Taxonomic assessment of *Cimicifuga elata* and its new variety *alpestris* in southern Oregon

Final Report

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Preface

This report is the result of a cooperative Challenge Cost Share project between the Institute for Applied Ecology (IAE) and a federal agency. IAE is a nonprofit with a mission to conserve native ecosystems through restoration, research and education. We serve the general public as well as private agencies and individuals by developing and communicating information on ecosystems, species, and effective management strategies and by conducting research, monitoring, and experiments. IAE offers educational opportunities through internships.

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Introduction

Cimicifuga elata (tall bugbane) is considered a Special Status Species (Bureau Sensitive) by the Bureau of Land Management and a Sensitive Species by the US Forest Service. It occurs in forests west of the Cascades in Oregon, Washington and British Columbia. Recently, a new variety of this species was described from southern Oregon by Lee and Park in the Journal Novon (2004). The new variety, *C. elata* var. *alpestris*, was reported only from the Grizzly Peak area near Ashland in Jackson County, Oregon. However, several other populations of *C. elata* occur in that area, and their relationship to the new variety has not been determined. Moreover, the full geographic range of the new variety has not been evaluated sufficiently to delineate its range relative to the typical variety (*C. elata* var. *elata*). This information is necessary to determine conservation status of both varieties and update the existing multi-district and multi-agency Conservation Strategy for the species.

Objectives – The purpose of this project is to evaluate the new variety and the taxonomic boundaries between it and the typical variety to support the Conservation Strategy for *Cimicifuga elata.*

Taxonomic note: *Cimicifuga* vs. *Actaea* – The genus *Cimicifuga* comprises 20 species distributed across eastern Asia, Europe and North America. It is closely related to *Actaea*, with 5 species and a similar geographic spread. Compton et al. (1998) used morphological and molecular data to suggest that *Actaea* is derived from within *Cimicifuga*, and proposed that the two be combined under *Actaea*, the earlier name with precedence, supporting revisions proposed by earlier taxonomists such as Prantl. Some treatments have followed this suggestion, such as the USDA PLANTS database (www.plants.usda.gov). Therefore, *Cimicifuga elata* Nutt. is synonymous with *Actaea elata* (Nutt.) Prantl. Both names are legitimate, but *C. elata* is used here because it is the more widely accepted name in our region.

Methods

Study sites/sample areas – Plant specimens were collected in the field at several locations in Oregon and Washington, and numerous herbarium specimens were also consulted. These samples and specimens were used to examine plant traits identified by Lee and Park (2004) as helpful for distinguishing the new variety and conduct a morphometric analysis. A total of 36 specimens were examined during this project, including 12 sampled during field surveys in Washington and Oregon, and 24 stored at the Oregon State University Herbarium. Table 1 lists all of the sites sampled during field work as part of this project, which are also mapped in Figures 1-3. See the Appendix A for a complete list of samples and specimens examined. Site selection involved coordination with agency botanists with specific knowledge of the species and pertinent locations. Specimens from the type localities were attributed to *C. elata* var. *alpestris* and those from Lane County and north were assumed to be *C. elata* var. *elata*. The

variety of populations from Douglas County and in Jackson County outside of the type localities was considered "unknown."

Field analysis – Lee and Park (2004) described three major morphological characters for distinguishing their new variety from the rest of the species as follows:

> "*Cimicifuga elata* var. *alpestris* differs from variety *elata* as well as the other members of *Cimicifuga* in having sheathing scales surrounding the lower stem node. In addition, upper surfaces of the major leaf veins are pubescent with multicellular uniseriate trichomes in variety *alpestris*, and the new variety often has more pistils (one to five) as compared to variety *elata* (one or two)."

The sheathing scales and numerous pistils are illustrated in their line drawing of the new variety (Figure 4).

We visited eleven field sites including five in southern Oregon in the vicinity of the new variety. One of these, Grizzly Peak, is the type locality and another, Shale City Road, is the location of the paratype. We attempted to confirm the characteristics of var. *alpestris* at the type locations by examining the sheathing scales, pistil numbers, and leaf vein pubescence, and contrast these with plants from other sites.

Morphometric analysis – Principal components analysis (PCA) was used to ordinate several morphological traits and examine the distribution of variability in these traits for clusters or discontinuities that might support the recognition of var. alpestris. A total of 13 traits were examined on 35 specimens, including 11 collected for this project and 24 held at the herbarium at Oregon State University (Table 2). The traits (Table 3) included seed length and coat surface texture, follicles per flower, follicle beak length, follicle length and surface vestiture (glandular or not), pubescence of veins on undersides of leaves, pubescence on leaflet branch nodes, pubescence on stems below inflorescence and at base of plant above the scale, scale length, and terminal inflorescence length. These traits were selected either because they were deemed important by Lee and Park (2004) for distinguishing var. *alpestris* or they were observed to vary among specimens during this project. Since several specimens at the OSU herbarium were incomplete, measurements of all traits on all specimens was not possible. Therefore, two PCA procedures were performed, the first with fewer (8) traits and 29 specimens, and the second with all traits (13) but only 9 specimens (Table 3). PCA included Varimax rotations and were performed with NCSS statistical software.

