC	4
P._bracteosa_B	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGC	GGC	ATA	AAT	GCC	CTT	CTC	
P._semibarbata_A	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGC	GGC	ATA	AAT	GCC	CTT	ATA	
P._semibarbata_B	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGC	GGC	ATA	AAT	GCC	CTT	ATA	
McBride_Springs	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGT	GGC	ATA	AAT	GCC	CTT	ATA	
Pinehurst	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGT	GGC	ATA	AAT	GCC	CTT	ATA	
Hobo_Gulch	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGT	GGC	ATA	AAT	GCC	CTT	ATA	
Inskip	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGT	GGC	ATA	AAT	GCC	CTT	ATA	
Weaver_Camp	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGT	GGC	ATA	AAT	GCC	CTT	ATA	
Hurles_Circle	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGT	GGC	ATA	AAT	GCC	CTT	ATA	
Briceland	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGT	GGC	ATA	AAT	GCC	CTT	ATA	
Mount_Diablo	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGT	GGC	ATA	AAT	GCC	CTT	ATA	
Missouri_Flat	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGT	GGC	ATA	AAT	GCC	CTT	ATA	
Round_Valley	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGT	GGC	ATA	AAT	GCC	CTT	ATA	
Paradise	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGT	GGC	ATA	AAT	GCC	CTT	ATA	
San_Marcos_Pass	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGT	GGC	ATA	AAT	GCC	CTT	ATA	
Pinnacles	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGT	GGC	ATA	AAT	GCC	CTT	ATA	
Bear_Valley	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGT	GGC	ATA	AAT	GCC	CTT	ATA	
Auberry_Road	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGT	GGC	ATA	AAT	GCC	CTT	ATA	
Lake_Santa_Margarita	TAT	TTT	TAT	TCT	TTT	TGA	CAA	ATG	TAT	TGT	GGC	ATA	AAT	GCC	CTT	ATA	

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Table 14 (cont'd)

	2	4	1	2	4	8
P._cystopteridifolia_A	:::	:::	:::	:::	:::	GGA GAA AAC
P._cystopteridifolia_B	:::	:::	:::	:::	:::	GGA GAA AAC
P._bracteosa_A	AAA	GCC	GTC	TTT	TTG	GGA GAA AAC
P._bracteosa_B	AAA	GCC	GTC	TTT	TTG	GGA GAA AAC
P._semibarbata_A	AAA	GCC	GTC	TTT	TTG	GGA GAA AAC
P._semibarbata_B	AAA	GCC	GTC	TTT	TTG	GGA GAA AAC
McBride_Springs	AAA	GCC	GTC	TTT	TTG	GGA GAA AAC
Pinehurst	AAA	GCC	GTC	TTT	TTG	GGA GAA AAC
Hobo_Gulch	AAA	GCC	GTC	TTT	TTG	GGA GAA AAC
Inskip	:::	:::	:::	:::	:::	GGA GAA AAC
Weaver_Camp	AAA	GCC	GTC	TTT	TTG	GGA GAA AAC
Hurles_Circle	AAA	GCC	GTC	TTT	TTG	GGA GAA AAC
Briceland	:::	:::	:::	:::	:::	GGA GAA AAC
Mount_Diablo	:::	:::	:::	:::	:::	GGA GAA AAC
Missouri_Flat	:::	:::	:::	:::	:::	GGA GAA AAC
Round_Valley	:::	:::	:::	:::	:::	GGA GAA AAC
Paradise	:::	:::	:::	:::	:::	GGA GAA AAC
San_Marcos_Pass	AAA	GCC	GTC	TTT	TTG	GGA GAA AAC
Pinnacles	AAA	GCC	GTC	TTT	TTG	GGA GAA AAC
Bear_Valley	AAA	GCC	GTC	TTT	TTG	GGA GAA AAC
Auberry_Road	AAA	GCC	GTC	TTT	TTG	GGA GAA AAC
Lake_Santa_Margarita	AAA	GCC	GTC	TTT	TTG	GGA GAA AAC

Table 14 (cont'd)

	2	3
	8	3
	9	6
P._cystopteridifolia_A	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TNA TCT
P._cystopteridifolia_B	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
P._bracteosa_A	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
P._bracteosa_B	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
P._semibarbata_A	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
P._semibarbata_B	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
McBride_Springs	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
Pinehurst	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
Hobo_Gulch	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
Inskip	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
Weaver_Camp	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
Hurles_Circle	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
Briceland	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
Mount_Diablo	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
Missouri_Flat	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
Round_Valley	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
Paradise	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
San_Marcos_Pass	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
Pinnacles	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
Bear_Valley	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
Auberry_Road	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT
Lake_Santa_Margarita	TTT	GTA ATC TCC CCC AGG CCT TTT AAT TGA CAT AGA CCC CAG TTA TCT

Table 14 (cont'd)

	3	4
	8	0
	5	4
P._cystopteridifolia_A	---	---
P._cystopteridifolia_B	AGC TGG TAG AGC AGA GGA CT	---
P._bracteosa_A	AGC TGG TAG AGC AGA ---	---
P._bracteosa_B	AGC TGG TAG AGC AGA GGA CT	---
P._semibarbata_A	AGC TGG TAG AGC AGA GGA CT	---
P._semibarbata_B	AGC TGG TAG AGC AGA GGA CT	---
McBride_Springs	A-- --- --- ---	---
Pinehurst	AGC TGG TAG AGC AGA GGA CT	---
Hobo_Gulch	AGC TGG TAG AGC AGA GGA CT	---
Inskip	AGC TGG TAG AGC AGA GGA CT	---
Weaver_Camp	AGC TGG TAG AGC AGA GGA CT	---
Hurles_Circle	---	---
Briceland	AGC TGG TAG AGC AGA GGA CT	---
Mount_Diablo	AGC TGG TAG AGC AGA GGA CT	---
Missouri_Flat	AGC TGG TAG AGC AGA GGA CT	---
Round_Valley	AGC TGG TAG AGC AGA G--	---
Paradise	---	---
San_Marcos_Pass	AGC TGG TAG AGC AGA GGA CT	---
Pinnacles	AGC TGG TAG AGC AGA GGA CT	---
Bear_Valley	AGC TGG TAG AGC AGA GGA CT	---
Auberry_Road	---	---
Lake_Santa_Margarita	AGC TGG TAG AGC AGA G--	---

APPENDIX C

Aligned sequences of *Pedicularis*:
intergenic region between *psbA* and *trnH* coding regions

Table 15. Aligned sequences of intergenic region between *psbA* and *trnH* coding regions from the taxa sampled in *Pedicularis*. Names correspond to vouchers listed in Table 1. Gaps indicated with "-"; Ambiguities indicated with "N", Missing data indicated with "-".

1 4
8

P._cystopteridifolia_A	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATC	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
P._cystopteridifolia_B	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATC	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
P._bracteosa_A	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATC	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
P._bracteosa_B	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATC	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
P._semibarbata_A	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATT	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
P._semibarbata_B	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATT	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
McBride_Springs	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Pinehurst	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATT	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
Hobo_Gulch	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATT	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
Inskip	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATT	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
Weaver_Camp	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATT	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
Hurles_Circle	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATT	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
Briceland	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATT	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
Mount_Diablo	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATT	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
Missouri_Flat	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATT	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
Round_Valley	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATT	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
Paradise	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATT	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
San_Marcos_Pass	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATT	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
Pinnacles	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATT	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
Bear_Valley	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATT	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
Auberry_Road	TTC	CCT	CTA	GAC	TTG	GCT	GCT	ATT	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC
Lake_Santa_Margarita	TTT	CCT	CTA	GAC	TTG	GCT	GCT	ATT	GAA	GCT	CCA	ACA	AAT	GGA	TAA	GAC

Table 15 (cont'd)

4	9	9	6
</			

Table 15 (cont'd)

	9	1
	7	4
		4
P._cystopteridifolia_A	AAG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
P._cystopteridifolia_B	AAG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
P._bracteosa_A	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
P._bracteosa_B	:AG GAG CAA TAA ACC CC: TCT TGG TAG ACC AAG AAA GAG TTT ATT GCT	
P._semibarbata_A	AAG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
P._semibarbata_B	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
McBride_Springs	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
Pinehurst	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
Hobo_Gulch	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
Inskip	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
Weaver_Camp	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
Hurles_Circle	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
Briceland	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
Mount_Diablo	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
Missouri_Flat	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
Round_Valley	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
Paradise	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
San_Marcos_Pass	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
Pinnacles	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
Bear_Valley	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
Auberry_Road	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	
Lake_Santa_Margarita	:AG GAG CAA TAA ACT ACT CTT TCT TGG TCT ACC AAG AGG GG: :TT TTT GCT	

1 1
4 4
5 5
1 1
9 9
2 2

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Table 15 (cont'd)

P._cystopteridifolia_A	TAC	TAA	ATT	TAG	TAT	TAT	TAT	TCT	ATT	GTC	ATT	TGT	CTA	ATT	TTT	TGT	CAA	3
P._cystopteridifolia_B	TAC	TAA	ATT	TAG	TAT	TAT	TAT	TCT	ATT	GTC	ATT	TGT	CTA	ATT	TTT	TGT	CAA	3
P._bracteosa_A	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TCT	TTT	G::	:::	:::	:::	:::	:::	:::	:::	6
P._bracteosa_B	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
P._semibarbata_A	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTC	G::	:::	:::	:::	:::	:::	:::	:::	
P._semibarbata_B	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTC	G::	:::	:::	:::	:::	:::	:::	:::	
McBride_Springs	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTT	G::	:::	:::	:::	:::	:::	:::	:::	
Pinehurst	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTT	G::	:::	:::	:::	:::	:::	:::	:::	
Hobo_Gulch	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTT	G::	:::	:::	:::	:::	:::	:::	:::	
Inskip	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTT	G::	:::	:::	:::	:::	:::	:::	:::	
Weaver_Camp	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTT	G::	:::	:::	:::	:::	:::	:::	:::	
Hurles_Circle	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTT	G::	:::	:::	:::	:::	:::	:::	:::	
Briceland	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTT	G::	:::	:::	:::	:::	:::	:::	:::	
Mount_Diablo	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTT	G::	:::	:::	:::	:::	:::	:::	:::	
Missouri_Flat	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTT	G::	:::	:::	:::	:::	:::	:::	:::	
Round_Valley	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTT	G::	:::	:::	:::	:::	:::	:::	:::	
Paradise	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTT	G::	:::	:::	:::	:::	:::	:::	:::	
San_Marcos_Pass	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTT	G::	:::	:::	:::	:::	:::	:::	:::	
Pinnacles	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTT	G::	:::	:::	:::	:::	:::	:::	:::	
Bear_Valley	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTT	G::	:::	:::	:::	:::	:::	:::	:::	
Auberry_Road	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTT	G::	:::	:::	:::	:::	:::	:::	:::	
Lake_Santa_Margarita	TAC	TAA	ATT	GAG	TAT	TAT	TAT	TTT	TTT	G::	:::	:::	:::	:::	:::	:::	:::	

Table 15 (cont'd)

P._cystopteridifolia_A	AAG	GTT	GGC	AAG	TTT	TGC	CAA	TTC	TAT	TTT	ATT	GAT	TAA	ATT	GAT	ATT	3
P._cystopteridifolia_B	AAG	GTT	GGC	AAG	TTT	TGC	CAA	TTC	TAT	TTT	ATT	GAT	TAA	ATT	GAT	ATT	8
P._bracteosa_A	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	4
P._bracteosa_B	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
P._semibarbata_A	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
P._semibarbata_B	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
McBride_Springs	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
Pinehurst	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
Hobo_Gulch	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
Inskip	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
Weaver_Camp	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
Hurles_Circle	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
Briceland	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
Mount_Diablo	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
Missouri_Flat	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
Round_Valley	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
Paradise	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
San_Marcos_Pass	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
Pinnacles	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
Bear_Valley	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
Auberry_Road	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	
Lake_Santa_Margarita	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	:::	

4 3 2

2

Table 15 (cont'd)

4

8

0

4
3
3

P._cystopteridifolia_A	ATC	TCA	GAN	NNN	NAG	NAG	ATA	TTT	GCT	CAT	TTT	TT-	---	---	---	---
P._cystopteridifolia_B	ATC	TCA	GAN	NNN	NAG	NAG	ATA	TTT	GCT	CAT	TTT	TT	---	---	---	---
P._bracteosa_A	AGC	TCC	GAA	AGA	AAG	AAG	ATA	TTT	GCT	CAT	TTT	TTT	ATA	TAA	AAA	TCG
P._bracteosa_B	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
P._semibarbata_A	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
P._semibarbata_B	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
McBride_Springs	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Pinehurst	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Hobo_Gulch	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Inskip	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Weaver_Camp	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Hurles_Circle	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Briceland	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Mount_Diablo	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Missouri_Flat	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Round_Valley	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Paradise	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
San_Marcos_Pass	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Pinnacles	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Bear_Valley	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Auberry_Road	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Lake_Santa_Margarita	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

4 8 1

Table 15 (cont'd)

P._cystopteridifolia_A	5	6
P._cystopteridifolia_B	7	0
P._bracteosa_A	7	5
P._bracteosa_B		
P._semibarbata_A		
P._semibarbata_B		
McBride_Springs		
Pinehurst		
Hobo_Gulch		
Inskip		
Weaver_Camp		
Hurles_Circle		
Briceland		
Mount_Diablo		
Missouri_Flat		
Round_Valley		
Paradise		
San_Marcos_Pass		
Pinnacles		
Bear_Valley		
Auberry_Road		
Lake_Santa_Margarita		

APPENDIX D

Aligned sequences of *Cantua*:
intergenic region between *trnT*5' and *trnL* coding regions

Table 16. Aligned sequences of the intergenic spacer region between the trnT5' and trnL coding regions for the taxa sampled in Cantua data set. Names correspond to specific epithets on vouchers listed in Table 4. Gaps indicated with ":", Ambiguities indicated with "N", Missing data indicated with "--". Specific insertion deletion events are labeled in the alignment with insertion deletion coding at the end of the sequence. In Indel Coding region at the end of the sequence, "C" represents gap presence, "A" represents gap absence.

1

4
8

flexuosa_A	CAT	AGG	AAT	TTA	ATA	AGA	TAT	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT
flexuosa_B	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
cuzcoensis	CAT	AGG	AAT	TTA	ATA	AGA	TAT	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT
bicolor	CAT	AGG	AAT	TTA	ATA	AGA	TAT	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT
buxifolia_A	CAT	AGG	AAT	TTA	ATA	AGA	TAT	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT
buxifolia_B	CAT	AGG	AAT	TTA	ATA	AGA	TAT	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT
buxifolia_C	CAT	AGG	AAT	TTA	ATA	AGA	TAT	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT
candelilla_A	CAT	AGG	AAT	TTA	ATA	AGA	TAT	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT
candelilla_B	CAT	AGG	AAT	TTA	ATA	AGA	TAT	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT
pyrifolia	CAT	AGG	AAT	TTA	ATA	AGA	TAT	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT
n.sp.	CAT	AGG	AAT	TTA	ATA	AGA	TAT	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT
volcanica_A	CAT	AGG	AAT	TTA	ATA	AGA	TAT	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT
volcanica_B	CAT	AGG	AAT	TTA	ATA	AGA	TAT	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT
quercifolia_A	CAT	AGC	AAT	TTA	ATA	AGA	TAT	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT
quercifolia_B	CAT	AGC	AAT	TTA	ATA	AGA	TAT	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT
quercifolia_C	CAT	AGC	AAT	TTA	ATA	AGA	TAT	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT
Bonplandia_geminiflora	CAT	AGG	AAT	TTA	ATA	AAA	TAC	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT
Cobaea_pachysepalala	CAT	AGG	AAT	TTA	ATA	AAA	TAT	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT
Cobaea_minor	TAT	AAG	AAT	TTA	ATA	AAA	TAT	TGG	AAT	CTT	AGC	TAT	TAC	TTA	TTC	GAT

Table 16 (cont'd)

flexuosa_A	TAT	TTT	CGA	TTC	AAT	TCA	GAA	TTC	ATA	TCA	ATA	TAA	AAT	ATT	CAT	ATA	9
flexuosa_B	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	6
cuzcoensis	TAT	TTT	CGA	TTC	AAT	TCA	GAA	TTC	ATA	TCA	ATA	TAA	AAT	ATT	CAT	ATA	
bicolor	TAT	TTT	CGA	TTC	AAT	TCA	GAA	TTC	ATA	TCA	ATA	TAA	AAT	ATT	CAT	ATA	
buxifolia_A	TAT	TTT	CGA	TTC	AAT	TCA	GAA	TTC	ATA	TCA	ATA	TAA	AAT	ATT	CAT	ATA	
buxifolia_B	TAT	TTT	CGA	TTC	AAT	TCA	GAA	TTC	ATA	TCA	ATA	TAA	AAT	ATT	CAT	ATA	
buxifolia_C	TAT	TTT	CGA	TTC	AAT	TCA	GAA	TTC	ATA	TCA	ATA	TAA	AAT	ATT	CAT	ATA	
candelilla_A	TAT	TTT	CGA	TTC	AAT	TCA	GAA	TTC	ATA	TCA	ATA	TAA	AAT	ATT	CAT	ATA	
candelilla_B	TAT	TTT	CGA	TTC	AAT	TCA	GAA	TTC	ATA	TCA	ATA	TAA	AAT	ATT	CAT	ATA	
pyrifolia	TAT	TTT	CGA	TTC	AAT	TCA	GAA	TTC	ATA	TCA	ATA	TAA	AAT	ATT	CAT	ATA	
n.sp.	TAT	TTT	CGA	TTC	AAT	TCA	GAA	TTC	ATA	TCA	ATA	TAA	AAT	ATT	CAT	ATA	
volcanica_A	TAT	TTT	CGA	TTC	AAT	TCA	GAA	TTC	ATA	TCA	ATA	TAA	AAT	ATT	CAT	ATA	
volcanica_B	TAT	TTT	CGA	TTC	AAT	TCA	GAA	TTC	ATA	TCA	ATA	TAA	AAT	ATT	CAT	ATA	
quercifolia_A	TAT	TTT	CGA	TTC	AAT	TCA	GAA	TTC	ATA	TCA	ATA	TAA	AAT	ATT	CAT	ATA	
quercifolia_B	TAT	TTT	CGA	TTC	AAT	TCA	GAA	TTC	ATA	TCA	ATA	TAA	AAT	ATT	CAT	ATA	
quercifolia_C	TAT	TTT	CGA	TTC	AAT	TCA	GAA	TTC	ATA	TCA	ATA	TAA	AAT	ATT	CAT	ATA	
Bonplandia_geminiflora	TAT	TTT	CGA	TTC	AAT	TCA	GAA	TTC	ATA	TCA	ATA	TAA	AAT	ATT	CAT	ATA	
Cobaea_pachysepala	TAT	TTT	CGA	TTC	CAT	TCA	GAA	TTC	ATA	TCA	CTC	TAA	AAT	ATT	CAT	ATA	
Cobaea_minor	TAT	TTT	CGA	TTC	AAT	TCA	GAA	TTC	ATA	TCA	ATA	TAA	AAT	ATT	CAT	ATA	

Table 16 (cont'd)

flexuosa_A	GAA	TAT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	ATT	TTA	GAA	CAT	AAC	AAT	TAA	1
flexuosa_B	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	4
cuzcoensis	GAA	TAT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	ATT	TTA	GAA	CAT	AAC	AAT	TAA	4
bicolor	GAA	TAT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	ATT	TTA	GAA	CAT	AAC	AAT	TAA	4
buxifolia_A	GAA	TAT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	ATT	TTA	GAA	CAT	AAC	AAT	TAA	
buxifolia_B	GAA	TAT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	ATT	TTA	GAA	CAT	AAC	AAT	TAA	
buxifolia_C	GAA	TAT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	ATT	TTA	GAA	CAT	AAC	AAT	TAA	
candelilla_A	GAA	TAT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	ATT	TTA	GAA	CAT	AAC	AAT	TAA	
candelilla_B	GAA	TAT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	ATT	TTA	GAA	CAT	AAC	AAT	TAA	
pyrifolia	GAA	TAT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	ATT	TTA	GAA	CAT	AAC	AAT	TAA	
n.sp.	GAA	TAT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	ATT	TTA	GAA	CAT	AAC	AAT	TAA	
volcanica_A	GAA	TAT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	ATT	TTA	GAA	CAT	AAC	AAT	TAA	
volcanica_B	GAA	TAT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	ATT	TTA	GAA	CAT	AAC	AAT	TAA	
quercifolia_A	GAA	TAT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	ATT	TTA	GAA	CAT	AAC	AAT	TAA	
quercifolia_B	GAA	TAT	AAT	TGC	AAA	TAA	ATA	TGG	AAT	ATT	TTA	GAA	CAT	AAC	AAT	TAA	
quercifolia_C	GAA	TAT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	ATT	TTA	GAA	CAT	AAC	AAT	TAA	
Bonplandia_geminiflora	GAA	TAT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	ATT	TTA	GAA	CAT	AAC	AAT	TAA	
Cobaea_pachysepala	GAA	TCT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	ATT	TTA	GAA	TAT	AAC	AAT	GAA	
Cobaea_minor	GAA	TCT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	ATT	TTA	GAA	CAT	AAC	AAT	TAA	
	GAA	TCT	AAT	TGC	AAA	TAA	ATA	TTG	AAT	TTT	TTA	GAA	CAT	AAC	AAT	TAA	

145

192

204

Table 16 (cont'd)

2	2	
4	8	
1	8	
flexuosa_A	GAA GAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TAA TTT	
flexuosa_B	--- --- --- --- --- --- --- --- --- --- --- ---	
cuzcoensis	GAA TAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TAA TTT	
bicolor	GAA GAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TAA TTT	
buxifolia_A	GAA GAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TAA TTT	
buxifolia_B	GAA GAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TAA TTT	
buxifolia_C	GAA GAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TAA TTT	
candelilla_A	GAA GAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TAA TTT	
candelilla_B	GAA GAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TAA TTT	
pyrifolia	GAA GAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TAA TTT	
n.sp.	GAA GAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TAA TTT	
volcanica_A	GAA GAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TAA TTT	
volcanica_B	GAA GAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TAA TTT	
quercifolia_A	GAA GAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TAA TTT	
quercifolia_B	GAA GAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TAA TTT	
quercifolia_C	GAA GAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TAA TTT	
Bonplandia_geminiflora	GAA GAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TAA TTT	
Cobaea_pachysepala	GAA GAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TCA TTT	
Cobaea_minor	GAA GAT AAG TTT AAT TAA TTT AAT CTA AAA TCT AAT TAA TTC TAA TTT	

Table 16 (cont'd)

flexuosa_A	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	GCC	TCT	GCT	2	3
flexuosa_B	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	3	3
cuzcoensis	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	GCC	TCC	GCT	3	6
bicolor	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	GCC	TCC	GCT		
buxifolia_A	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	GCC	TCC	GCT		
buxifolia_B	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	GCC	TCC	GCT		
buxifolia_C	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	GCC	TCC	GCT		
candelilla_A	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	GCC	TCC	GCT		
candelilla_B	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	GCC	TCC	GCT		
pyrifolia	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	GCC	TCC	GCT		
n.sp.	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	GCC	TCC	GCT		
volcanica_A	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	GCC	TCC	GCT		
volcanica_B	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	GCC	TCC	ACT		
quercifolia_A	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	GCC	TCC	ACT		
quercifolia_B	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	GCC	TCC	GCT		
quercifolia_C	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	GCC	TCC	GCT		
Bonplandia_geminiflora	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	GCC	TCC	GCT		
Cobaea_pachysepala	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	TCC	GCC	GCT		
Cobaea_minor	TTG	TAT	AAT	TTT	ATT	AAT	AGA	CCA	ATT	AAT	TAT	ATC	CAC	TCC	TCC	GCT		

Table 16 (cont'd)

	3	4
	8	3
	5	2
flexuosa_A	AAG TAT TCA AAA TTA CAT GAT AAA TTT TAG AAA TGG AGA AAG ATA GAA	
flexuosa_B	--- --- --- --- --- --- --- --- --- --- ---	
cuzcoensis	AAG TAT TCA AAA TTA CAT GAT AAA TTT TCG AAA TGG AGA AAG ATA GAA	
bicolor	AAG TAT TCA AAA TTA CAT GAT AAA TTT TAG AAA TGG AGA AAG ATA GAA	
buxifolia_A	AAG TAT TCA AAA TTA CAT GAT AAA TTT TTT AAA TGG AGA AAG ATA GAA	
buxifolia_B	AAG TAT TCA AAA TTA CAT GAT AAA TTT TTT AAA TGG AGA AAG ATA GAA	
buxifolia_C	AAG TAT TCA AAA TTA CAT GAT AAA TTT TAG AAA TGG AGA AAG ATA GAA	
candelilla_A	AAG TAT TCA AAA TTA CAT GAT AAA TTT TAG AAA TGG AGA AAG ATA GAA	
candelilla_B	AAG TAT TCA AAA TTA CAT GAT AAA TTT TAG AAA TGG AGA AAG ATA GAA	
pyrifolia	AAG TAT TCA AAA TTA CAT GAT AAA TTT TTT AAA TGG AGA AAG ATA GAA	
n.sp.	AAG TAT TCA AAA TTA CAT GAT AAA TTT TTT AAA TGG AGA AAG ATA GAA	
volcanica_A	AAG TAT TCA AAA TTA CAT GAT AAA TTT TAG AAA TGG AGA AAG ATA GAA	
volcanica_B	AAG TAT TCA AAA TTA CAT GAT AAA TTT TAG AAA TGG AGA AAG ATA GAA	
quercifolia_A	AAG TAT TCA AAA TTA CAT GAT AAA TTT TAG AAA TGG AGA AAG ATA GAA	
quercifolia_B	AAG TAT TCA AAA TTA CAT GAT AAA TTT TAG AAA TGG AGA AAG ATA GAA	
quercifolia_C	AAG TAT TCA AAA TTA CAT GAT AAA TTT TAG AAA TGG AGA AAG ATA GAA	
Bonplandia_geminiflora	AAG TAT TCA AAA TTA CAT GAT AAA TTT TAG AAA TGG AGA AAG ATA GAA	
Cobaea_pachysepala	AAG TAT TCA AAA TTA CAT GAT AAA TTT TAG AAA TGG AGA AAG ATA GAA	
Cobaea_minor	AAG TAT TCA AAA TTA CAT GAT AAA TTT TAG AAA TGG AGA AAG ATA GAA	

Table 16 (cont'd)

	4	4
	3	8
	3	0
flexuosa_A	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	
flexuosa_B	--- --- --- --- --- --- --- --- --- ---	
cuzcoensis	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	
bicolor	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	
buxifolia_A	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	
buxifolia_B	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	
buxifolia_C	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	
candelilla_A	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	
candelilla_B	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	
pyrifolia	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	
n.sp.	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	
volcanica_A	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	
volcanica_B	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	
quercifolia_A	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	
quercifolia_B	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	
quercifolia_C	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	
Bonplandia_geminiflora	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	
Cobaea_pachysepala	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	
Cobaea_minor	ATG TGG TAT ATA TCC ATC TAT ATT GAA TTG CGA ATA CAG AAA TGA TAA	

Table 16 (cont'd)

4	5	2	8
8			
1			

↓Indel 4

Table 16 (cont'd)

5	5
2	7
9	6
flexuosa_A	AGA TAG GGG AGA AAT TCA TGA AGA GAA AAC AGG TTT CGA GAT AGG GAT
flexuosa_B	--- --- --- --- --- --- --- --- --- --- ---
cuzcoensis	AGA TAG GGG AGA AAT TCA TGA AGA GAA AAC AGG TTT CGA GAT AGG GAT
bicolor	AGA TAG GGG AGA AAT TCA TGA AGA GAA AAC AGG TTT CGA GAT AGG GAT
buxifolia_A	AGA TAG GGG AGA AAT TCA TGA AGA GAA AAC AGG TTT CGA GAT AGG GAT
buxifolia_B	AGA TAG GGG AGA AAT TCA TGA AGA GAA AAC AGG TTT CGA GAT AGG GAT
buxifolia_C	AGA TAG GGG AGA AAT TCA TGA AGA GAA AAC AGG TTT CGA GAT AGG GAT
candelilla_A	AGA TAG GGG AGA AAT TCA TGA AGA GAA AAC AGG TTT CGA GAT AGG GAT
candelilla_B	AGA TAG GGG AGA AAT TCA TGA AGA GAA AAC AGG TTT CGA GAT AGG GAT
pyrifolia	AGA TAG GGG AGA AAT TCA TGA AGA GAA AAC AGG TTT CGA GAT AGG GAT
n.sp.	AGA TAG GGG AGA AAT TCA TGA AGA GAA AAC AGG TTT CGA GAT AGG GAT
volcanica_A	AGA TAG GGG AGA AAT TCA TGA AGA GAA AAC AGG TTT CGA GAT AGG GAT
volcanica_B	AGA TAG GGG AGA AAT TCA TGA AGA GAA AAC AGG TTT CGA GAT AGG GAT
quercifolia_A	AGA TAG GGG AGA AAT TCA TGA AGA GAA AAC AGG TTT CGA GAT AGG GAT
quercifolia_B	AGA TAG GGG AGA AAT TCA TGA AGA GAA AAC AGG TTT CGA GAT AGG GAT
quercifolia_C	AGA TAG GGG AGA AAT TCA TGA AGA GAA AAC AGG TTT CGA GAT AGG GAT
Bonplandia_geminiflora	::: :AG GGG AGA AAT CCA TGA AGA GAA AAC AGG TTT CGA GAT AGG GAT
Cobaea_pachysepala	AGA TAG GGG AGA AAT CCA TGA AGA GAA AAC AGG TTT CGA GAT AGG GAT
Cobaea_minor	AGA TAG GGG AGA AAT CCA TGA AGA AAA AAC AGA TTT CGA GAT AGG GAT

Table 16 (cont'd)

5	6	
7	2	
7	4	
flexuosa_A	TGG TAT CTA ATG AAT TCA ATG ATT TCA GTA TAA ACG TAA GAA AGG GGA	
flexuosa_B	--- --- --- --- --- --- --- --- --- ---	
cuzcoensis	TGG TAT CTA ATG AAT TCA ATG ATT TCA GTA TAA ACG TAA GAA AGG GGA	
bicolor	TGG TAT CTA ATG AAT TCA ATG ATT TCA GTA TAA ACG TAA GAA AGG GGA	
buxifolia_A	TGG TAT CTA ATG AAT TCA ATG ATT TCA GTA TAA ACG TAA GAA AGG GGA	
buxifolia_B	TGG TAT CTA ATG AAT TCA ATG ATT TCA GTA TAA ACG TAA GAA AGG GGA	
buxifolia_C	TGG TAT CTA ATG AAT TCA ATG ATT TCA GTA TAA ACG TAA GAA AGG GGA	
candelilla_A	TGG TAT CTA ATG AAT TCA ATG ATT TCA GTA TAA ACG TAA GAA AGG GGA	
candelilla_B	TGG TAT CTA ATG AAT TCA ATG ATT TCA GTA TAA ACG TAA GAA AGG GGA	
pyrifolia	TGG TAT CTA ATG AAT TCA ATG ATT TCA GTA TAA ACG TAA GAA AGG GGA	
n.sp.	TGG TAT CTA ATG AAT TCA ATG ATT TCA GTA TAA ACG TAA GAA AGG GGA	
volcanica_A	TGG TAT CTA ATG AAT TCA ATG ATT TCA GTA TAA ACG TAA GAA AGG GGA	
volcanica_B	TGG TAT CTA ATG AAT TCA ATG ATT TCA GTA TAA ACG TAA GAA AGG GGA	
quercifolia_A	TGG TCT CTA ATG AAT TCA ATG ATT TCA GTA TAA ACG TAA GAA AGG GGA	
quercifolia_B	TGG TCT CTA ATG AAT TCA ATG ATT TCA GTA TAA ACG TAA GAA AGG GGA	
quercifolia_C	TGG TAT CTA ATG AAT TCA ATG ATT TCA GTA TAA ACG TAA GAA A-- ---	
Bonplandia_geminiflora	TGG TAT CTA ATG AAT TCA ATG ATT TCA GTA TAA ACG TAA GAA AGG GGA	
Cobaea_pachysepala	TGG TAT CTA ATG AAT TCA ATG ATT TCA GTA TAA ACG TAA GAA AGG G--	
Cobaea_minor	TGG TAT CTA ATG AAT TCA ATG ATT TCA CTA TAA ACG TAA GAA AAG G--	

APPENDIX E

Aligned sequences of *Cantua*:
intergenic region between *trnL*3' and *trnF* coding regions

Table 17. Aligned sequences of the intergenic spacer region between the trnL3' and trnF coding regions for the taxa sampled in Cantua data set. Names correspond to specific epithets on vouchers listed in Table 4. Gaps indicated with ":", Ambiguities indicated with "N", Missing data indicated with "-". Specific insertion deletion events are labeled in the alignment with insertion deletion coding at the end of the sequence. In Indel Coding region at the end of the sequence, "C" represents gap presence, "A" represents gap absence.

1

4

8

	↓Indel 1															
flexuosa_A	---	AAA	GCA	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATA	AAA	GCA
flexuosa_B	CCA	AAA	GCA	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATA	AAA	GCA
cuzcoensis	CCA	AAA	::	::	::	::	::	::	::	::	::	::	::	::	::	GCA
bicolor	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
buxifolia_A	CCA	AAA	::	::	::	::	::	::	::	::	::	::	::	::	::	GCA
buxifolia_B	CCA	AAA	::	::	::	::	::	::	::	::	::	::	::	::	::	GCA
buxifolia_C	CCA	AAA	::	::	::	::	::	::	::	::	::	::	::	::	::	GCA
candelilla_A	CCA	AAA	::	::	::	::	::	::	::	::	::	::	::	::	::	GCA
candelilla_B	CCA	AAA	::	::	::	::	::	::	::	::	::	::	::	::	::	GCA
pyrifolia	CCA	AAA	::	::	::	::	::	::	::	::	::	::	::	::	::	GCA
n_sp.	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	GCA
volcanica_A	---	AAA	::	::	::	::	::	::	::	::	::	::	::	::	::	GCA
volcanica_B	---	AAA	::	::	::	::	::	::	::	::	::	::	::	::	::	GCT
quercifolia_A	CCM	AAA	::	::	::	::	::	::	::	::	::	::	::	::	::	GCA
quercifolia_B	CCA	AAA	::	::	::	::	::	::	::	::	::	::	::	::	::	GCA
quercifolia_C	CCA	AAA	::	::	::	::	::	::	::	::	::	::	::	::	::	GCA
Bonplandia_geminiflora	CCA	AAA	::	::	::	::	::	::	::	::	::	::	::	::	::	GCA
Cobaea_pachysepala	CCA	AAA	::	::	::	::	::	::	::	::	::	::	::	::	::	GCA
Cobaea_minor	CCA	AAA	::	::	::	::	::	::	::	::	::	::	::	::	::	GCA

Table 17 (cont'd)

4	9	9	6													
		↓	↓Indel 2													
flexuosa_A	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTA	TCC
flexuosa_B	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTA	TCC
cuzcoensis	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTA	TCC
bicolor	- - -	-TG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTA	TCC
buxifolia_A	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTA	TCC
buxifolia_B	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTA	TCC
buxifolia_C	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTA	TCC
candelilla_A	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTA	TCC
candelilla_B	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTA	TCC
pyrifolia	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTA	TCC
n._sp.	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTA	TCC
volcanica_A	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTA	TCC
volcanica_B	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTA	TCC
quercifolia_A	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTA	TCC
quercifolia_B	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTA	TCC
quercifolia_C	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTA	TCC
Bonplandia_geminiflora	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTA	TCC
Cobaea_pachysepala	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	GCT	ATC	TTT	TCT	TAT	CTT	ATT
Cobaea minor	TAT	TTG	ATT	TAC	TCC	TTA	ATA	ATT	TAT	CCT	ATC	TTT	TCT	TAT	TTT	CTT

Table 17 (cont'd)

2	3
8	3
9	6
flexuosa_A	AAA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG GAA TAG CTT ATC
flexuosa_B	AAA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG GAA TAG CTT ATC
cuzcoensis	AAA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG GAA TAG CTT ATC
bicolor	AAA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG GAA TAG CTT ATC
buxifolia_A	AAA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG GAA TAG CTT ATC
buxifolia_B	AAA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG GAA TAG CTT ATC
buxifolia_C	AAA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG GAA TAG CTT ATC
candelilla_A	AAA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG GAA TAG CTT ATC
candelilla_B	AAA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG GAA TAG CTT ATC
pyrifolia	AAA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG GAA TAG CTT ATC
n._sp.	AAA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG GAA TAG CTT ATC
volcanica_A	AAA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG GAA TAG CTT ATC
volcanica_B	AAA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG GAA TAG CTT ATC
quercifolia_A	AAA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG GAA TAG CTT ATC
quercifolia_B	AAA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG GAA TAG CTT ATC
quercifolia_C	AAA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG GAA TAG CTT ATC
Bonplandia_geminiflora	:AA TCC AAG AAA TTC CAA AGT CTT ATC CAG GCT TTG GAA TAG CTT ATC
Cobaea_pachysepala	:AA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG AAA TAG CTT ATC
Cobaea_minor	:AA TCC AAG AAA TTC CAA AGC CTG GAT AAG ACT TTG GAA TAG CTT ATC

Year	Number of cases
2017	7
2018	3
2019	3
2020	3
2021	8
2022	4

223

Table 17 (cont'd)

	3	4	
	8	3	
	5	2	
flexuosa_A	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
flexuosa_B	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
cuzcoensis	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
bicolor	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
buxifolia_A	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
buxifolia_B	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
buxifolia_C	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
candelilla_A	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
candelilla_B	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
pyrifolia	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
n._sp.	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
volcanica_A	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
volcanica_B	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
quercifolia_A	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
quercifolia_B	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
quercifolia_C	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
Bonplandia_geminiflora	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
Cobaea_pachysepalala	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---
Cobaea_minor	ATG ATG TAT TCT GAA TGG TCG GGA TAG CTC AGC TGC	---	---

APPENDIX F

Aligned sequences of *Cantua*:
938 base pairs of the *ndhF* coding region

Table 18. Aligned sequences of 938 basepairs of the *ndhF* coding region from the taxa sampled in the Cantua data set. Names correspond to specific epithets on vouchers listed in Table 4. Gaps indicated with ":", Ambiguities indicated with "N", Missing data indicated with "-".