Results

Field analysis – We encountered some inconsistencies with each of the characteristics identified by Lee and Park (2004) as distinguishing *C. elata* var. *alpestris* from the typical variety. Samples from the type locality at Grizzly Peak (Jackson County); Bald Mountain (Jackson County), a site 14 air miles southwest and across Bear Creek Valley from Grizzly Peak; and McDonald Forest, a site in Benton County in the Willamette

Valley, Oregon are emphasized here to illustrate these inconsistencies, although specimens from throughout the species' range were examined.

Sheathing scales: Plants in southern Oregon had the sheathing scales described by Lee and Park for var. *alpestris*, but so did plants elsewhere in Oregon and Washington. Figure 5 shows that this characteristic was present at Grizzly Peak and Bald Mountain, but also at McDonald Forest. We found this character to be ubiquitous at all populations we visited. However, the scale appeared to increase in length and appear more sheathing on samples from southern portions of the study area, especially in Jackson County.

Pistil number: Pistil number appeared to vary from plant to plant (and even on the same plant), but high numbers (3-5) of pistils per flower were more frequent in southwestern Oregon populations than elsewhere in Oregon or in Washington. Even so, greater than two pistils per flower was uncommon even on southwestern Oregon (Jackson County) plants. Multi-pistilled flowers were most common at the base of the lead inflorescences. Plants from the type locality and Bald Mountain frequently had two or more pistils, while those at McDonald Forest typically had only one (Figure 6). Plants on the Rogue-Umpqua Divide at high elevations in northern Douglas County appeared especially likely to have numerous pistils per flower.

Leaf vein pubescence: We failed to find any pubescence on the upper surfaces of the leaves on plants from the type locality, elsewhere in southern Oregon, or any other site. The major leaf veins were completely glabrous on all specimens we examined (see Figure 7 for examples). It is possible that Lee and Park intended to describe the pubescence on the major veins on the *undersides* of the leaves, although they described pubescence there also. Veins on the lower leaf surfaces often had copious pubescence, especially at the base of the leaf (Figure 8). This was true for plants from Jackson County as well as plants from most other areas we examined, with notable exceptions from Washington and the Rogue-Umpqua Divide in Douglas County, Oregon.

Morphometric analysis – The first PCA approach did not support the recognition or clear geographic delineation of var. *alpestris* in southwestern Oregon, although specimens from Jackson County all grouped together. PCA procedure 2 showed some segregation of the variety and suggested that Jackson County populations and some in Douglas County grouped together and may represent one cohesive group.

In the first PCA with 29 samples and 8 traits, axes 1, 2 and 3 accounted for 22%, 15% and 13% of the variation, respectively (Appendix B). Axis 1 was highly loaded with the leaf pubescence traits (pubescence of leaf veins and leaflet nodes), and clearly divided the specimens into two groups emphasizing pubescence traits, i.e., glabrous and hairy plants (Figure 9). Axis 2 represented a continuum from one to several follicles per flower. Specimens of var. *alpestris* tended to group together as hairy-leaved plants with numerous follicles per flower, but they shared ordination space with samples from Douglas County and the Willamette Valley. Glabrous specimens were found in Douglas County on or near the Rogue Umpqua Divide as well as in Washington, while pubescent specimens came from throughout the species range. Although plant pubescence strongly

divided the samples, this trait did not segregate the specimens well geographically. In fact, of the two samples examined from the Olympic Peninsula in Washington, one was glabrous while the other had pubescent leaves. Axis 3 (not shown) was correlated with increasing length of the follicle beak, but this axis did not segregate specimens geographically.

In the second PCA with 9 samples and 13 traits, axes 1, 2 and 3 accounted for 20%, 22% and 11% of the variation, respectively (Appendix B). Axis 1 was again loaded with pubescence features (leaf veins, leaflet nodes, basal stems) and divided the samples along these traits. Axis 2 also again represented follicle number. In this analysis, axis 3 represented scale length. Scales are a trait important in the original delineation of var. *alpestris*. Plants from southwestern Oregon sites, including Jackson County and Douglas County sites, tended to have longer scales than other samples. Unfortunately, most specimens at the OSU herbarium did not include the base of the plant and so this trait was omitted from all but one of the collections there.

Discussion

These results suggest that *C. elata* var. *alpestris* is weakly differentiated from var. *elata*. Of the three traits identified by Lee and Park (2004) as useful for identifying the variety, none were completely unique. Taken together, however, they loosely circumscribed this variety.