1	4	8
flexuosa_A	GGT CCA AAG ATG AGA TTC TTA ATG ATA GTT GGT TGT ATT CAT CTA TTT	
flexuosa_B	GGT CCA AAG ATG AGA TTC TTA ATG ATA GTT GGT TGT ATT CAT CTA TTT	
cuzcoensis	GGT CCA AAG ATG AGA TTC TTA ATG ATA GTT GGT TGT ATT CAT CTA TTT	
bicolor	GGT CCA AAG ATG AGA TTC TTA ATG ATA GTT GGT TGT ATT CAT CTA TTT	
buxifolia_A	GGT CCA AAG ATG AGA TTC TTA ATG ATA GTT GGT TGT ATT CAT CTA TTT	
buxifolia_B	GGT CCA AAG ATG AGA TTC TTA ATG ATA GTT GGT TGT ATT CAT CTA TTT	
buxifolia_C	GGT CCA AAG ATG AGA TTC TTA ATG ATA GTT GGT TGT ATT CAT CTA TTT	
candelilla_A	GGT CCA AAG ATG AGA TTC TTA ATG ATA GTT GGT TGT ATT CAT CTA TTT	
candelilla_B	GGT CCA AAG ATG AGA TTC TTA ATG ATA GTT GGT TGT ATT CAT CTA TTT	
pyrifolia	GGT CCA AAG ATG AGA TTC TTA ATG ATA GTT GGT TGT ATT CAT CTA TTT	
n._sp.	GGT CCA AAG ATG AGA TTC TTA ATG ATA GTT GGT TGT ATT CAT CTA TTT	
volcanica_A	GGT CNA NAG ATG AGA TTC TTA ATG ATA GCT GGT TGT ATT CAT ATA TTT	
volcanica_B	GGT CCA AAG ATG AGA TTC TTA ATG ATA GCT GGT TGT ATT CAT ATA TTT	
quercifolia_A	GGT CCA AAG ATG AGA TTC TTA ATG ATA GTT GGT TGT ATT CAT CTA TTT	
quercifolia_B	GGT CCA AAG ATG AGA TTC TTA ATG ATA GTT GGT TGT ATT CAT CTA TTT	
quercifolia_C	GGT CCA AAG ATG AGA TTC TTA ATG ATA GTT GGT TGT ATT CAT CTA TTT	
Bonplandia_geminiflora	--- --- --- --- -C TTA ATG ATA GTT GGT TGT ATT CAT TTA TTT	
Cobaea_pachysepala	GGT CCA AAG ATG AGA TTC TTA ATG ATA GTT GGT TGT ATT CAT CTA TTT	
Cobaea_minor	--- --- --- --- AGA TTC TTA ATG ATA GTT GGT TGT ATT CAT CTA TTT	

Table 18 (cont'd)

flexuosa_A	TCG	CAA	TAA	TAG	CTT	CGT	CTA	CAG	CAG	GAT	TAA	CCG	CAT	TTT	ATA	TGT
flexuosa_B	TCG	CAA	TAA	TAG	CTT	CGT	CTA	CAG	CAG	GAT	TAA	CCG	CAT	TTT	ATA	TGT
cuzcoensis	TCG	CAA	TAA	TAG	CTT	CGT	CTA	CAG	CAG	GAT	TAA	CCG	CAT	TTT	ATA	TGT
bicolor	TCG	CAA	TAA	TAG	CTT	CGT	CTA	CAG	CAG	GAT	TAA	CCG	CAT	TTT	ATA	TGT
buxifolia_A	TCG	CAA	TAA	TAG	CTT	CGT	CTA	CAG	CAG	GAT	TAA	CCG	CAT	TTT	ATA	TGT
buxifolia_B	TCG	CAA	TAA	TAG	CTT	CGT	CTA	CAG	CAG	GAT	TAA	CCG	CAT	TTT	ATA	TGT
buxifolia_C	TCG	CAA	TAA	TAG	CTT	CGT	CTA	CAG	CAG	GAT	TAA	CCG	CAT	TTT	ATA	TGT
candelilla_A	TCG	CAA	TAA	TAG	CTT	CGT	CTA	CAG	CAG	GAT	TAA	CCG	CAT	TTT	ATA	TGT
candelilla_B	TCG	CAA	TAA	TAG	CTT	CGT	CTA	CAG	CAG	GAT	TAA	CCG	CAT	TTT	ATA	TGT
pyrifolia	TCG	CAA	TAA	TAG	CTT	CGT	CTA	CAG	CAG	GAT	TAA	CCG	CAT	TTT	ATA	TGT
n_sp.	TCG	CAA	TAA	TAG	CTT	CGT	CTA	CAG	CAG	GAT	TAA	CCG	CAT	TTT	ATA	TGT
volcanica_A	TCG	CAA	TAA	TAG	CTT	CGT	CTA	CAG	CAG	GAT	TAA	CCG	CAT	TTT	ANA	TGT
volcanica_B	TCG	CAA	TAA	TAG	CTT	CGT	CTA	CAG	CAG	GAT	TAA	CCG	CAT	TTT	ATA	TGT
quercifolia_A	TCG	CAA	TAT	TAG	CTT	CGT	CTA	CAG	CAG	GAT	TAA	CCG	CAT	TTT	ATA	TGT
quercifolia_B	TCG	CAA	TAT	TAG	CTT	CGT	CTA	CAG	CAG	GAT	TAA	CCG	CAT	TTT	ATA	TGT
quercifolia_C	TCG	CAA	TAT	TAG	CTT	CGT	CTA	CAG	CAG	GAT	TAA	CCG	CAT	TTT	ATA	TGT
Bonplandia_geminiflora	TCG	CAA	TAA	TAG	CTT	GGT	CTA	CAG	CAG	GAT	TAA	CCG	CAT	TTT	ATA	TGT
Cobaea_pachysepala	TCG	CAA	TAA	TAG	CTT	GGT	CTA	CAG	CAG	GAT	TAA	CCG	CCT	TTT	ATA	TGT
Cobaea_minor	TCG	CAA	TAA	TAG	CTT	GGT	CTA	CAG	CAG	GAT	TAA	CCG	CCT	TTT	ATA	TGT

Table 18 (cont'd)

	1	1
	4	9
	5	2
flexuosa_A	AAA ATT ACG GTA GCA AAA AAA AAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
flexuosa_B	AAA ATT ACG GTA GCA AAA AAA AAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
cuzcoensis	AAA ATT ACG GTA GCA AAA AAA AAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
bicolor	AAA ATT ACG GTA GCA AAA AAA AAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
buxifolia_A	AAA ATT ACG GTA GCA AAA AAA AAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
buxifolia_B	AAA ATT ACG GTA GCA AAA AAA AAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
buxifolia_C	AAA ATT ACG GTA GCA AAA AAA AAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
candelilla_A	AAA ATT ACG GTA GCA AAA AAA AAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
candelilla_B	AAA ATT ACG GTA GCA AAA AAA AAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
pyrifolia	AAA ATT ACG GTA GCA AAA AAA AAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
n._sp.	AAA ATT ACG GTA GCA AAA AAA AAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
volcanica_A	AAA ATT ACG GTA GCA AAA NAA NAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
volcanica_B	AAA ATT ACG GTA GCA AAA AAA AAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
quercifolia_A	AAA ATT ACG GTA GCA AAA AAA AAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
quercifolia_B	AAA ATT ACG GTA GCA AAA AAA AAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
quercifolia_C	AAA ATT ACG GTA GCA AAA AAA AAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
Bonplandia_geminiflora	AAA ATT ACG GTA GCA AAA AAA AAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
Cobaea_pachysepala	AAA ATT ACG GTA GCA AAA AAA AAA GTA ACT ACT TCT ACT CAA TTT CTC TAT	
Cobaea_minor	AAA ATT ACG GTA GCA AAA AAA AAA ATA ACT ACT TCT ACT CAA TTT CTC TAT	

Table 18 (cont'd)

1	2	3	4	0												
flexuosa_A	GGG	GAC	AGG	CAG	GTT	TGA	AAA	GAA	TTA	ACA	AAA	GTT	TTT	GTT	TTT	TAA
flexuosa_B	GGG	GAC	AGG	CAG	GTT	TGA	AAA	GAA	TTA	ACA	AAA	GTT	TTT	GTT	TTT	TAA
cuzcoensis	GGG	GAC	AGG	CAG	GTT	TGA	AAA	GAA	TTA	ACA	AAA	GTT	TTT	GTT	TTT	TAA
bicolor	GGG	GAC	AGG	CAG	GTT	TGA	AAA	GAA	TTA	ACA	AAA	GTT	TTT	GTT	TTT	TAA
buxifolia_A	GGG	GAC	AGG	CAG	GTT	TGA	AAA	GAA	TTA	ACA	AAA	GTT	TTT	GTT	TTT	TAA
buxifolia_B	GGG	GAC	AGG	CAG	GTT	TGA	AAA	GAA	TTA	ACA	AAA	GTT	TTT	GTT	TTT	TAA
buxifolia_C	GGG	GAC	AGG	CAG	GTT	TGA	AAA	GAA	TTA	ACA	AAA	GTT	TTT	GTT	TTT	TAA
candelilla_A	GGG	GAC	AGG	CAG	GTT	TGA	AAA	GAA	TTA	ACA	AAA	GTT	TTT	GTT	TTT	TAA
candelilla_B	GGG	GAC	AGG	CAG	GTT	TGA	AAA	GAA	TTA	ACA	AAA	GTT	TTT	GTT	TTT	TAA
pyrifolia	GGG	GAC	AGG	CAG	GTT	TGA	AAA	GAA	TTA	ACA	AAA	GTT	TTT	GTT	TTT	TAA
n_sp.	GGG	GAC	AGG	CAG	GTT	TGA	AAA	GAA	TTA	ACA	AAA	GTT	TTT	GTT	TTT	TAA
volcanica_A	GGG	GAC	AGG	CAG	GTT	TGA	AAA	GAA	TTA	ACA	AAA	GTT	TTT	GTT	TTT	TAA
volcanica_B	GGG	GAC	AGG	CAG	GTT	TGA	AAA	GAA	TTA	ACA	AAA	GTT	TTT	GTT	TTT	TAA
quercifolia_A	GGG	GAC	AGG	CAG	GTT	TGA	AAA	GAA	TTA	ACA	AAA	GTT	TTT	GTT	TTT	TAA
quercifolia_B	GGG	GAC	AGG	CAG	GTT	TGA	AAA	GAA	TTA	ACA	AAA	GTT	TTT	GTT	TTT	TAA
quercifolia_C	GGG	GAC	AGG	CAG	GTT	TGA	AAA	GAA	TTA	ACA	AAA	GTT	TTT	GTT	TTT	TAA
Bonplandia_geminiflora	GGG	GGC	AGG	GAG	GTT	TGA	AAA	GAA	TTA	ACA	AAA	GTT	TTT	GTT	TTT	TAA
Cobaea_pachysepala	GGG	GGC	AGG	GAG	GTT	TGA	AAA	TAA	TTA	AAA	AAA	GTT	TTT	GTT	TTT	TAA
Cobaea minor	GGG	GGC	AGG	GAG	GTT	TGA	AAA	TAA	TAA	AAA	AAA	ATG	TTT	GTT	TTT	TAA

Table 18 (cont'd)

	2	2
	4	8
	1	8
flexuosa_A	CCT TAT TAA GAA TGA ATA ATA ATG AAA GTA CTT TGT TTT TTT CAA AGA	
flexuosa_B	CCT TAT TAA GAA TGA ATA ATA ATG AAA GTA CTT TGT TTT TTT CAA AGA	
cuzcoensis	CCT TAT TAA GAA TGA ATA ATA ATG AAA GTA CTT TGT TTT TTT CAA AGA	
bicolor	CCT TAT TAA GAA TAA TGA ATA ATA ATG AAA GTA CTT TGT TTT TTT CAA AGA	
buxifolia_A	CCT TAT TAA GAA TGA ATA ATA ATG AAA GTA CTT TGT TTT TTT CAA AGA	
buxifolia_B	CCT TAT TAA GAA TGA ATA ATA ATG AAA GTA CTT TGT TTT TTT CAA AGA	
buxifolia_C	CCT TAT TAA GAA TGA ATA ATA ATG AAA GTA CTT TGT TTT TTT CAA AGA	
candelilla_A	CCT TAT TAA GAA TGA ATA ATA ATG AAA GTA CTT TGT TTT TTT CAA AGA	
candelilla_B	CCT TAT TAA GAA TGA ATA ATA ATG AAA GTA CTT TGT TTT TTT CAA AGA	
pyrifolia	CCT TAT TAA GAA TGA ATA ATA ATG ACA GTA CTT TGT TTT TTT CAA AGA	
n._sp.	CCT TAT TAA GAA TGA ATA ATA ATG ACA GTA CTT TGT TTT TTT CAA AGA	
volcanica_A	CCT TAT TAA GAA TGA ATA ATA ATG AAA GTA CTT TGT TTT TTT CAA AGA	
volcanica_B	CCT TAT TAA GAA TGA ATA ATA ATG AAA GTA CTT TGT TTT TTT CAA AGA	
quercifolia_A	CCT TAT TAA GAA TGA ATA ATA ATG AAA GTA CTT TGT TTT TTT TAA AGA	
quercifolia_B	CCT TAT TAA GAA TGA ATA ATA ATG AAA GTA CTT TGT TTT TTT TAA AGA	
quercifolia_C	CCT TAT TAA GAA TGA ATA ATA ATG AAA GTA CTT TGT TTT TTT TAA AGA	
Bonplandia_geminiflora	GCT TAT TAA AAA TGA ATA ATA ATG AAA GTA GTT CTC TTT TTT CAA AGA	
Cobaea_pachysepala	CCT TAT TAA GAA TGA ATA ATA ATG AAA GTA CTT CTC TTT TTT CAA AGA	
Cobaea_minor	CCT TAT TAA GAA TTA ATA ATA ATG AAA GTC CTT CTA TTT TTT CAA AGA	

Table 18 (cont'd)

	2	3
	8	3
	9	6
flexuosa_A	AGC CGT ATC GAA TTA ATG ATA ATG	GAA AGC TGA TAC GAC CTT TTA
flexuosa_B	AGC CGT ATC GAA TTA ATG ATA ATG	TAA GAA AGC TGA TAC GAC CTT TTA
cuzcoensis	AGC CGT ATC GAA TTA ATG ATA ATG	TAA GAA AGC TGA TAC GAC CTT TTA
bicolor	AGC CGT ATC GAA TTA ATG ATA ATG	TAA GAA AGC TGA TAC GAC CTT TTA
buxifolia_A	AGC CGT ATC GAA TTA ATG ATA ATG	TAA GAA AGC TGA TAC GAC CTT TTA
buxifolia_B	AGC CGT ATC GAA TTA ATG ATA ATG	TAA GAA AGC TGA TAC GAC CTT TTA
buxifolia_C	AGC CGT ATC GAA TTA ATG ATA ATG	TAA GAA AGC TGA TAC GAC CTT TTA
candelilla_A	AGC CGT ATC GAA TTA ATG ATA ATG	TAA GAA AGC TGA TAC GAC CTT TTA
candelilla_B	AGC CGT ATC GAA TTA ATG ATA ATG	TAA GAA AGC TGA TAC GAC CTT TTA
pyrifolia	AGC CGT ATC GAA TTA ATG ATA ATG	TAA GAA AGC TGA TAC GAC CTT TTA
n._sp.	AGC CGT ATC GAA TTA ATG ATA ATG	TAA GAA AGC TGA TAC GAC CTT TTA
volcanica_A	AGC CGT ATC GAA TTA ATG ATA ATG	TAA GAA AGC TGA TAC GAC CTT TTA
volcanica_B	AGC CGT ATC GAA TTA ATG ATA ATG	TAA GAA AGC TGA TAC GAC CTT TTA
quercifolia_A	AGC CAT ATC GAA TTA ATG ATA ATG	TAA GAA AGT TGA TAC GAC CTT TTA
quercifolia_B	AGC CAT ATC GAA TTA ATG ATA ATG	TAA GAA AGT TGA TAC GAC CTT TTA
quercifolia_C	AGC CAT ATC GAA TTA ATG ATA ATG	TAA GAA AGT TGA TAC GAC CTT TTA
Bonplandia_geminiflora	GGC CGT ATC GAA TTA ATG ATA ATG	TAA GAA AGA TGA TAC GAC CTT TTA
Cobaea_pachysepala	AGC CGT ATC GAA TTA ATG ATA ATG	TAA GAA AGA TGA TAC GAC CTT TTA
Cobaea_minor	AGC CCT ATC AAA TTA ATG ATA ATG	TAA GAA AGA TGA TAC GAC CTT TTC

Table 18 (cont'd)

	3	3	3
	3	3	8
	7	3	4
flexuosa_A	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		
flexuosa_B	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		
cuzcoensis	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		
bicolor	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		
buxifolia_A	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		
buxifolia_B	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		
buxifolia_C	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		
candelilla_A	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		
candelilla_B	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		
pyrifolia	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		
n._sp.	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		
volcanica_A	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		
volcanica_B	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		
quercifolia_A	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		
quercifolia_B	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		
quercifolia_C	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		
Bonplandia_geminiflora	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT TCT ATC CTT ATG		
Cobaea_pachysepala	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		
Cobaea_minor	TTA CTA TTA ATC ATT TTG GCA ACA AAA ATA ATA GTT ATT ATT CCT ATC CTT ATG		

Table 18 (cont'd)

	3	4
	8	3
	5	2
flexuosa_A	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGG TAC TAT TGA	
flexuosa_B	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGG TAC TAT TGA	
cuzcoensis	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGG TAC TAT TGA	
bicolor	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGG TAC TAT TGA	
buxifolia_A	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGG TAC TAT TGA	
buxifolia_B	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGG TAC TAT TGA	
buxifolia_C	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGG TAC TAT TGA	
candelilla_A	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGG TAC TAT TGA	
candelilla_B	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGG TAC TAT TGA	
pyrifolia	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGG TAC TAT TGA	
n._sp.	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGG TAC TAT TGA	
volcanica_A	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGG TAC TAT TGA	
volcanica_B	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGG TAC TAT TGA	
quercifolia_A	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGG TAC TAT TGA	
quercifolia_B	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGG TAC TAT TGA	
quercifolia_C	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGG TAC TAT TGA	
Bonplandia_geminiflora	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGG TAC TAT TGA	
Cobaea_pachysepala	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TCT TAT TGG CAC TAT TGA	
Cobaea_minor	AAT CAG ATA ATA CTA TGT TAT TTC CTC TAC TTT TAT TGT CAC TAT TGA	

Table 18 (cont'd)

	4	4
	3	8
	3	0
flexuosa_A	CTC	TCT TTG TTG TTG GAT TCA TAG GAA TTC CTT TCA ATC AAG AAG GGT TAG
flexuosa_B	CTC	TCT TTG TTG GAT TCA TAG GAA TTC CTT TCA ATC AAG AAG GGT TAG
cuzcoensis	CTC	TCT TTG TTG GAT TCA TAG GAA TTC CTT TCA ATC AAG AAG GGT TAG
bicolor	CTC	TCT TTG TTG GAT TCA TAG GAA TTC CTT TCA ATC AAG AAG GGT TAG
buxifolia_A	CTC	TCT TTG TTG GAT TCA TAG GAA TTC CTT TCA ATC AAG AAA GGT TAG
buxifolia_B	CTC	TCT TTG TTG GAT TCA TAG GAA TTC CTT TCA ATC AAG AAA GGT TAG
buxifolia_C	CTC	TCT TTG TTG GAT TCA TAG GAA TTC CTT TCA ATC AAG AAG GGT TAG
candelilla_A	CTC	TCT TTG TTG GAT TCA TAG GAA TTC CTT TCA ATC AAG AAG GGT TAG
candelilla_B	CTC	TCT TTG TTG GAT TCA TAG GAA TTC CTT TCA ATC AAG AAG GGT TAG
pyrifolia	CTC	TCT TTG TTG GAT TCA TAG GAA TTC CTT TCA ATC AAG AAA GGT TAG
n._sp.	CTC	TCT TTG TTG GAT TCA TAG GAA TTC CTT TCA ATC AAG AAA GGT TAG
volcanica_A	CTC	TCT TTG TTG GAT TCA TAG GAA TTC CTT TCA ATC AAG AAG GGT TGG
volcanica_B	CTC	TCT TTG TTG GAT TCA TAG GAA TTC CTT TCA ATC AAG AAG GGT TGG
quercifolia_A	CTC	TCT TTG TTG GAT TCA TAG GAA TTC CTT TCA ATC AAG AAG GGT TGG
quercifolia_B	CTC	TCT TTG TTG GAT TCA TAG GAA TTC CTT TCA ATC AAG AAG GGT TGG
quercifolia_C	CTC	TCT TTG TTG GAT TCA TAG GAA TTC CTT TCA ATC AAG AAG GGT TGG
Bonplandia_geminiflora	CTC	TTT TTG TTG GAT TCA TAG GAA TTT CTT TCA ATC AAG AAG GGT TGG
Cobaea_pachysepala	CTC	TCT TTG TTG GAT TCA TAG GAA TTC CTT TCA ATC AAG AAG GAT TGG
Cobaea_minor	CTC	TCT TKG TTG GAT TTA TAG GAA TTC CTT TCA ATC AAG AAG GAT TGA

Table 18 (cont'd)

	4	5
	8	2
	1	8
flexuosa_A	ATT TGG ATA TTT TAT CTA AAT GGT TAA CTC CTG CTA TAA ATC TTT TAC	
flexuosa_B	ATT TGG ATA TTT TAT CTA AAT GGT TAA CTC CTG CTA TAA ATC TTT TAC	
cuzcoensis	ATT TGG ATA TTT TAT CCA AAT GGT TAA CTC CTG CTA TAA ATC TTT TAC	
bicolor	ATT TGG ATA TTT TAT CCA AAT GGT TAA CTC CTG CTA TAA ATC TTT TAC	
buxifolia_A	ATT TGG ATA TTT TAT CCA AAT GGT TAA CTC CTG CTA TAA ATC TTT TAC	
buxifolia_B	ATT TGG ATA TTT TAT CCA AAT GGT TAA CTC CTG CTA TAA ATC TTT TAC	
buxifolia_C	ATT TGG ATA TTT TAT CCA AAT GGT TAA CTC CTG CTA TAA ATC TTT TAC	
candelilla_A	ATT TGG ATA TTT TAT CCA AAT GGT TAA CTC CTG CTA TAA ATC TTT TAC	
candelilla_B	ATT TGG ATA TTT TAT CCA AAT GGT TAA CTC CTG CTA TAA ATC TTT TAC	
pyrifolia	ATT TGG ATA TTT TAT CCA AAT GGT TAA CTC CTG CTA TAA ATC TTT TAC	
n._sp.	ATT TGG ATA TTT TAT CCA AAT GGT TAA CTC CTG CTA TAA ATC TTT TAC	
volcanica_A	ATT TGG ATA TTT TAT CCA AAT GGT TAA TGC CTG CTA TAA ATC TTT TAC	
volcanica_B	ATT TGG ATA TTT TAT CCA AAT GGT TAA TGC CTG CTA TAA ATC TTT TAC	
quercifolia_A	ATT TGG ATA TTT TAT CCA AAT GGT TAA CTC CTG CTA TAA ATC TTT TAC	
quercifolia_B	ATT TGG ATA TTT TAT CCA AAT GGT TAA CTC CTG CTA TAA ATC TTT TAC	
quercifolia_C	ATT TGG ATA TTT TAT CCA AAT GGT TAA CTC CTG CTA TAA ATC TTT TAC	
Bonplandia_geminiflora	ATT TGG ATA TTT TAT CAA AAT GGT TAA CTC CTG CTA TAA ATC TTT TAC	
Cobaea_pachysepala	ATT TGG ATA TTT TAT CAA AAT GGT TAA CTC CTG CTA TAA ATC TTT TAC	
Cobaea_minor	ATT TGG ATA TTT TAT CCA AAT GGT TAA CTC CTG CTA TAA ATC TTT TAC	

Table 18 (cont'd)

	5	5
	2	7
	9	6
flexuosa_A	ATC AAA ATT TGA ACA ATT CTT TCG ATT GGG ATG AAT TTT TAA AAG ATG	
flexuosa_B	ATC AAA ATT TGA ACA ATT CTT TCG ATT GGG ATG AAT TTT TAA AAG ATG	
cuzcoensis	ATC AAA ATT TGA ACA ATT CTT TCG ATT GGG ATG AAT TTG TAA AAG ATG	
bicolor	ATC AAA ATT TGA ACA ATT CTT TCG ATT GGG ATG AAT TTG TAA AAG ATG	
buxifolia_A	ATC AAA ATT TGA ACA ATT CTT TCG ATT GGG ATG AAT TTG TAA AAG ATG	
buxifolia_B	ATC AAA ATT TGA ACA ATT CTT TCG ATT GGG ATG AAT TTG TAA AAG ATG	
buxifolia_C	ATC AAA ATT TGA ACA ATT CTT TCG ATT GGG ATG AAT TTG TAA AAG ATG	
candelilla_A	ATC AAA ATT TGA ACA ATT CTT TCG ATT GGG ATG AAT TTG TAA AAG ATG	
candelilla_B	ATC AAA ATT TGA ACA ATT CTT TCG ATT GGG ATG AAT TTG TAA AAG ATG	
pyrifolia	ATC AAA ATT TGA ACA ATT CTT TCG ATT GGG ATG AAT TTG TAA AAG ATG	
n._sp.	ATC CCA ATT TGA AAA ATT CTT TCG AGT GGG ATG AAT TTG TAA AAG ATG	
volcanica_A	ATC CCA ATT TGA AAA ATT CTT TCG AGT GGG ATG AAT TTG TAA AAG ATG	
volcanica_B	ATC CCA ATT TGA AAA ATT CTT TCG AGT GGG ATG AAT TTG TAA AAG ATG	
quercifolia_A	ATC CAA ATT TGC AAA ATT CTT TCG AGT GGG ATG AAT TTG TAA AAG ATG	
quercifolia_B	ATC CAA ATT TGC AAA ATT CTT TCG AGT GGG ATG AAT TTG TAA AAG ATG	
quercifolia_C	ATC CAA ATT TGC AAA ATT CTT TCG AGT GGG ATG AAT TTG TAA AAG ATG	
Bonplandia_geminiflora	ATC CAA ATT TGA AAA ATT ATT TCG ATT GGT ATG AAT TTG TAA AAG ATG	
Cobaea_pachysepala	ATC AAA ATT GGA AAA ATT CTT TCG ATN GGT ATG AAT TTG TAA AAG ATG	
Cobaea_minor	ATC CAA ATT GGA AAA ATT ATT TCG ATT GGT ATG AAT TTG TAA AAG ATA	

Year	Number of cases
2015	5
2016	7
2017	7
2018	7
2019	4
2020	2
2021	6

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Table 18 (cont'd)

	6	6
	2	7
	5	2
flexuosa_A	TTT TCT ATA AAC CTT TTT ATT CAT CTT TGC AAA ATT TTG ATT TAA TTA	TTA
flexuosa_B	TTT TCT ATA AAC CTT TTT ATT CAT CTT TGC AAA ATT TTG ATT TAA TTA	TTA
cuzcoensis	TTT TCT ATA AAC CTT TTT ATT CAT CTT TGC AAA ATT TTG ATT TAA TTA	TTA
bicolor	TTT TCT ATA AAC CTT TTT ATT CAT CTT TGC AAA ATT TTG ATT TAA TTA	TTA
buxifolia_A	TTT TCT ATA AAC CTT TTT ATT CAT CTT TGC AAA ATT TTG ATT TAA TTA	TTA
buxifolia_B	TTT TCT ATA AAC CTT TTT ATT CAT CTT TGC AAA ATT TTG ATT TAA TTA	TTA
buxifolia_C	TTT TCT ATA AAC CTT TTT ATT CAT CTT TGC AAA ATT TTG ATT TAA TTA	TTA
candelilla_A	TTT TCT ATA AAC CTT TTT ATT CAT CTT TGC AAA ATT TTG ATT TAA TTA	TTA
candelilla_B	TTT TCT ATA AAC CTT TTT ATT CAT CTT TGC AAA ATT TTG ATT TAA TTA	TTA
pyrifolia	TTT TCT ATA AAC CTT TTT ATT CAT CTT TGC AAA ATT TTG ATT TAA TTA	TTA
n._sp.	TTT TCT ATA AAC CTT TTT ATT CAT CTT TGC AAA ATT TTG ATT TAA TTA	TTA
volcanica_A	TTT TCT ANA AAC CTT TTT ATT CAT CTT TGC AAA ATT TTN ANT TAA TTA	TTA
volcanica_B	TTT TCT ATA AAC CTT TTT ATT CAT CTT TGC AAA ATT TTT ATT TAA TTA	TTA
quercifolia_A	TTT TCT ATA AAC CTT TTT ATT CAT CTT TGC AAA ATT TTG ATT TAA TTA	TTA
quercifolia_B	TTT TCT ATA AAC CTT TTT ATT CAT CTT TGC AAA ATT TTG ATT TAA TTA	TTA
quercifolia_C	TTT TCT ATA AAC CTT TTT ATT CAT CTT TGC AAA ATT TTG ATT TAA TTA	TTA
Bonplandia_geminiflora	TTT TGT ATA ACC CTT T-- --- --- --- --- --- ---	---
Cobaea_pachysepala	TTT TCT ATA AAC CTT --- --- --- --- --- --- ---	---
Cobaea_minor	TTT TCT ATA AAC CTT T-- --- --- --- --- --- ---	---

Table 18 (cont'd)

	6	7	2	0												
	7															
	3															
flexuosa_A	ATT	CAT	TTG	TTA	AAA	TGG	GCT	CTA	AGA	GAA	TTT	TAG	GGG	ACA	ACA	TAA
flexuosa_B	ATT	CAT	TTG	TTA	AAA	TGG	GCT	CTA	AGA	GAA	TTT	TAG	GGG	ACA	ACA	TAA
cuzcoensis	ATT	CAT	TTG	TTA	AAA	TGG	GCT	CTA	AGA	TAA	TTT	TAT	GGG	ACA	ACA	TAA
bicolor	ATT	CAT	TTG	TTA	AAA	TGG	GCT	CTA	AGA	GAA	TTT	TAG	GGG	ACA	ACA	TAA
buxifolia_A	ATT	CAT	TTG	TTA	AAA	TGG	GCT	CTA	AGA	GAA	TTT	TAG	GGG	ACA	ACA	TAA
buxifolia_B	ATT	CAT	TTG	TTA	AAA	TGG	GCT	CTA	AGA	GAA	TTT	TAG	GGG	ACA	ACA	TAA
buxifolia_C	ATT	CAT	TTG	TTA	AAA	TGG	GCT	CTA	AGA	GAA	TTT	TAG	GGG	ACA	ACA	TAA
candelilla_A	ATT	CAT	TTG	TTA	AAA	TGG	GCT	CTA	AGA	GAA	TTT	TAG	GGG	ACA	ACA	TAA
candelilla_B	ATT	CAT	TTG	TTA	AAA	TGG	GCT	CTA	AGA	GAA	TTT	TAG	GGG	ACA	ACA	TAA
pyrifolia	ATT	CAT	TTG	TTA	AAA	TGG	GCT	CTA	AGA	GAA	TTT	TAG	GGG	ACA	ACA	TAA
n._sp.	ATT	CAT	TTG	TTA	AAA	TGG	GCT	CTA	AGA	GAA	TTT	TAG	GGG	ACA	ACA	TAA
volcanica_A	ATT	CAT	TTG	TTA	AAA	TGG	GCT	CTA	AGA	GAA	TTT	TAG	GGG	ACA	ACA	TAA
volcanica_B	ATT	CAT	TTG	TTA	AAA	TGG	GCT	CTA	AGA	GAA	TTT	TAG	GGG	ACA	ACA	TAA
quercifolia_A	ATT	CAT	TTG	TTA	AAA	TGG	GCT	CTA	AGA	GAA	TTT	TAG	GGG	ATA	ACA	TAA
quercifolia_B	ATT	CAT	TTG	TTA	AAA	TGG	GCT	CTA	AGA	GAA	TTT	TAG	GGG	ATA	ACA	TAA
quercifolia_C	ATT	CAT	TTG	TTA	AAA	TGG	GCT	CTA	AGA	GAA	TTT	TAG	GGG	ATA	ACA	TAA
Bonplandia_geminiflora	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Cobaea_pachysepala	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Cobaea_minor	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Table 18 (cont'd)

	7	7
	2	6
	1	8
flexuosa_A	AGA CTT TCA TAT ATG ATT GGT CAT ATA ATC GTG GTT ACA TAG ATG CTT	
flexuosa_B	AGA CTT TCA TAT ATG ATT GGT CAT ATA ATC GTG GTT ACA TAG ATG CTT	
cuzcoensis	AGA CTT TCA TAT ATG ATT GGT CAT ATA ATC GTG GTT ACA TCG ATG CTT	
bicolor	AGA CTT TCA TAT ATG ATT GGT CAT ATA ATC GTG GTT ACA TAG ATG CTT	
buxifolia_A	AGA CTT TCA TAT ATG ATT GGT CAT ATA ATC GTG GTT ACA TAG ATG CTT	
buxifolia_B	AGA CTT TCA TAT ATG ATT GGT CAT ATA ATC GTG GTT ACA TAG ATG CTT	
buxifolia_C	AGA CTT TCA TAT ATG ATT GGT CAT ATA ATC GTG GTT ACA TAG ATG CTT	
candelilla_A	AGA CTT TCA TAT ATG ATT GGT CAT ATA ATC GTG GTT ACA TAG ATG CTT	
candelilla_B	AGA CTT TCA TAT ATG ATT GGT CAT ATA ATC GTG GTT ACA TAG ATG CTT	
pyrifolia	AGA CTT TCA TAT ATG ATT GGT CAT ATA ATC GTG GTT ACA TAG ATG CTT	
n._sp.	AGA CTT TCA TAT ATG ATT GGT CAT ATA ATC GTG GTT ACA TAG ATG CTT	
volcanica_A	AGA CTT TCA TAT ATG ATT GGT CAT ATA ATC GTG GTT ACA TAG ATG CTT	
volcanica_1	AGA CTT TCA TAT ATG ATT GGT CAT ATA ATC GTG GTT ACA TAG ATG CTT	
quercifolia_A	AGA CTT TCA TAT ATG ATT GGT CAT ATA ATC GTG GTT ACA TAG ATG CTT	
quercifolia_B	AGA CTT TCA TAT ATG ATT GGT CAT ATA ATC GTG GTT ACA TAG ATG CTT	
quercifolia_C	AGA CTT TCA TAT ATG ATT GGT CAT ATA ATC GTG GTT ACA TAG ATG CTT	
Bonplandia_geminiflora	--- --- --- --- --- --- --- --- --- --- --- ---	
Cobaea_pachysepala	--- --- --- --- --- --- --- --- --- --- --- ---	
Cobaea_minor	--- --- --- --- --- --- --- --- --- --- --- ---	

Table 18 (cont'd)

	7	8
	6	1
	9	6
flexuosa_A	TTT ATG CAG CAT CCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
flexuosa_B	TTT ATG CAG CAT CCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
cuzcoensis	TTT ATG CAG CAT CCT TAA CTG TCG GTA TAA GAG GAT TGG CTG AAT TAA	
bicolor	TTT ATG CAG CAT CCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
buxifolia_A	TTT ATG CAG CAT CCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
buxifolia_B	TTT ATG CAG CAT CCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
buxifolia_C	TTT ATG CAG CAT CCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
candelilla_A	TTT ATG CAG CAT CCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
candelilla_B	TTT ATG CAG CAT CCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
pyrifolia	TTT ATG CAG CAT CCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
n._sp.	TTT ATG CAG CAT CCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
volcanica_A	TTT ATG CAG CAT CCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
volcanica_B	TTT ATG CAG CAT CCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
quercifolia_A	TTT ATG CAG CAT CCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
quercifolia_B	TTT ATG CAG CAT CCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
quercifolia_C	TTT ATG CAG CAT CCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
Bonplandia_geminiflora	TTT ATA CAG CAT TCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
Cobaea_pachysepala	TTT ATA CAG CAT TCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
Cobaea_minor	TTT ATA CAG CAT TCT TAA CTG TCG GGA TAA GAG GAT TGG CTG AAT TAA	
	---	---
	---	---
	---	---

Table 18 (cont'd)

	8	8
	1	6
	7	4
flexuosa_A	CTC ATT TTT TTG ATA TAC GAG TAA TAG ATG GAA TTA CAA ATG GAG TTG	TTG
flexuosa_B	CTC ATT TTT TTG ATA TAC GAG TAA TAG ATG GAA TTA CAA ATG GAG TTG	TTG
cuzcoensis	CTC ATT TTT TTG ATA TAC GAG TAA TAG ATG GAA TTA CAA ATG GAG TTG	TTG
bicolor	CTC ATT TTT TTG ATA TAC GAG TAA TAG ATG GAA TTA CAA ATG GAG TTG	TTG
buxifolia_A	CTC ATT TTT TTG ATA GAC GAG TAA TAG ATG GAA TTA CAA ATG GAG TTG	TTG
buxifolia_B	CTC ATT TTT TTG ATA GAC GAG TAA TAG ATG GAA TTA CAA ATG GAG TTG	TTG
buxifolia_C	CTC ATT TTT TTG ATA TAC GAG TAA TAG ATG GAA TTA CAA ATG GAG TTG	TTG
candelilla_A	CTC ATT TTT TTG ATA TAC GAG TAA TAG ATG GAA TTA CAA ATG GAG TTG	TTG
candelilla_B	CTC ATT TTT TTG ATA TAC GAG TAA TAG ATG GAA TTA CAA ATG GAG TTG	TTG
pyrifolia	CTC ATT TTT TTG ATA GAC GAG TAA TAG ATG GAA TTA CAA ATG GAG TTG	TTG
n._sp.	CTC ATT TTT TTG ATA GAC GAG TAA TAG ATG GAA TTA CAA ATG GAG TTG	TTG
volcanica_A	CTT ATT TTT TTG ATA GAC GAG TAA TAG ATG GAA TTA CGA ATG GAG TTG	TTG
volcanica_B	CTT ATT TTT TTG ATA GAC GAG TAA TAG ATG GAA TTA CGA ATG GAG TTG	TTG
quercifolia_A	CTG ATT TTT TTG ATA GAC GAG TAA TAG ATG GAA TTA CGA ATG GAG TTG	TTG
quercifolia_B	CTG ATT TTT TTG ATA GAC GAG TAA TAG ATG GAA TTA CGA ATG GAG TTG	TTG
quercifolia_C	CTT ATT TTT TTG ATA GAC GAG TAA TAG ATG GAA TTA CGA ATG GAG TTG	TTG
Bonplandia_geminiflora	---	---
Cobaea_pachysepala	---	---
Cobaea_minor	---	---

Table 18 (cont'd)

	8	9
	6	1
	5	2
flexuosa_A	GTT TGA TGA TGA GTT TTT TTG TAG GAG AGG GCA TCA AAT ATG TAG GGA GTG	
flexuosa_B	GTT TGA --- --- --- --- --- --- --- --- ---	
cuzcoensis	GTT TGA TGA GTT TTT TTG TAG GAG AGG GCA TCA AAT ATG TAG GGG GGG	
bicolor	GTT TGA TGA GTT TTT TTG TAG GAG AGG GCA TCA AAT ATG TAG GGG GTG	
buxifolia_A	GTT TTA TGA GTT TTT TTG TAG GAG AGG GCA TCA AAT ATG TAG GGG GTG	
buxifolia_B	GTT TTA TGA GTT TTT TTG TAG GAG AGG GCA TCA AAT ATG TAG GGG GTG	
buxifolia_C	GTT TGA TGA GTT TTT TTG TAG GAG AGG GCA TCA AAT ATG TAG GGG GTG	
candelilla_A	GTT TGA TGA GTT TTT TTG TAG GAG AGG GCA TAA AAT ATG TAG GGG GTG	
candelilla_B	GTT TGA TGA GTT TTT TTG TAG GAG AGG GCA TAA AAT ATG TAG GGG GTG	
pyrifolia	GTT TTA TGA GTT TTT TTG TAG GAG AGG GCA TCA AAT ATG TAG GGG GTG	
n._sp.	GTT TTA TGA GTT TTT TTG TAG GAG AGG GCA TCA AAT ATG TAG GGG GTG	
volcanica_A	GTT TTA TGA GTT TTT TTG TAG GAG AGG GCA TCA AAT ATG TAG GGG GTG	
volcanica_B	GTT TTA TGA GTT TTT TTG TAG GAG AGG GCA TCA AAT ATG TAG GGG GTG	
quercifolia_A	GTT TTA TGA GTT TTT TTG TAG GAG AGG GCA TCA AAT ATG TAG GGG GTG	
quercifolia_B	GTT TTA TGA GTT TTT TTG TAG GAG AGG GCA TCA AAT ATG TAG GGG GTG	
quercifolia_C	GTT TTA TGA GTT TTT TTG TAG GAG AGG GCA TCA AAT ATG TAG GGG GTG	
Bonplandia_geminiflora	--- --- --- --- --- --- --- --- ---	
Cobaea_pachysepala	--- --- --- --- --- --- --- --- ---	
Cobaea_minor	--- --- --- --- --- --- --- --- ---	

9 3 8

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APPENDIX G

Aligned sequences of *Cantua*:
nuclear ribosomal internal transcribed spacer regions and 5.8S ribosomal RNA gene

Table 19 (cont'd)

	4	9	9	6
	↓Indel 5	↓Indel 7	↓Indel 9	↓Indel 10
		↓Indel 8		Indel 11↓
flexuosa_A	GGG GGC GCG ATC GAT :CG A:C TCC GGT CCT CGG TCG TTG CCA CCG CGT			
flexuosa_B	GGG GGC GCG ATC GAT :CG A:C TCC GGT CCT CGG TCG TTG CCA CCG CGT			
cuzcoensis	GGG GGC GCG ATC GAT :CG A:C TCC GGT CCT CGG TCG TTG CCA CCG CGT			
bicolor	GGG GGC GCG ATC GAT :CG A:C TCC GGT CCT CGG TCG TTG CCA TCG CGT			
buxifolia_A	GGG GGC GCG ATC GAT :CG A:C TCC GGT CCT CGG TCG TTG CCA CCG CGT			
buxifolia_B	GGG GGC GCG ATC GAT :CG A:C TCC GGT CCT CGG TCG TTG CCA CCG CGT			
buxifolia_C	GGG GGC GCG ATC GAT :CG A:C TCC GGT CCT CGG TCG TTG CCA CCG CGT			
candelilla_A	GGG GGC GCG ATC GAT :CG A:C TCC GGT CCT CGG TCG TTG CCA CCG CGT			
candelilla_B	GGG GGC GCG ATC GAT :CG A:C TCC GGT CCT CGG TCG TTG CCA CCG CGT			
pyrifolia	GGG GGC GCG ATC GAT :CG A:C TCC GGT CCT CGG TCG TTG CCA CCG CGT			
n._sp.	GGG GGC GCG ATC GAT :CG A:C TCC GGT CCT CGG TCG TTG CCA CCG CGT			
volcanica_A	GGG GGC GCG ATC GAT :CG A:C TCC GGT CCT CGG TCG TTG CCA CCG CGT			
volcanica_B	GGG GGC GCG ATC GAT :CG A:C TCC GGT CCT CGG TCG TTG CCA CCG CGT			
quercifolia_A	GGG TGC ACG GTC GAT :TG G:C TTT GGT CAT CGG TCG TTG CCA CCG CGT			
quercifolia_B	GGG TGC ACG GTC GAT :TG G:C TTT GGT CAT CGG TCG TTG CCA CCG CGT			
quercifolia_C	GGG TGC ACG GTC GAT :TG G:C TTT GGT CAT CGG TCG TTG CCA CCG CGT			
Bonplandia_geminiflora	GGG TGC ACG GTC GAT :TG G:C TTT GGT CAT CGG TCG TTG CCA CCG CGT			
Cobaea_pachysepala	:GG GGC ACT CGG CCT TCG AAC TCC GGT CCT CGG TCG TTG CCA CCG CGT			
Cobaea_minor	GGT GGC ACA ATT G:: :CG GAC TTC GGT CCT CAT TTG TTC C:: CCT TT:			
	GGT GGC ACG ATC G:: :TA GAC TTC GGT CCT CGG TCG TTG C:: CCC TCA			

Table 19 (cont'd)

	9	1
	7	4
		4
	↓Indel12	↓Indel 19
	↓Indel 13 ↓Indel 15	↓Indel 20
	↓Indel 14	Indel 21↓
flexuosa_A	CGG TGG YGT AGT CAC TTG CCT ::: :GG CGA GAG CTT C:G GCA TTG ATT	
flexuosa_B	CGG TGG YGT AGT CAC TTG CCT ::: :GG CGA GAG CTT C:G GCA TTG ATT	
cuzcoensis	CGG TGG CGT AGT CAC TTG CCT ::: :GG CGA GAG CTT C:G GCA TTG ATT	
bicolor	CGG TGG CGT AGT CAC TTG CCT ::: :GG CGA GAG CTT C:G GCA TTG ATT	
buxifolia_A	CGG TGG CGT AGT CAC TTG CCT ::: :GG CGA GAG CTT C:G GCA TTG ATT	
buxifolia_B	CGG TGG CGT AGT CAC TTG CCT ::: :GG CGA GAG CTT C:G GCA TTG ATT	
buxifolia_C	CGG TGG CGT AGT CAC TTG CCT ::: :GG CGA GAG CTT C:G GCA TTG ATT	
candelilla_A	CGG TGG CGT AGT CAC TTG CCT ::: :GG CGA GAG CTT C:G GCA TTG ATT	
candelilla_B	CGG TGG CGT AGT CAC TTG CCT ::: :GG CGA GAG CTT C:G GCA TTG ATT	
pyrifolia	CGG TGG CGT AGT CAC TTG CCT ::: :GG CGA GAG CTT C:G GCA TTG ATT	
n._sp.	CGG TGG CGT AGT CAC TTG CCT ::: :GG CGA GAG CTT C:G GCA TTG ATT	
volcanica_A	CGG TGG TGT AAC CAC TTG CTT ::: :GG CGT GAG CTT C:G GCA TTG GTT	
volcanica_B	CGG TGG TGT AAC CAC TTG CTT ::: :GG CGT GAG CTT C:G GCA TTG GTT	
quercifolia_A	TGG TGG TGT GAC CAC TCG CCC CAG CGG CGT GAG CTT CTG GTG ATG GTT	
quercifolia_B	TGG TGG TGT GAC CAC TCG CCC :AG CGG CGT GAG CTT CTG GTG ATG GTT	
quercifolia_C	TGG TGG TGT GAC CAC TCG CCC :GG CGG CGT GAG CTT CTG GTG ATG GTT	
Bonplandia_geminiflora	G:T CGG :GA TG: CAC GCA CCG :CG CGG CGA AAG CTC GCG AG: GCG :T	
Cobaea_pachysepala	GCT :GG TGA TGC AGT CGT TTC ATA :G CGA GAG CTC T:G TCA ATT ACT	
Cobaea_minor	GCT :GG TGA TGT GGT CAT TTC ACA :G CGA GAG CTT T:G TCA CTG ACT	

Table 19 (cont'd)

		v5.8s Ribosomal DNA	
	2		2
	4		8
	1		8
		↓Indel126 ↓Indel 27	
		↓Indel 28	
flexuosa_A	CYG AAG GAC AGA G:C CAT CTT ACA CGG AAC AAA ACG ACT CTC GGC AAC		
flexuosa_B	CCG AAG GAC AGA G:C CAT CTT ACA CGG AAC AAA ACG ACT CTC GGC AAC		
cuzcoensis	CCG AAG GAC AGA G:C CAT CTT ACA CGG AMC AAA ACG ACT CTC GGC AAC		
bicolor	CCG AAG GAC AGA G:C CAT CTT ACA CGA AAC AAA ATG ACT CTC GGC AAC		
buxifolia_A	CCG AAG GAC ATA G:C CAT CTT ACA CGG AMC AAA ACG ACT CTC GGC AAC		
buxifolia_B	CCG AAG GAC AKA G:C CAT CTT ACA CGG ACC AAA ACG ACT CTC GGC AAC		
buxifolia_C	CCG AAG GAC ATA G:C CAT CTT ACA CGG AAC AAA ACG ACT CTC GGC AAC		
candelilla_A	CCG AAG GAC AGA G:C CAT CTT ACA CGG AAC AAA ACG ACT CTC GGC AAC		
candelilla_B	CCG AAG GAC AGA G:C CAT CTT ACA CGG AAC AAA ACG ACT CTC GGC AAC		
pyrifolia	CCG AAG GAC GGA G:C CAT CTT ACA CGG AAC AAA ACG ACT CTC GGC AAC		
n_sp.	CCG AAG GAC GGA G:C CAT CTT ACA CGG AAC AAA ACG ACT CTC GGC AAC		
volcanica_A	CTG ATG GTG CGT GGC CAT CTC ACA TGA AAT TGA ACG ACT CTC GGC AAC		
volcanica_B	CTG ATG GTG CGT GGC CAT CTC ACA TGA AAT TGA ACG ACT CTC GGC AAC		
quercifolia_A	TCG AAG GGG TGC GGC CAT CTG ACG CGA AAT GAA ATG ACT CTC GGC AAC		
quercifolia_B	TCG AAG GGG TGC GGC CAT CTG ACG CGA AAT TAA ATG ACT CTC GGC AAC		
quercifolia_C	TCG AAG GGG TGC GGC CRT CTG ACG CGA AAT GAA ATG ACT CTC GGC AAC		
Bonplandia_geminiflora	CCG AAG G:G CAA TGC CAT CTT ACT CAA TAC TAA ACG ACT CTC GGC AAC		
Cobaea_pachysepala	TCA AAG G:G CAA TGC TGT CTT ACA CAA TAC --- --- --- --- ---		
Cobaea_minor	CTG AAG G:G AAA AGC T:T CTT ACA CAA TAC --- --- --- --- ---		

Table 19 (cont'd)

2	3
8	3
9	6
flexuosa_A	GGA TAT CTC GGC TCT CGC ATC GAT GAA GAA CGT AGC GAA ATG CGA TAC
flexuosa_B	GGA TAT CTC GGC TCT CGC ATC GAT GAA GAA CGT AGC GAA ATG CGA TAC
cuzcoensis	GGA TAT CTC GGC TCT CGC ATC GAT GAA GAA CGT AGC GAA ATG CGA TAC
bicolor	GGA TAT CTC GGC TCT CGC ATC GAT GAA GAA CGT AGC GAA ATG CGA TAC
buxifolia_A	GGA TAT CTC GGC TCT CGC ATC GAT GAA GAA CGT AGC GAA ATG CGA TAC
buxifolia_B	GGA TAT CTC GGC TCT CGC ATC GAT GAA GAA CGT AGC GAA ATG CGA TAC
buxifolia_C	GGA TAT CTC GGC TCT CGC ATC GAT GAA GAA CGT AGC GAA ATG CGA TAC
candelilla_A	GGA TAT CTC GGC TCT CGC ATC GAT GAA GAA CGT AGC GAA ATG CGA TAC
candelilla_B	GGA TAT CTC GGC TCT CGC ATC GAT GAA GAA CGT AGC GAA ATG CGA TAC
pyrifolia	GGA TAT CTC GGC TCT CGC ATC GAT GAA GAA CGT AGC GAA ATG CGA TAC
n._sp.	GGA TAT CTC GGC TCT CGC ATC GAT GAA GAA CGT AGC GAA ATG CGA TAC
volcanica_A	GGA TAT CTC GGC TCT CGC ATC GAT GAA GAA CGT AGC GAA ATG CGA TAC
volcanica_B	GGA TAT CTC GGC TCT CGC ATC GAT GAA GAA CGT AGC GAA ATG CGA TAC
quercifolia_A	GGA TAT CTC GGC TCT CGC ATC GAT GAA GAA CGT AGC GAA ATG CGA TAC
quercifolia_B	GGA TAT CTC GGC TCT CGC ATC GAT GAA GAA CGT AGC GAA ATG CGA TAC
quercifolia_C	GGA TAT CTC GGC TCT CGC ATC GAT GAA GAA CGT AGC GAA ATG CGA TAC
Bonplandia_geminiflora	GGA TAT CTC GGC TCT CGC ATC GAT GAA GAA CGT AGC GAA ATG CGA TAC
Cobaea_pachysepala	--- --- --- --- --- --- --- --- --- --- --- ---
Cobaea_minor	--- --- --- --- --- --- --- --- --- --- --- ---

Table 19 (cont'd)

	3	3
	3	8
	7	4
flexuosa_A	TTG GTG TGA ATT GCA GAA TCC CGT GAA CCA TCG AGT TTT TGA ACG CAA	
flexuosa_B	TTG GTG TGA ATT GCA GAA TCC CGT GAA CCA TCG AGT TTT TGA ACG CAA	
cuzcoensis	TTG GTG TGA ATT GCA GAA TCC CGT GAA CCA TCG AGT TTT TGA ACG CAA	
bicolor	TTG GTG TGA ATT GCA GAA TCC CGT GAA CCA TCG AGT TTT TGA ACG CAA	
buxifolia_A	TTG GTG TGA ATT GCA GAA TCC CGT GAA CCA TCG AGT TTT TGA ACG CAA	
buxifolia_B	TTG GTG TGA ATT GCA GAA TCC CGT GAA CCA TCG AGT TTT TGA ACG CAA	
buxifolia_C	TTG GTG TGA ATT GCA GAA TCC CGT GAA CCA TCG AGT TTT TGA ACG CAA	
candelilla_A	TTG ATG TGA ATT GCA GAA TCC CGT GAA CCA TCG AGT TTT TGA ACG CAA	
candelilla_B	TTG ATG TGA ATT GCA GAA TCC CGT GAA CCA TCG AGT TTT TGA ACG CAA	
pyrifolia	TTG GTG TGA ATT GCA GAA TCC CGT GAA CCA TCG AGT TTT TGA ACG CAA	
n._sp.	TTG GTG TGA ATT GCA GAA TCC CGT GAA CCA TCG AGT TTT TGA ACG CAA	
volcanica_A	TTG GTG TGA ATT GCA GAA TCC CGT GAA CCA TCG AGT TTT TGA ACG CAA	
volcanica_B	TTG GTG TGA ATT GCA GAA TCC CGT GAA CCA TCG AGT TTT TGA ACG CAA	
quercifolia_A	TTG GTG TGA ATT GCA GAA TCC CGT GAA CCA TCG AGT TTT TGA ACG CAA	
quercifolia_B	TTG GTG TGA ATT GCA GAA TCC CGT GAA CCA TCG AGT TTT TGA ACG CAA	
quercifolia_C	TTG GTG TGA ATT GCA GAA TCC CGT GAA CCA TCG AGT TTT TGA ACG CAA	
Bonplandia_geminiflora	TTG GTG TGA ATT GCA GAA TCC CGT GAA CCA TCG AGT TTT TGA ACG CAA	
Cobaea_pachysepala	---	---
Cobaea_minor	---	---

Table 19 (cont'd)

	3	4
	8	3
	5	2
flexuosa_A	GTT GCG CCC GAA GCC ATT AGG CCG AGG GCA CGT CTG CCT GGG CGT CTC	CTC
flexuosa_B	GTT GCG CCC GAA GCC ATT AGG CCG AGG GCA CGT CTG CCT GGG CGT CTC	CTC
cuzcoensis	GTT GCG CCC GAA GCC ATT AGG CCG AGG GCA CGT CTG CCT GGG CGT CTC	CTC
bicolor	GTT GCG CCC GAA GCC ATT AGG CCG AGG GCA CGT CTG CTT GGG CGT CTC	CTC
buxifolia_A	GTT GCG CCC GAA GCC ATT AGG CCG AGG GCA CGT CTG CCT GGG CGT CTC	CTC
buxifolia_B	GTT GCG CCC GAA GCC ATT AGG CCG AGG GCA CGT CTG CCT GGG CGT CTC	CTC
buxifolia_C	GTT GCG CCC GAA GCC ATT AGG CCG AGG GCA CGT CTG CCT GGG CGT CTC	CTC
candelilla_A	GTT GCG CCC GAA GCC ATT AGG CCG AGG GCA CGT CTG CCT GGG CGT CTC	CTC
candelilla_B	GTT GCG CCC GAA GCC ATT AGG CCG AGG GCA CGT CTG CCT GGG CGT CTC	CTC
pyrifolia	GTT GCG CCC GAA GCC ATT AGG CCG AGG GCA CGT CTG CCT GGG CGT CTC	CTC
n._sp.	GTT GCG CCC GAA GCC ATT AGG CCG AGG GCA CGT CTG CCT GGG CGT CTC	CTC
volcanica_A	GTT GCG CCC GAA GCC ATT AGG CCG AGG GCA CGT CTG CCT GGG CGT CTC	CTC
volcanica_B	GTT GCG CCC GAA GCC ATT AGG CCG AGG GCA CGT CTG CCT GGG CGT CTC	CTC
quercifolia_A	GTT GCG CCC GAA GCC ATT AGG CCG AGG GCA CGT CTG CCT GGG CGT CTC	CTC
quercifolia_B	GTT GCG CCC GAA GCC ATT AGG CCG AGG GCA CGT CTG CCT GGG CGT CTC	CTC
quercifolia_C	GTT GCG CCC GAA GCC ATT AGG CCG AGG GCA CGT CTG CCT GGG CGT CTC	CTC
Bonplandia_geminiflora	GTT GCG CCC GAA GCC ATT AGG CCG AGG GCA CGT CTG CCT GGG CGT CTC	CTC
Cobaea_pachysepalata	---	---
Cobaea_minor	---	---

▼ITs2

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Table 19 (cont'd)

	4	5
	8	2
	1	8
	↓Indel 34	
	↓Indel 35	
flexuosa_A	GGG :CG GAA ATT GGC CTC CCG CGC ACT GCG TTG AGC GGT TGG CCC AAA	
flexuosa_B	GGG :CG GAA ATT GGC CTC CCG CGC ACT GCG TTG AGC GGT TGG CCC AAA	
cuzcoensis	GGG :CG GAA ATT GGT CTC CCG CGC ACT GCG TTG AGC GGT TGG CCY AAA	
bicolor	GGG :CG GAA ATT GGT CTC CCG CGC ACT GCG TTG AGC GGT TGG CCC AAA	
buxifolia_A	GGG :CG GAA ATT GGT CTC CCG CGC ACT RCG TTG AGC GGT TGG CCY AAA	
buxifolia_B	GGG :CG GAA ATT GGT CTC CCG CGC ACT RCG TTG AGC GGT TGG CCY AAA	
buxifolia_C	GGG :CG GAA ATT GGT CTC CCG CGC ACT ACG TTG AGC GGT TGG CCC AAA	
candelilla_A	GGG :CG GAA ATT GGT CTC CCG CGC ACT ACG TTG AGC GGT TGG CCT AAA	
candelilla_B	GGG :CG GAA ATT GGT CTC CCG CGC ACT ACG TTG AGC GGT TGG CCT AAA	
pyrifolia	GGG :CG GAA ATT GGT CTC CCG CGC ACT ACG TTG AGC GGT TGG CCT AAA	
n._sp.	GGG :CG GAA ATT GGT CTC CCG CGC ACT ACG TTG AGC GGT TGG CCT AAA	
volcanica_A	GGG :CG GAA ATT GGT CTC CCG TGC AAA TTA TTG AGC GGT TGG CCT AAA	
volcanica_B	GGG :CG GAA ATT GGT CTC CCG TGC AAA TTA TTG AGC GGT TGG CCT AAA	
quercifolia_A	GGG :CG GAG ATT GGC CTC CCG TGC ACA TCG TTG AGC GGT TGG CCT AAA	
quercifolia_B	GGG :CG GAG ATT GGC CTC CCG TGC ACA TCG TTG AGC GGT TGG CCT AAA	
quercifolia_C	GGG :CG GAG ATT GGC CTC CCG TGC ACA TCG TTG AGC GGT TGG CCT AAA	
Bonplandia_geminiflora	GGA GCG GAA ATT GGT CTC CCG TGC GCC TAG CCG TGC GGT TGG CCT AAA	
Cobaea_pachysepala	G:A GCG GAA ATT GGT TTC CCG TGC ACA TTG TTG TGT TGG CCT AAA	
Cobaea_minor	GGA GCG GAA ATT GGT CTC CCG TGC ACT TTG TTG TGC GGT TGG CCT AAA	

5 2 9

259

5

9

2

2

2

4

260

[illegible]

Table 19 (cont'd)

	INDEL CODING CON'T															
flexuosa_A	111	111	122	222	222	222	223	333	333	333	444	444	444			
flexuosa_B	345	678	901	234	567	890	123	456	789	012	345					
cuzcoensis	↓ ↓ ↓	↓ ↓ ↓	↓ ↓ ↓	↓ ↓ ↓	↓ ↓ ↓	↓ ↓ ↓	↓ ↓ ↓	↓ ↓ ↓	↓ ↓ ↓	↓ ↓ ↓	↓ ↓ ↓	↓ ↓ ↓	↓ ↓ ↓			
bicolor	AAA	C-A	CAA	CCC	AAC	ACC	-AC	ACA	AAC	CAA	CCA					
buxifolia_A	AAA	C-A	CAA	CCC	AAC	ACC	-AC	ACA	AAC	CAA	CCA					
buxifolia_B	AAA	C-A	CAA	CCC	AAC	ACC	-AC	ACA	AAC	AAA	CCA					
buxifolia_C	AAA	C-A	CAA	CCC	AAC	ACC	-AC	ACA	AAC	CAA	CCA					
candelilla_A	AAA	C-A	CAA	CCC	AAC	ACC	-AC	ACA	AAC	CAA	CCA					
candelilla_B	AAA	C-A	CAA	CCC	AAC	ACC	-AC	ACA	AAC	CAA	CCA					
pyrifolia	AAA	C-A	CAA	CCC	AAC	ACC	-AC	ACA	AAC	CAA	CCA					
n._sp.	AAA	C-A	CAA	CCC	AAC	ACC	-AC	ACA	AAC	CAA	CCA					
volcanica_A	AAA	C-A	CAA	CCC	AAC	ACC	-AC	ACA	AAC	CAA	CCA					
volcanica_B	AAA	C-A	CAA	CCC	AAA	ACC	-AC	ACC	AAC	CA-	---					
quercifolia_A	AAA	C-A	CAA	CCC	AAA	ACC	-AC	ACC	AAC	CAC	ACA					
quercifolia_B	AAA	ACA	AAA	CAA	AAA	AAC	-AC	ACC	AAA	CAA	ACC					
quercifolia_C	AAA	ACA	AAA	CCC	AAA	AAC	-AC	ACC	AAA	CAC	ACC					
Bonplandia_geminiflora	ACC	ACA	ACC	ACC	CCA	AAA	AAA	AAC	AAA	CAA	AAA					
Cobaea_pachysepala	CAA	AAC	CAA	CCA	ACA	AAA	CAA	CAC	ACA	CCA	ACA					
Cobaea_minor	CAA	AAC	CAA	CCC	ACA	CAA	CCA	AAC	CCA	CCA	ACA					

APPENDIX H

Aligned sequences of *Brassicaceae*:
771 base pairs of the *ndhF* coding region

Table 20. Aligned sequences of 11 basepairs of the *trnL* coding region from the *trnL* sampled in the Brassicaceae data set. Names correspond to voucher specimens listed in Table 8. Gaps indicated with ":", Ambiguities indicated with "N", Missing data indicated with "-".

1 4 8

Cleome spinosa	---	--A	TTT	ACT	TAC	TTT	TGA	AGG	ACA	TTT	TAA	TAC	TCA	TTT	TCA	AAA
Aethionema_arabicum	GAT	TTA	TTT	ACT	TAC	TTT	TGA	AGG	ACA	TTT	AAA	CAC	TTA	TTT	TCT	GAA
Aethionema_grandiflorum	GAT	TTA	TTT	ACT	TAC	TTT	TGA	AGG	ACA	TTT	AAA	CAC	TTA	TTT	TCT	GAA
Brassica_nigra	---	---	---	---	---	---	---	---	ACA	TTT	AAA	CAC	TTA	TTT	TAT	AAA
Raphanus_raphanistrum	---	---	---	---	---	---	---	---	GG	ACA	TTT	AAA	CAC	TTT	TAT	AAA
Raphanus_sativus	---	---	---	---	---	---	---	---	AGG	ACA	TTT	AAA	CAC	TTT	TAT	AAA
Lobularia_maritima	---	---	---	---	---	---	---	---	GG	ACA	TTT	AAA	CAC	TTT	TCT	AAA
Hesperis_matronalis	---	---	---	---	---	---	---	---	GG	ACA	TTT	AAA	CAC	TTT	TAT	AAA
Arabidopsis_lyrata	---	---	---	---	---	---	---	---	GG	ACA	TTT	AAA	CAC	TTT	TCT	AAA
Arabidopsis_hirsuta	---	---	---	---	---	---	---	---	---	ACA	TTT	AAA	CAC	TTT	TGT	AAA
Iberis	---	--A	TTT	ACT	TAC	TTT	TGA	AGG	ACA	TTT	AAA	CAC	TTA	TTG	TAT	AAA
Cakile_edentula	---	--A	TTT	ACT	TAC	TTT	TGA	AGG	ACA	TTT	AAA	CAC	TAA	TTT	TAT	AAA
Sisymbrium_altissimum	GAT	TTA	TTT	ACT	TAC	TTT	TGA	AGG	ACA	TTT	AAA	CAC	TTA	TTT	TAT	AAA
Sisymbrium_pinnatum	GAT	TTA	TTT	ACT	TAC	TTT	TGA	AGG	ACA	TTT	AAA	CAC	TTA	TTT	TAT	AAA
Barbarea_vulgaris	GAT	TTA	TTT	ACT	TAC	TTT	TGA	AGG	ACA	TTT	AAA	CAC	TTA	TTT	TAT	AAA
Arabidopsis_thaliana	GAT	TTA	TTT	ACT	TAC	TTT	TGA	AGG	ACA	TTT	AAA	CAC	TTA	TTT	TAT	AAA
Capsella_bursa-pastoris	GAT	TTA	TTT	ACT	TAC	TTT	TGA	AGG	ACA	TTT	AAA	CAC	TTA	TTT	TCT	AAA
Nasturtium_officinale	GAT	TTA	TTT	ACT	TAC	TTT	TGA	AGG	ACA	TTT	AAA	CAC	TTA	TTT	TCT	AAA
Brassica_oleracea	GAT	TTA	TTT	ACT	TAC	TTT	TGA	AGG	ACA	TTT	AAA	CAC	TTA	TTT	TAT	AAA
Barbarea_verna	GAT	TTA	TTT	ACT	TAC	TTT	TGA	AGG	CCA	TTT	AAA	CAC	TTA	TTT	TAT	AAA
Brassica_napus	GAT	TTA	TTT	ACT	TAC	TTT	TGA	AGG	ACA	TTT	AAA	CAC	TTA	TTT	TAT	AAA
Alliaria_petiolata	---	--A	TTT	ACT	TAC	TTT	TGA	AGG	CCA	TTT	AAA	CAC	TTA	TTT	TAT	AAA
Cardamine_concatenata	---	---	---	---	---	---	--A	AGG	ACA	TTT	AAA	CAC	TTA	TTT	TAT	AAA
Brassica_rapa	---	---	---	---	---	---	---	---	---	CA	TTT	AAA	CAC	TTT	TAT	AAA
Matthiola	GAT	GTA	TTT	ACT	CAC	TTT	TGA	AGG	ACA	TTT	AAA	CAC	TTA	TTT	TAT	AAA

Table 20 (cont'd)

4	9	9	6													
Cleome_spinosa	TTA	CAG	TGG	AAA	AAC	CAG	TAG	CTC	GTT	CTA	TTC	AAT	CTC	TCT	ATG	GGG
Aethionema_arabicum	TTA	TAG	TGG	AAA	AAA	AAG	TAG	CTC	CTT	CTA	TTC	AAT	CTC	TTT	ATG	GGG
Aethionema_grandiflorum	TTA	TAG	TGG	AAA	AAA	AAG	TAG	CTC	CGT	CTA	TTC	AAT	CTC	TTT	ATG	GGG
Brassica_nigra	TTA	TAG	TGG	AAA	AAA	AAG	TCG	CTC	CTT	CTA	TTC	AAT	CTC	TTT	ATG	GGG
Raphanus_raphanistrum	TTA	TAG	TGG	AAA	AAA	AAG	TCG	TTC	CTT	CTA	TTC	AAT	CTC	TTT	ATG	GGG
Raphanus_sativus	TTA	TAG	TGG	AAA	AAA	AAG	TCG	CTC	CTT	CTA	TTC	AAT	CTC	TTT	ATG	GGG
Lobularia_maritima	TTA	CAG	TGG	AAA	AAA	AAG	TAG	CTC	CTT	CTA	TTC	AAT	TTC	TTT	ATG	GGG
Hesperis_matronalis	TTA	CAG	TGG	AAA	AAA	AAG	CAG	CTC	CTT	ATA	TTC	AAT	CTC	TTT	ATG	GGG
Arabis_lyrata	TTA	CAG	TGG	AAA	AAA	AAG	TAG	CTC	CTT	CTA	TTC	ACT	CTC	TTT	ATG	GGG
Arabis_hirsuta	TTA	CAG	TGG	AAA	AAA	AAG	CAG	CTC	CTT	CTA	TTC	AAT	CTC	TTT	ATG	GGG
Iberis	TTA	CAG	TGG	AAA	AAA	AAG	TAG	CTC	CGT	CTA	TTC	AAT	CTC	TTT	ATG	GGG
Cakile_edentula	TTA	TAG	TGG	AAA	AAA	AAG	TCG	CTC	CTT	CTA	TTC	AAT	CTC	TTT	GTG	GGG
Sisymbrium_altissimum	TTA	CAG	TGG	AAA	AAA	AAG	TAG	CTC	CTT	CTA	CTC	AAT	CTC	TTT	ATG	GGG
Sisymbrium_pinnatum	TTA	CAG	TGG	AAA	AAA	AAG	TAG	CTC	CTT	CTA	TTC	AAT	CTC	TTT	ATG	GGG
Barbarea_vulgaris	TTA	CAG	TGG	AAA	AAA	AAG	TAG	CTC	CTT	CTA	TTC	AAT	CTC	TTT	ATG	GGG
Arabis_thaliana	TTA	CAG	TGG	AAA	AAA	AAG	TGG	CTC	CTT	CTA	TTC	ACT	CTC	TTT	ATG	GGG
Capsella_bursa-pastoris	TTA	CAG	TGG	AAA	AAA	AAG	TCG	CTC	CTT	CTA	TTC	ACT	CTC	TTT	ATG	GGG
Nasturtium_officinale	TTA	CAG	TGG	AAA	AAA	AAG	CAG	CTC	CGT	CTA	TTC	AAT	CTC	TTT	ATG	GGG
Brassica_oleracea	TTA	TAG	TGG	AAA	AAA	AAG	TCG	CTC	CTT	CTA	TTC	AAT	TTC	TTT	ATG	GGG
Barbarea_verna	TTA	CAG	TGG	AAA	AAA	AAG	TAG	CTC	TTT	CTA	TTC	AAT	CTC	TTT	ATG	GGG
Brassica_napus	TTA	TAG	TGG	AAA	AAA	AAG	TAG	CTC	CTT	CTA	TTC	AAT	TTC	TTT	ATG	GGG
Alliaria_petiolata	TTA	CAG	TGG	AAA	AAA	AAG	TAG	TTC	CTT	CTA	TTC	ACT	CTC	TTT	ATG	GGG
Cardamine_concatenata	TTA	CAG	TGG	AAA	AAA	AAG	TAG	CTC	CTT	CTA	TTC	AAT	CTC	TTT	ATG	GGG
Brassica_rapa	TTA	TAG	TGG	AAA	AAA	AAG	TCG	CTC	CTT	CTA	TTC	AAT	TTC	TTT	ATG	GGG
Matthiola	TTA	CAG	TGG	AAA	AAA	AAG	TAG	CTC	CTT	ATA	TTC	AAT	CTC	TTT	ATG	GGG

Table 20 (cont'd)

	9	1
	7	4
		4
Cleome_spinosa	TAA AGA AGA AGA AGG AAA AAA AAT TAA TAA TTT TTG TTT AGT ACC ATT	
Aethionema_arabicum	TAA AGA AGA TGA AAA AAA AAT TAA TAA TTT TTG TTT AGT ACC GTT	
Aethionema_grandiflorum	TAA AGA AGA CGG AAA AAA AAT TAA TAA TTT TTG TTT AGT ACC ATT	
Brassica_nigra	GAA AGA AGA AGA TAA AAA ACT TAA TAG CAA TTT TGG GTT AGT ACC ATT	
Raphanus_raphanistrum	TAA AGA AGA AGA TAA CAA ACT TAA TAG AAA TTT TGG GTT AGT ACC ATT	
Raphanus_sativus	TAA AGA AGA AGA TAA TAA ACT TAA TAG AAA TTT TGG GTT AGT ACC ATT	
Lobularia_maritima	TAA AGA AGA AGA AAA AAA CCT TAA TAA AAA TTT TGG GTT AGT ACC ATT	
Hesperis_matronalis	TAA AGA AGA AGA AAA AAA ACT TAA TAG AAA TTT TGA GTT AGT ACC GTT	
Arabidopsis_lyrata	TAA AGA AGA AGA AAA AAA ACT TAA TAA AAA TTT TGG GTT AGT ACC ATT	
Arabis_hirsuta	GAA AGA AGA AGA ACA AAA ACT TAA TAG AAA TTT CGG GTT AGT ACC ATT	
Iberis	TAA AGA AGA AGA TAA AAA ACT TAA TAG AAA TTT TGG GTT AGT ACC ATT	
Cakile_edentula	TAA AGA AGA AGA TAA AAA ACT TAA TAG AAA TTT TGG GTT AGT ACC ATT	
Sisymbrium_altissimum	TAA AGA AGA AGA TAA AAA ACT TAA TAG AAA TTT TGG GTT AGT ACC ATT	
Sisymbrium_pinnatum	TAA AGA AGA AGA TAA AAA ACT TAA TAG AAA TTT TGG GTT AGT ACC ATT	
Barbarea_vulgaris	TAA AGA AGA AGA TAA AAA ACT TAA TAG AAA TTT TGG GTT AGT ACC ATT	
Arabidopsis_thaliana	TAA AGA AGA AGA AAA AAA ACT TAA TAG AAA TTT TGG GTT AGT ACC ATT	
Capsella_bursa-pastoris	TAA AGA AGA AGA AAA AAA ACT TAA TAG AAA TTT TGG GTT AGT ACC ATT	
Nasturtium_officinale	TAA AGA AGA AGA TAA AAA ACT TAA TAG AAA TTT TGG GTT AGT ACC ATT	
Brassica_oleracea	TAA AGA AGA AGA TAA AAA ACT TAA TAG AAA TTT TGG GTT AGT ACC ATT	
Barbarea_verna	TAA AGA AGA AGA TAA AAA ACT TAA TAG AAA TTT TGG GTT AGT ACC ATT	
Brassica_napus	TAA AGA AGA AGA TAA AAA ACT TAA TAG AAA TTT TGG GTT AGT ACC ATT	
Alliaria_petiolata	TAA AGA AGA AGA AAA AAA ACT TAA TAG AAA TTT TGG GTT AGT ACC ATT	
Cardamine_concatenata	TAA AGA AGA AGA AAA AAA ACT TAA TAG AAA TTT TGG GTT AGT ACC ATT	
Brassica_rapa	TAA AGA AGA AGA TAA AAA ACT TAA TAG AAA TTT TGG GTT AGT ACC ATT	
Matthiola	TAA AGA AGA AGA AAA AAA ACT TAA TAG AAA TTT TGA ATT AGT ACC GTT	

1
4
5

267

Table 20 (cont'd)

	1	2	3	4	0
Cleome_spinosa	ATA TAA AAT TAG TAA TAA TAA TGT AAG AAA TCA AAC TTT TCT TAC TGT TGT TGC				
Aethionema_arabicum	ATA TAA AAT TAA TAA TAA TGT AAG AAA TAA AAC TTT GAT TAC TGT TGT TGC				
Aethionema_grandiflorum	ATA TCA AAT TAA TAA TAA TGT AAG AAA TCA AAC TTT GAT TAC TGT TGT TGC				
Brassica_nigra	ATA TAA AAT TAA TAA TAA TGT AAG AAA TCA AAC TTT TAT TAC TGT TGT TGA				
Raphanus_raphanistrum	ATA TAA AAT TAG TAA TAA TGT AAG AAA TCA AAC TTT TAT TAC TGT TGT TGA				
Raphanus_sativus	ATA TAA AAT TAG TAA TAA TGT AAG AAA TCA AAC TTT TAT TAC TGT TGT TGA				
Lobularia_maritima	ATA TAA AAT TAG TAA TAA TGT AAG AAA TCA AAC TTT TAT TAC TGT TGT TGA				
Hesperis_matronalis	ATA TAA AAT TAG TAA TAA TGT AAG AAA TAA AAC TTT TAT TAC TGT TGT TGA				
Arabisopsis_lyrata	ATA TAA AAT TAG TAA TAA TGT AAG AAA TCA AAC TTT TAT TAC TGT TGT TGA				
Arabis_hirsuta	ATA TCA AAT TAG TAA TAA TGT AAG AAA TGA AAT TTT TAT TAC TGT TGT TGA				
Iberis	ATA TAA AAT TAG TAA TAA TGT AAG AAA TCA AAC TTT TAT TAC TGT TGT TGA				
Cakile_edentula	ATA TAA AAT TAG TAA TAA TGT AAG AAA TAA AAC TTT TAT TAC TGT TGT TGA				
Sisymbrium_altissimum	ATA TAA AAT TAG TAA TAA TGT AAG AAA TAA AAC TTT TAT TAC TGT TGT TGA				
Stanleya_pinnata	ATA TAA AAT TAG TAA TAA TGT AAG AAA TAA AAC TTT TAT TAC TGT TGT TGA				
Barbarea_vulgaris	ATA TAA AAT TAG TAA TAA TGT AAG AAA TCA AAC TTT TAT TAC TGT TGT TGA				
Arabisopsis_thaliana	ATA TAA AAT TAG TAA TAA TGT AAG AAA TCA AAC TTT TAT TAC TGT TGT TGA				
Capsella_bursa-pastoris	ATA TAA AAT TAG TAA TAA TGT AAG AAA TAA AAC TTT TAT TAC TGT TGT TGA				
Nasturtium_officinale	ATA TAA AAT TAG TAA TAA TGT AAG AAA TCA AAC TTT TAT TAC TGT TGT TGA				
Brassica_oleraceae	ATA TAA AAT TAG TAA TAA TGT AAG AAA TCA AAC TTT TAT TAC TGT TGT TGA				
Barbarea_verna	ATA TAA AAT TAG TAA TAA TGT AAG AAA TCA AAC TTT TAT TAC TGT TGT TGA				
Brassica_napus	ATA TAA AAT TAG TAA TAA TGT AAG AAA TCA AAC TTT TAT TAC TGT TGT TGA				
Alliaria_petiolata	ATA TAA AAT TAG TAA TAA TGT AAG AAA TAA AAC TTT TAT TAC TGT TGT TGA				
Cardamine_concatenata	ATA TAA AAT TAG TAA TAA TGT AAG AAA TCA AAC TTT TAT TAC TGT TGT TGA				
Brassica_rapa	ATA TAA AAT TAG TAA TAA TGT AAG AAA TCA AAC TTT TAT TAC TGT TGT TGA				
Matthiola	ATA TAA CAT TAG TAA TAA TGT AAG AAA TAA AAC TTT TAT TAC TGT TGT TGA				

Table 20 (cont'd)

Cleome_spinosa	GAA	TTT	TGG	CCT	TAA	TAC	AAG	AAC	TTT	CTC	TTA	TCC	CCA	TGA	ATC	GGA	2
Aethionema_arabicum	AAA	TTG	TGC	ACT	TAA	TAA	AAG	AAC	TTT	CTA	TTA	TCC	CCG	TGA	ATC	AGA	8
Aethionema_grandiflorum	AAA	TTG	TGC	ACT	TAA	TAA	AAA	AAT	TTA	TTA	TTA	TCC	CCA	TGA	ATC	AGA	8
Brassica_nigra	AAA	TTT	TGG	ACT	TAA	TAC	AAG	AAC	TTT	CTA	TTA	TCC	CCA	TGA	ATC	AGA	8
Raphanus_raphanistrum	AAA	TTT	TGG	ACT	TAA	TAC	AAG	AAC	TTT	CTA	TTA	TCC	CCA	TGA	ATC	AGA	8
Raphanus_sativus	AAA	TTT	TGG	ACT	TAA	TAC	AAG	AAC	TTT	CTA	TTA	TCC	CCA	TGA	ATC	AGA	8
Lobularia_maritima	AAA	TTT	TGG	ACT	TAA	TAC	AAG	AAC	TTT	CTA	TTA	TCC	CCA	GGA	ATC	AGA	8
Hesperis_matronalis	AAA	TTG	TGG	ACT	TAA	TAC	AAG	AAC	TTT	CTA	TTA	TCC	CCA	TGA	ATC	AGA	8
Arabis_hirsuta	AAA	TTT	TGG	ACT	TAA	TAC	AAG	AAC	TTT	CTA	TTA	TCC	CCA	TGA	ATC	AGA	8
Iberis	AAA	CTT	TGG	ACT	TAA	TAA	AAG	AAC	TTT	TTA	TTA	TCC	CCA	TGA	ATC	AGA	8
Cakile_edentula	AAA	TTT	TGG	ACT	TAA	TAC	AAG	AAC	TTT	CTA	TTA	TCC	CCA	TGA	ATC	AGA	8
Sisymbrium_altissimum	AAA	TTT	TGG	ACT	TAA	TAC	AAG	AAC	TTT	CTA	TTA	TCC	CAA	TGA	ATC	AGA	8
Stanleya_pinnata	AAA	TTT	TGG	ACT	TAA	TAC	AAG	AAC	TTT	CTA	TTA	TCC	CAA	TGA	ATC	AGA	8
Barbarea_vulgaris	AAA	TTT	TGG	ACT	TAA	TAC	AAG	AAC	TTT	CTA	TTA	TCC	CCA	AGA	ATC	AGA	8
Arabis_bursa-pastoris	AAA	TTT	TGG	ACT	TAA	TAC	AAG	AAC	TTT	CTA	TTA	TCC	GCA	TGA	ATC	AGA	8
Nasturtium_officinale	AAA	TTT	TGG	ACT	TAA	TCC	AAG	AAC	TTT	CTA	TTA	TCC	CCA	TGA	ATC	AGA	8
Brassica_oleraceae	AAA	TTT	TGG	ACT	TAA	TAC	AAG	AAC	TTT	CTA	TTA	TCC	CCA	TGA	ATC	AGA	8
Brassica_verna	AAA	TTT	TGG	ACT	TAA	TAC	AAG	AAC	TTT	CTA	TTA	TCC	CCA	AGA	ATC	AGA	8
Brassica_napus	AAA	TTT	TGG	ACT	TAA	TAC	AAG	AAC	TTT	CTA	TTA	TCC	CCA	TGA	ATC	AGA	8
Alliaria_petiolata	AAA	TTT	TGG	ACT	TAA	TAC	AAG	AAC	TTT	CTA	TTA	TCC	CCA	TGA	ATC	AGA	8
Cardamine_concatenata	AAA	TTT	TGG	ACT	TAA	TCC	AAG	AAC	TTT	CTA	TTA	TCC	CCA	TGA	ATC	AGA	8
Brassica_rapa	AAA	TTT	TGG	ACT	TAA	TAC	AAG	AAC	TTT	CTA	TTA	TCC	CCA	TGA	ATC	AGA	8
Matthiola	AAA	TTT	TGG	ACT	TAA	TAC	AAA	AAC	TTT	CTA	TTA	TCC	CCA	TGA	ATC	AGA	8

Table 20 (cont'd)

	2	3
	8	3
	9	6
Cleome_spinosa	CAA TAA TAT TCT ATT TCC TAT GCT TGT ATT GGT TTT TTT TTT TTT GTT	GTT
Aethionema_arabicum	CAA TAC TAT TTT ATT TCC TAT GCT TGT ATT ACT TTT TTT TTT TTT GTT	GTT
Aethionema_grandiflorum	CAA TAC TAT TTT ATT TCC TAT GCT TGT ATT ACT TTT TTT TTT TTT GTT	GTT
Brassica_nigra	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT ATT	ATT
Raphanus_raphanistrum	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Raphanus_sativus	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Lobularia_maritima	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Hesperis_matronalis	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Arabidopsis_lyrata	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Arabis_hirsuta	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Iberis	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Cakile_edentula	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Sisymbrium_altissimum	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Stanleya_pinnata	TAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Barbarea_vulgaris	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT ATT	ATT
Arabidopsis_thaliana	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Capsella_bursa-pastoris	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Nasturtium_officinale	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Brassica_oleraceae	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Barbarea_verna	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Brassica_napus	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Alliaria_petiolata	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Cardamine_concatenata	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Brassica_rapa	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT
Matthiola	CAA TAC TAT TCT ATT TCC TAT GCT TGT ATT GCT TTT TTT TTT TTT GTT	GTT

Table 20 (cont'd)

Cleome_spinosa	TGT	TGG	AGT	CAT	AGG	AAT	TCC	TTT	GAA	TCA	AAA	AGG	AAT	AGA	CTT	TGA	3
Aethionema_arabicum	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	GAA	TCA	AGA	AGG	A::	:::	:TT	TGA	8
Aethionema_grandiflorum	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	GAA	TCA	AGA	AGG	ANN	NNN	NTT	TAA	4
Brassica_nigra	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	CAA	TCA	AGA	AGG	AAT	CGA	CTT	TGA	
Raphanus_raphanistrum	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	
Raphanus_sativus	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	
Lobularia_maritima	TGT	TGG	AGC	CAT	AGG	AAT	TCC	CTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	
Hesperis_matronalis	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	CAA	TCA	AGA	AGG	AAG	AGA	CTT	TGA	
Arabidopsis_lyrata	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	
Arabidopsis_hirsuta	TGT	TGG	AAC	CAT	AGG	AAT	TCC	TTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	
Iberis	TAT	TGG	AGC	CAT	AGG	AAT	TCC	CTT	CAC	TCA	AGA	AGG	AAT	CGA	CGT	TGA	
Cakile_edentula	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	
Sisymbrium_altissimum	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	
Stanleya_pinnata	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	
Barbarea_vulgaris	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	
Arabidopsis_thaliana	TAT	TGG	AGC	CAT	AGG	AAT	TCT	TTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	
Capsella_bursa-pastoris	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	
Nasturtium_officinale	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	TAA	CCA	AGA	AGG	CCT	AGA	CTT	TGA	
Brassica_oleraceae	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	
Barbarea_verna	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	
Brassica_napus	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	
Alliaria_petiolata	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	
Cardamine_concatenata	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	
Brassica_rapa	TAT	TGG	AGC	CAT	AGG	AAT	TCC	TTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	
Matthiola	TAT	TGG	AGC	CAT	AGG	AAT	TCC	CTT	CAA	TCA	AGA	AGG	AAT	AGA	CTT	TGA	

Table 20 (cont'd)

3	8	5	4	3	2	Cleome_spinosa	TAT	ATT	ATC	AAA	ATT	ATT	ATT	GAC	GCC	ATC	TAT	AAA	TCT	TTT	GCA	TAA	AAA
						Aethionema_arabicum	TAT	ATT	ATC	AAA	ATT	ATT	ATT	CAC	GCC	ATC	AAT	AAA	CCT	TTT	GCA	TAA	AAA
						Aethionema_grandiflorum	TAT	ATT	ATC	AAA	ATT	ATT	ATT	CAC	GCC	ATC	GAT	AAA	CCT	TTT	GCA	TAA	AAA
						Brassica_nigra	TAT	ATT	ATC	AAA	ATT	ATT	ATT	AAC	GCC	GTC	GAT	AAA	CCT	TTT	GCA	TAC	CAA
						Raphanus_raphanistrum	TAT	ATT	ATC	AAA	ATT	ATT	ATT	AAC	GCC	GTC	GAT	AAA	CCT	TTT	GCA	TAC	CAA
						Raphanus_sativus	TAT	ATT	ATC	AAA	ATT	ATT	ATT	AAC	GCC	GTC	GAT	AAA	CCT	TTT	GCA	TAC	CAA
						Lobularia_maritima	TAT	ATT	ATC	AAA	ATT	ATT	ATT	CAT	GCC	GTC	AAT	AAA	CCT	TTT	GCA	TAA	AAA
						Hesperis_matronalis	TAT	ATT	ATC	AAA	ATT	ATT	ATT	CAC	GCC	GTC	GAT	AAA	CCT	TTT	GCA	TAA	AAA
						Arabidopsis_lyrata	TAT	ATT	ATC	AAA	ATT	ATT	ATT	CAC	GCC	GTC	AAT	AAA	CCT	TTT	GCA	TAA	AAA
						Arabis_hirsuta	TAT	ATT	ATC	AAA	ATT	ATT	ATT	CAC	GCC	GTC	GAT	AAA	CCT	TTT	GCA	TAA	AAA
						Iberis	TAT	ATT	ATC	AAA	ATT	ATT	ATT	CAC	ACC	GTC	AAT	AAA	CCT	TTT	GCA	TAA	AAA
						Cakile_edentula	TAT	ATT	ATC	AAA	ATT	ATT	ATT	AAC	GCC	GTC	GAT	AAA	TCT	TTT	GCA	TAC	CAA
						Sisymbrium_altissimum	TAT	ATT	ATC	AAA	ATT	ATT	ATT	AAC	GCC	GTC	GAT	AAA	CCT	TTT	GCA	TAC	CAA
						Stanleya_pinnata	TAT	ATT	ATC	AAA	ATT	ATT	ATT	AAC	GCC	GTC	GAT	AAA	CCT	TTT	GCA	TAC	CAA
						Barbarea_vulgaris	TAT	ATT	ATC	AAA	ATT	ATT	ATT	CAC	GCC	GTC	GAT	AAA	CCT	TTT	GCA	TAA	AAA
						Arabidopsis_thaliana	TAT	ATT	ATC	AAA	ATT	TTT	TTT	CAC	GCC	GTC	AAT	AAA	CCT	TTT	GCA	TAA	AAA
						Capsella_bursa-pastoris	TAT	ATT	ATC	AAA	ATT	ATT	ATT	CAC	GCC	GTC	AAT	AAA	CCT	TTT	GCA	TAA	CAA
						Nasturtium_officinale	TAT	ATT	ATC	AAA	ATT	ATT	ATT	CAC	ACC	GTC	GAT	AAA	CCT	TTT	GCA	TAA	AAA
						Brassica_oleraceae	TAT	ATT	ATC	AAA	ATT	AGT	AGT	AAC	GCC	GTC	GAT	AAA	CCT	TTT	GCA	TAC	CAA
						Barbarea_verna	TAT	ATT	ATC	AAA	ATT	ATT	ATT	CAC	GCC	GTC	GAT	AAA	CCT	TTT	GCA	TAA	AAA
						Brassica_napus	TAT	ATT	ATC	AAA	ATT	ATT	ATT	AAC	GCC	GTC	GAT	AAA	CCT	TTT	GCA	TAC	CAA
						Alliaria_petiolata	TAT	ATT	ATC	AAA	ATT	ATT	ATT	CAC	GCC	GTC	GAT	AAA	CCT	TTT	GCA	TAA	AAA
						Cardamine_concatenata	TAT	ATT	ATC	AAA	ATT	ATT	ATT	CAC	ACC	GTC	GAT	AAA	CCT	TTT	GCA	TAA	AAA
						Brassica_rapa	TAT	ATT	ATC	AAA	ATT	ATT	ATT	AAC	GCC	GTC	GAT	AAA	CCT	TTT	GCA	TAC	CAA
						Matthiola	TAT	ATT	ATC	AAA	ATT	ATT	ATT	CAC	GCC	GTC	AAT	AAA	CCT	TTT	GCA	TAA	AAA

Table 20 (cont'd)

	4	4	4
	3	3	8
	3	3	0
Cleome_spinosa	TTC AAA TAA TTT TGT AGA TTG GTA TGA ATT TTT GAG AAA TGC AAC TTT		
Aethionema_arabicum	TTC AAC AAA TTT TGT GGA TTG GTA TGA ATT TTT TAG AAA TGC TAC TTT		
Aethionema_grandiflorum	TTC AAC AAA TTT TGT GGA TTG GTA TGA ATT TTT TAG AAA TGC AAC TTT		
Brassica_nigra	TTC ACA AAA TTT TGT AGA TTG GTA TGA ATT TTT GAA AAA TGC AAC TTT		
Raphanus_raphanistrum	TTC AGA AAA TTT TGT AGA TTG GTA TGA ATT TTT GAA AAA TGC AAT TTT		
Raphanus_sativus	TTC AGA AAA TTT TGT AGA TTG GTA TGA ATT TTT TAA AAA TGC AAT TTT		
Lobularia_maritima	TGC ACA AAA TTT TGT AGA TTG GTA TGA ATT TTT TAG AAA TGC AAC TTT		
Hesperis_matronalis	TTC ACA AAT TTT TGT AGA TTG GTA TGA ATT TTT TAG AAA TGC AAC TTT		
Arabis_opsis_lyrata	TTC ACA AAA TTT TGT AGA TTG GTA TGA ATT TTT GAG AAA TGC AAC TTT		
Arabis_hirsuta	TTC ACA AAA TTT TGT GGA TTG GTA TGA ATT TTT GCA AAA TGT AAC TTT		
Iberis	TTC ACA AAA TTT TGT AGA TTG GTA TGA ATT TTT TAA AAA TGC AAC TTT		
Cakile_edentula	TTC ACA AAA TTT TGT AGA TTG GTA TGA ATT TTT GAA AAA TGC AAT TTT		
Sisymbrium_altissimum	CTC CCA AAA TTT TGT AGA TTG GTA TGA ATT TTT GAA AAA TGC AAT TTT		
Stanleya_pinnata	TTC AGA AAA TTT TGT AGA TTG GTA TGA ATT TTT GAA AAA TGC AAT TTT		
Barbarea_vulgaris	TTC GCA AAG TTT TGT AGA TTG GTA TGA ATT TTT GAG AAA TGC AAC TTT		
Arabis_opsis_thaliana	TTC ACA AAA TTT TGT AGA TTG GTA TGA ATT TTT GAG AAA TGC AAC TTT		
Capsella_bursa-pastoris	TTC ACA AAA TTT TGT AGA TTG GTA TGA ATT TTT GCG AAA TGC AAC TTT		
Nasturtium_officinale	TTC AGA AAG TTT TGT AGA TTG GTA TGA ATT TTT GAG AAA TGC AAC TTT		
Brassica_oleraceae	TTC AGA AAA TTT TGT AGA TTG GTA TGA ATT TTT GAA AAA TGC AAT TTT		
Barbarea_verna	TTC GCA AAG TTT TGT AGA TTG GTA TGA ATT TTT GAG AAA TGC AAC TTT		
Brassica_napus	TTC AGA AAA TTT TGT AGA TTG GTA TGA ATT TTT GAA AAA TGC AAT TTT		
Alliaria_petiolata	TTC ACA AAA TTT TGT AGA TTG GTA TGA ATT TTT AAA AAA TGC AAC TTT		
Cardamine_concatenata	TTC GCA AAG TTT TGT AGA TTG GTA TGA ATT TTT GAG AAA TGC AAC TTT		
Brassica_rapa	TTC AGA AAA TTT TGT AGA TTG GTA TGA ATT TTT GAA AAA TGC AAT TTT		
Matthiola	TTC ACA AAA TTT TGT AGA TTG GTA TGA ATT TTT GAG AAA TGC AAC TTT		

Table 20 (cont'd)

	4	5
	8	2
	1	8
Cleome_spinosa	TTC AGT CAG TAT AGC TTT TTT TGG AAT ATT TAT AGC ATA CTG CTT ATA	
Aethionema_arabicum	TTC AGT CAG TAT AGC TTT TTT TGG AAT ATT TAT AGC ATA TTK KTW ATA	
Aethionema_grandiflorum	TTC AGT CAG TAT AGC TTT TTT TGG AAT ATT TAT AGC ATA CTG GTT GTA	
Brassica_nigra	TTC AGT CAG TAT AGC TTT GTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Raphanus_raphanistrum	TTC AGT CAG TAT AGC TTT GTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Raphanus_sativus	TTC AGT CAG TAT AGC TTT GTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Lobularia_maritima	TTC AGT CAG TAT AGC TTT GTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Hesperis_matronalis	TTC AGT CAG TAT AGC TTT TTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Arabidopsis_lyrata	TTC AGT GAG TAT AGC TTT TTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Arabis_hirsuta	TTC AGT CAG TAT AGC TTT GTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Iberis	TTC AGT CAG TAT AGC TTT GTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Cakile_edentula	TTC AGT CAG TAT AGC TTT GTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Sisymbrium_altissimum	TTC AGT CAG TAT AGC TTT GTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Stanleya_pinnata	TTC AGT CAG TAT AGC TTT GTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Barbarea_vulgaris	TTC AGT CAG TAT AGC TTT TTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Arabidopsis_thaliana	TTC GGT CAG TAT AGC CTT TTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Capsella_bursa-pastoris	TTC AGT CAG TAT AGC TTT TTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Nasturtium_officinale	TTC AGT TAG TAT AGC TTT TTT TGG AAT ATT TAT AGC ATA CTA TTT ATA	
Brassica_oleraceae	TTC AGT CAG TAT AGC TTT GTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Barbarea_verna	TTC AGT CAG TAT AGC TTT TTT TGG AAT ATT TAT AGC ATA TTG TTT ATA	
Brassica_napus	TTC AGT CAG TAT AGC TTT GTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Alliaria_petiolata	TTC AGT CAG TAT AGC TTT GTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Cardamine_concatenata	TTC AGT CAG TAT AGC TTT TTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Brassica_rapa	TTC AGT CAG TAT AGC TTT GTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	
Matthiola	TTC AGT CAG TAT AGC TTT TTT TGG AAT ATT TAT AGC ATA CTG TTT ATA	

Table 20 (cont'd)

	5	5
	2	7
	9	6
Cleome_spinosa	TAA GCC TTT TTA TTC ATC TTT ATT AAA TTT AAA CTT AGT TAA TTC ATT	
Aethionema_arabicum	TAA GCC TTT TAA TTC ATC TTT ATT AAA TTT AAC CTT ACT TAA TTC ATT	
Aethionema_grandiflorum	TAA GCC TTT TTA TTC ATC TTT ATT AAA TTT AAC CTT ACT TAA TTC ATT	
Brassica_nigra	TAA GCC TTT TTA TTC ATC TAA ATT AAA TTT AAC CTT ACT GAA TTC ATT	
Raphanus_raphanistrum	TAA GCC TTT TTA TTC ATC TAA ATT AAA TTT AAC CTT ACT TAA TTC ATT	
Raphanus_sativus	TAA GCC TTT TTA TTC ATC TAA ATT AAA TTT AAC CTT ACT TAA TTC ATT	
Lobularia_maritima	TAA GCC TTT TTA TTC ATC TTT ATT AAA TTT AAC CGT ACT TAA TTC ATT	
Hesperis_matronalis	TAA GCC TTT TTA TTC ATC TTT ATT AAA TTT AAC CTT ACT TAA TTC ATT	
Arabidopsis_lyrata	TAA GCC TTT TTA TTC ATC TTT ATT AAA TTT AAC CTT ACT TAA TTC ATT	
Arabis_hirsuta	TAA GCC TTT TTA TTC ATC TTT ATT AAA TTT AAC CTT ACT TAA TTC ATT	
Iberis	TAA GCC TTT TTA TTC ATC GTT ATT AAA TTT AAC CTT ACT TAA TTC ATT	
Cakile_edentula	TAA GCC TTT TTA TTC ATC TAA ATT AAA TTT AAC CTT ACT GAA TTC ATT	
Sisymbrium_altissimum	TAA ACC TTT TTA TTC ATC TAA ATT AAA TTT AAC CTT ACT TAA TTC ATT	
Stanleya_pinnata	TAA GCC TTT TTA TTC ATC TAA ATT AAA TTT CAC CTT ACT TAA TTC ATT	
Barbarea_vulgaris	TAA GCC TTT TTA TTC ATC TTT ATT AAA TTT AAC CTT ACT TAA TTC ATT	
Arabidopsis_thaliana	TAA GCC TTT TTA TTC ATC TTT ATT AAA TTT AAC CTT ACT TAA TTC ATT	
Capsella_bursa-pastoris	TAA GCC TTT TTA TTC ATC TTT ATT AAA TTT AAC CTT ACT TAA TTC ATT	
Nasturtium_officinale	TAA GCC TTT TTA TTC ATC TTT ATT AAA TTT AAC CTT ACT TAA TTC ATT	
Brassica_oleraceae	TAA GCC TTT TTA TTC ATC TAG ATT AAA TTT CAC TTT ACT TAA TTC ATT	
Barbarea_verna	TAA GCC TTT TTA TTC ATC TTT ATT AAA TTT AAC CTT ACT TAA TTC ATT	
Brassica_napus	TAA GCC TTT TTA TTC ATC TAG ATT AAA TTT AAC TTT ACT TAA TTC ATT	
Alliaria_petiolata	TAA GCC TTT TTA TTC ATC TTT ATT AAA TTT AAC CTT ACT GAA TTC ATT	
Cardamine_concatenata	TAA GCC TTT TTA TTC ATC TTT ATT AAA TTT AAC CCT ACT TAA TTC ATT	
Brassica_rapa	TAA GCC TTT TTA TTC ATC TAG ATT AAA TTT AAC TTT ACT TAA TTC ATT	
Matthiola	TAA GCC TTT TTA TTC ATC TTT ATT AAA TTT AAC CTT ACT TAA TTC ATT	

Table 20 (cont'd)

Cleome_spinosa	TCA	AAA	ATG	GGG	TTC	GAA	AAG	AAT	TCT	GTG	GGA	AAA	ACC	AAT	AAA	TTT	6
Aethionema_arabicum	TCA	AAA	ATG	GAG	TTC	TAA	ACC	TAT	TTA	TTG	GGA	AAA	ACT	AAT	AAA	TTG	2
Aethionema_grandiflorum	TCA	AAA	ATG	GAA	TTC	TAA	CCC	AAG	TTG	TTG	GGA	AAA	ACT	AAT	AAA	TTG	4
Brassica_nigra	TCA	AAA	GTG	GAA	TTC	TAA	AAG	AAT	TAG	GTG	GGA	AAG	ACT	AAT	AAA	TTT	
Raphanus_raphanistrum	TCA	AAA	GTG	GAG	TTC	TAA	AAG	AAT	TAG	GTG	GGA	AAA	ACC	AAT	CAA	TTT	
Raphanus_sativus	TCA	AAA	GTG	GAG	TTC	TAA	AAG	AAT	TAG	GTG	GGA	AAA	ACC	AAT	CAA	TTT	
Lobularia_maritima	TCA	AAC	CTG	GAG	TTC	TAA	AAG	AAT	TCG	GTG	GGA	AAA	ACT	AAT	AAA	TTT	
Hesperis_matronalis	TCA	AAA	ATG	GAG	TTA	TAA	AAG	AAT	TCG	GTG	GGA	AAA	ACT	AAT	AAA	TTT	
Arabidopsis_lyrata	TCA	AAA	ATG	GAA	TTC	TAA	AAG	AAT	TCG	TTG	GGA	AAA	ACT	AAT	AAA	TTT	
Arabis_hirsuta	TAA	AAA	ATG	GAG	TTC	TAA	AAG	AAT	TGG	GTG	GGA	AAA	ACT	AAT	AAA	TTT	
Iberis	TCA	AAA	CTG	GAG	TTC	TAA	CCG	ACT	TAG	GTG	GGA	AAA	ACT	AAT	AAA	TTT	
Cakile_edentula	TCA	AAA	GTG	GAG	TTC	TAA	AAG	AAT	TAG	GTG	GGA	AAA	ACT	AAT	AAA	TTT	
Sisymbrium_altissimum	TCA	AAA	GTG	GAG	TTC	TAA	AAG	AAT	TAG	GTG	GGA	AAA	ACT	AAT	AAA	TAT	
Stanleya_pinnata	TCA	AAA	GTG	GAG	TTC	TAA	AAG	AAT	TAG	GTG	GGA	AAA	ACT	AAT	CAA	TTT	
Barbarea_vulgaris	TCA	AAA	ATG	GAA	TTC	TAA	ACG	AAT	TCG	TTG	GGA	AAA	ACT	AAT	AAA	TTT	
Arabidopsis_thaliana	TCA	AAA	ATG	GAA	TTC	TAA	ACG	AAT	TCA	TTG	GGA	AAA	ACT	AAT	AAA	TTT	
Capsella_bursa-pastoris	TCA	AAA	ATG	GAA	TTC	TAA	ACG	AAT	TCG	TTG	GGA	AAA	ACT	AAT	AAA	TTT	
Nasturtium_officinale	TCA	AAA	ATT	GAA	TTC	TAA	ACG	AAT	TCG	TTG	GGA	AAA	ACT	AAT	AAA	TTT	
Brassica_oleraceae	TCA	AAA	GTG	GAG	TTC	TAA	AAG	AAT	TAG	GTG	GGA	AAA	ACC	AAT	CAA	TTT	
Barbarea_verna	TCA	AAA	ATG	GAA	TTC	TAA	ACG	AAT	TCG	TTG	GGA	AAA	ACT	AAT	AAA	TTT	
Brassica_napus	TCA	AAA	GTG	GAG	TTC	TAA	AAG	AAT	TAG	GTG	GGA	AAA	ACC	AAT	AAA	TTT	
Alliaria_petiolata	TCA	AAA	ATG	GAG	TTC	TAA	AAG	AAT	TAG	GTG	GGA	AAA	ACT	AAT	AAA	TTT	
Cardamine_concatenata	TCA	AAA	ATT	GAA	TTC	TAA	ACG	AAT	TCG	TTG	GGA	AAA	ACT	AAT	AAA	TTT	
Brassica_rapa	TCA	AAA	GTG	GAG	TTC	TAA	AAG	AAT	TAG	GTG	GGA	AAA	ACC	AAT	WAA	TTT	
Matthiola	TAA	AAA	GTG	GAG	TTC	TAA	AAG	AAT	TAG	GTG	GGA	AAA	ACT	TAT	AAA	TTT	

Table 20 (cont'd)

	6	6
	2	7
	5	2
Cleome_spinosa	GGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTA TAA	TAA
Aethionema_arabicum	TCT ATA TAA TTG GTC GTA TAA TCG TGC TTA CAT AGA TAC TTT TTA TAA	TAA
Aethionema_grandiflorum	TGT ATA TAA TTG GTC GTA TAA TCG TGG TTA CAT AGA TAC TTT TTA TAA	TAA
Brassica_nigra	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA
Raphanus_raphanistrum	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TAC TTT TTT AAA	AAA
Raphanus_sativus	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TAC TTT TTT AAA	AAA
Lobularia_maritima	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA
Hesperis_matronalis	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA
Arabis_hirsuta	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA
Iberis	TTT GTA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA
Cakile_edentula	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA
Sisymbrium_altissimum	TAT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	AAA
Stanleya_pinnata	TTT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA
Barbarea_vulgaris	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA
Arabis_hirsuta	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA
Capsella_bursa-pastoris	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA
Nasturtium_officinale	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA
Brassica_oleraceae	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA
Brassica_verna	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA
Brassica_napus	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA
Alliaria_petiolata	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA
Cardamine_concarnata	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA
Brassica_rapa	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA
Matthiola	TGT ATA TAA TTG GTC ATA TAA TCG TGG TTA CAT AGA TGC TTT TTT TAA	TAA

Table 20 (cont'd)

Cleome_spinosa	AAC ATC TTT AAC CGA AAG TAT AAG AAG ATT AGC AAA ACA GAC TCA TTT	6	7
Aethionema_arabicum	AAA ATC TTT AAC TGG AAG TAT AAG AAG ATT AGC AAA ACA AAT TCA ATT	7	2
Aethionema_grandiflorum	AAA ATC CTT AAC TGA AAG TAT AAG AAG ATT AGC AAA ACA AAT TAA TTT	3	0
Brassica_nigra	AAA ATC TTT AAC TGA AAA TAT AAG AAA ATT AGC AAA ACA GAA TTT		
Raphanus_raphanistrum	AAA ATC TTT AAC TGA AAG TAT AAG AAA ATT AGC AAA ACA GAA TTT		
Raphanus_sativus	AAA ATC TTT AAC TGA AAG TAT AAG AAA ATT AGC AAA ACA GAA TTT		
Lobularia_maritima	AAC ATC TTT AAC TGA AAG TAT AAT AAG ATT AGC AAA ACA GAA TTT		
Hesperis_matronalis	AAC ATC TTT AAC TGA AAG TAT AAG AAC ATT AGC AAA ACA GAA TTT		
Arabis_lyrata	AAC ATC TTT AAC TGA AAG TAT AAG AAG ATT AGC AAA ACA GAA TTT		
Arabis_hirsuta	AAC ATC TTT AAC TGA AAG TAT AAG AAG ATT AGC AAA ACA GAA TTT		
Iberis	AAC ATC TTT AAC TGA AAG TAT AAG AAG ATT AGC AAA ACA GAA TTT		
Cakile_edentula	AAA ATA TTT AAC TGA AAG TAT AAG AAA ATT AGC AAA ACA GAA TTT		
Sisymbrium_altissimum	AAA ATC GTT AAC TGA AAG TAT AAG AAC ATT AGC AAA ACA GAA TTT		
Stanleya_pinnata	AAN ATC TTT AAC TGA AAA TAT AAG AAC ATT AGC AAA ACA GAA TTT		
Barbarea_vulgaris	AAC ATC CTT AAC TGA AAG TAT AAG AAC ATT AGC AAA ACA GAA TTT		
Arabis_thaliana	AAC ATA TTT AAC TGA AAG TAT AAG AAC ATT AGC AAA ACA GAA TTT		
Capsella_bursa-pastoris	AAC ATC TTT AAC TGA AAG TAT AAG AAC ATT AGC AAA ACA GAA TTT		
Nasturtium_officinale	AAA ATC TTT AAC TGA AAG TAT AAG AAC ATT AGC AAA ACA GAA TTT		
Brassica_oleraceae	AAC ATC TTT AAC TGA AAG TAT AAG AAC ATT AGC AAA ACA GAA TTT		
Brassica_verna	AAA ATC TTT AAC TGA AAG TAT AAG AAC ATT AGC AAA ACA GAA TTT		
Brassica_napus	AAC ATC TTT AAC TGA AAG TAT AAG AAC ATT AGC AAA ACA GAA TTT		
Alliaria_petiolata	AAC ATC TTT AAC TGA AAG TAT AAG AAC ATT AGC AAA ACA GAA TTT		
Cardamine_concatenata	AAA ATC TTT AAC TGA AAG TAT AAG AAC ATT AGC AAA ACA GAA TTT		
Brassica_rapa	AAC ATC TTT AAC TGA AAG TAT AAG AAC ATT AGC AAA ACA GAA TTT		
Matthiola	AAC ATC TTT AAC TGA AAG TAT AAG AAC ATT AGC AAA ACA GAA TTT		

Table 20 (cont'd)

	7	7	
	2	6	
	1	8	
Cleome_spinosa	TTT TGA TAG ACG AAT AAT AAT TGA TGG AAT TAC AAA CGC AGT AGG T-- ---		
Aethionema_arabicum	TTT NGA TAA ACG AAT AAT AAT TGA TGG AAT TAC AAA TGG AGT AGG TAT TAC		
Aethionema_grandiflorum	TTT TGA TAA ACG AAT AAT AAT TGA TGG AAT TAC AAA TGG AGT AGG TAT TAC		
Brassica_nigra	TTT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TGG AGT AG- --- ---		
Raphanus_raphanistrum	TTT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TGG AGT --- --- ---		
Raphanus_sativus	TTT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TGG AGT A-- --- ---		
Lobularia_maritima	TTT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TGG AGT A-- --- ---		
Hesperis_matronalis	TTT TGA TAA ACG AAT TGT TGA TGG AAT TAC AAA TG- --- --- ---		
Arabidopsis_lyrata	TTT TGA TAA ACA AAT CAT TGA TGG AAT TAC AAA TGG AGT AGG T-- ---		
Arabis_hirsuta	TTT TGA TAA AAA AAT CAT TGA TGG AAT TAC AAA TG- --- --- ---		
Iberis	TTT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TGG AGT AGG TAT TAC		
Cakile_edentula	TTT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TG- --- --- ---		
Sisymbrium_altissimum	TTT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TGG AGT AGG TAT TAC		
Stanleya_pinnata	TTT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TGG AGT AGG TAT TAC		
Barbarea_vulgaris	TTT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TGG GGT AGG TAT TAC		
Arabidopsis_thaliana	TTT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TGG AGT AGG TAT TAC		
Capsella_bursa-pastoris	TGT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TGG AGT AGG TAT TAC		
Nasturtium_officinale	TTT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TGG GGT AGG TAT TAC		
Brassica_oleraceae	TTT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TGG AGT AGG TAT TAC		
Barbarea_verna	TTT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TGG GGT AGG TAT TAC		
Brassica_napus	TTT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TGG AGT AGG TAT ---		
Alliaria_petiolata	TTT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TGG AGT AGG TAT TAC		
Cardamine_concatenata	TTT NGA TNA ACG AAT CAT TGA TGG AAT TAC NAA TNG --- --- ---		
Brassica_rapa	TTT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TGG AGT AG- --- ---		
Matthiola	TTT TGA TAA ACG AAT CAT TGA TGG AAT TAC AAA TGG AGT AGG TAT TAC		

Table 20 (cont'd)

Cleome_spinosa	---	7 7
Aethionema_arabicum	AAG	6 7
Aethionema_grandiflorum	AA-	9 1
Brassica_nigra	---	
Raphanus_raphanistrum	---	
Raphanus_sativus	---	
Lobularia_maritima	---	
Hesperis_matronalis	---	
Arabis_hirsuta	---	
Iberis	AAG	
Cakile_edentula	---	
Sisymbrium_altissimum	AAG	
Stanleya_pinnata	AAG	
Barbarea_vulgaris	AAG	
Arabis_hirsuta	AAG	
Capsella_bursa-pastoris	AAG	
Nasturtium_officinale	AAG	
Brassica_oleraceae	AAG	
Barbarea_verna	CAG	
Brassica_napus	---	
Alliaria_petiolata	CAG	
Cardamine_concatenata	---	
Brassica_rapa	---	
Matthiola	AAG	

APPENDIX I

Pollen data for *Cantua* (Polemoniaceae):
Light microscopy pollen diameter and style length analysis

Table 21: Pollen grain diameter and style length mean, sample size (N), standard deviation, and range for *Cantua* herbarium specimens used in light microscopy pollen analysis.

Species	Voucher	Pollen (µm)			Styles (mm)		
		Mean (N)	SD	range	Mean (N)	SD	range
<i>Cantua bicolor</i> Lem.	Cardenas 5479 (HUH)	61.76 (29)	5.25	51.45-73.50	36.12 (4)	0.73	35.21-36.93
<i>Cantua bicolor</i>	Beck, Kiestling & Metzling 22154 (MSC)	72.85 (30)	3.75	63.70-78.40	42.36 (3)	0.30	42.12-42.69
<i>Cantua buxifolia</i> Lam.	Gentry, Smith & Tredwell 37515 (MO)	74.32 (15)	3.16	68.60-80.85	73.89 (6)	5.31	67.56-80.30
<i>Cantua buxifolia</i>	Lopez & Sagastegui 8023 (LL)	72.48 (24)	4.21	61.25-78.40	60.24 (5)	16.02	35.02-73.85
<i>Cantua buxifolia</i>	Ploorman & Davis 4653 (HUH)	72.68 (30)	5.51	51.45-78.40	72.10 (8)	5.65	63.08-77.53
<i>Cantua buxifolia</i>	Bohs 2053A(HUH)	77.75 (30)	4.12	71.05-85.75	69.67 (3)	3.49	65.65-71.97
<i>Cantua candellilla</i> Brand	Hutchison 1252 (UC)	81.34 (30)	3.72	73.50-90.65	65.01 (8)	7.12	56.86-73.95
<i>Cantua candellilla</i>	Hutchinson & Wright 7235 (UC)	82.57 (30)	3.16	73.50-85.75	66.36 (4)	2.79	62.92-68.72
<i>Cantua cuervoensis</i> Infantes	Vargas 9785 (MO)	75.87 (30)	3.55	63.70-80.85	55.40 (5)	1.68	53.54-57.96
<i>Cantua cuervoensis</i>	Balls B6903 (UC)	69.73 (30)	3.85	63.70-78.40	51.68 (6)	2.96	48.50-55.88
<i>Cantua flexuosa</i> Pers.	Gentry, Smith & Tredwell 37518 (NY)	77.01 (30)	3.00	71.05-83.30	30.92 (1)	One style	One style
<i>Cantua flexuosa</i>	Beck 1349 (MSC)	65.66 (10)	4.87	58.80-73.50	37.28 (5)	2.04	35.16-39.67
<i>Cantua n. sp.</i>	Knapp & Alcorn 7556 (NY)	75.34 (4)	5.43	68.60-80.85	42.78 (6)	2.93	38.27-45.95
<i>Cantua n. sp.</i>	Leiva, Chuna & Cadle 1419 (F)	76.47 (19)	3.33	71.05-80.85	No style	No style	No style
<i>Cantua pyrifolia</i> Luss.	Hitchcock 21580 (HUH)	75.46 (30)	3.61	63.70-80.85	26.03 (2)	1.51	24.96-27.10
<i>Cantua pyrifolia</i>	Sagastegui & Cabanillas 8560 (MO)	72.96 (9)	6.46	66.15-83.30	27.51 (1)	One style	One style
<i>Cantua pyrifolia</i>	Van der Werff & Palacios 8891 (NY)	80.69 (30)	4.02	73.50-85.75	36.71 (6)	3.45	33.07-41.14
<i>Cantua pyrifolia</i>	Woytkowski 7670 (HUH)	82.08 (30)	2.86	75.95-85.75	41.68 (4)	5.90	33.17-46.77
<i>Cantua pyrifolia</i>	Camp 4280 (NY)	74.97 (6)	2.19	73.50-78.40	No style	No style	No style
<i>Cantua quercifolia</i>	Wrigley 2 (MSC)	87.22 (30)	2.92	80.85-93.10	87.22 (1)	One style	One style
<i>Cantua quercifolia</i>	Hutchison & Wright 3482 (HUH)	84.65 (20)	3.13	78.40-90.65	45.00 (5)	4.61	39.87-52.13
<i>Cantua volcanica</i> (Brand)	West 7139 (MO)	62.64 (30)	2.55	58.80-68.60	20.08 (3)	4.17	16.42-24.62
<i>Cantua volcanica</i>	J. M. Porter & Prather						
<i>Cantua volcanica</i>	Vargas 19918 (US)	62.26 (29)	2.58	53.90-66.15	22.23 (4)	1.35	20.79-23.48

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