- The sheathing scale was present on all samples examined on which the base of the stem collected, but this feature tended to be larger on plants from southwestern Oregon, including the type localities. Scale presence, as suggested by Lee and Park (2004) does not differentiate this species, but the size of the scale may be diagnostic.
- Pistil number varied substantially from plant to plant and even within inflorescences on the same plant. Samples from southwestern Oregon and some Douglas County samples, especially those from the Rogue-Umpqua Divide, tended to have the most pistils per flower, but this trend was inconsistent. Some samples from northern Oregon also had high pistil numbers.
- Leaf pubescence on the undersides of the leaves varied substantially but did not seem to follow clear geographic patterns. Glabrous-leaved plants were found on the Rogue-Umpqua Divide (Douglas County) and also most frequently in Washington. At one site on the Olympic Peninsula, both hairy-leaved and glabrous plants were found together.

These and other morphological traits appeared to vary substantially across the species' range, but in a mix-and-match fashion. All populations in southwestern Oregon (Jackson County) were morphologically similar to one another and clustered together in PCA ordination space, but they generally overlapped with other populations, especially in the first PCA that included more samples but fewer morphological traits. It may be that these traits are controlled by individual alleles that are combined in unique ways at some

populations, possibly reflecting a history of incomplete isolation leading to local fixation of some traits, such as pubescence.

We found some support for the observation that the scale at the base of the flowering stem is better developed on plants at the southern portion of the species' range. This trait appeared to show clinal variation, increasing continuously from north to south. In the second PCA procedure, axis 3, which largely represented scale length, tended to separate the Jackson County (and a single Douglas County), Oregon samples, from other populations. We examined only 12 samples from 10 locations that included this scale; more intensive sampling of this trait might find a geographic region of discontinuous variation. Either way, combined with leaf and lower stem pubescence and higher pistil number this trait circumscribes a distinct group of populations in southwestern Oregon.

Further analysis, including molecular genetic work, may find additional support for recognizing *C. elata* var. *alpestris*. Lee and Park (2004) stated "allozyme analysis indicated that populations of *Cimicifuga elata* var. *alpestris* have genetically diverged from those of variety *elata*," and that this analysis was in preparation to be published elsewhere. Attempts to correspond with Lee and Park in South Korea to determine where this genetic study was published and clarify the location of the leaf-vein pubescence they observed have not been returned. However, previous unpublished genetic studies of *C. elata* have yielded inconsistent results regarding the distinctness of populations from southwestern Oregon. Evans (1993) used allozymes to study patterns of genetic variation in *C. elata* and found populations in Jackson County to be distinct from more northern sites. In a more comprehensive evaluation using chloroplast DNA and inter-simple sequence repeat markers that incorporated more populations than Evans work, Liston and Gray (1998) and Gray and Liston (1999) found no evidence that populations in southwestern Oregon were differentiated from those farther north.

Conclusions

Geographic extent of varieties -- *Cimicifuga elata* var. *alpestris* appears to form a group that is more or less morphologically distinct in southwestern Oregon. The geographical boundaries of the variety appear to include all populations in Jackson County, as well as at least some populations in Douglas County, Oregon. *C. elata* var. *elata* occurs north of Douglas County through northern Oregon, western Washington and into British Columbia. Note that plants occurring along the Rogue-Umpqua Divide in northern Douglas County have the high number of pistils per flower and longer scale at the base of the stem characteristic of var. *alpestris*, but lack leaf pubescence. Plants in this region form a unique local variant that can be considered a glabrous form of var. *alpestris*.

Traits useful for differentiating the varieties – In general, *C. elata* var. *elata* plants are smaller and less robust than var. alpestris. This applies to various features of the plants, including height, number of leaves, number of flowering stems, etc. The following traits are proposed as refinements to Lee and Park's (2004) original description of *C. elata* var. *alpestris* (see also Table 4):

Basal sheathing scale: The scale at the base of flowering stem is < 20 mm in var. *elata* and ≥ 20 mm in var. *alpestris*. Although present on all reproductive plants we examined throughout the range of *C. elata*, this scale sheaths the stem, as Lee and Park describe, to a greater degree when it is longer.

Pistil number: *C. elata* var. elata generally has 1-2 pistils per flower while var. *alpestris* often had 3 or more, at least on some plants in the population. This feature is best examined at the base of the lead raceme, where pistils tend to be most numerous. Elsewhere in the inflorescence pistil number may be 1 per flower regardless of the variety.

Leaf and stem pubescence: I believe these pubescence traits are not useful for distinguishing varieties of *C. elata*; var. *elata* may or may not be pubescent along the veins on the underside of the leaves and on the stem near the base. The same applies to var. *alpestris* if the glabrous specimens from the Rogue-Umpqua Divide in Douglas County are included in this variety as suggested here. Neither variety is pubescent along the mid-veins on the upper sides of the leaves.

Number of reproductive stems: Plants of var. *elata* nearly always have ≤ 3 reproductive stems (generally only 1 or 2), while at least some plants in a given population of var. *alpestris* have > 3 stems, and often over 10.

Habitat: *C. elata* var. *elata* typically occurs in low to mid-elevation (100-2250 ft) Douglas-fir (*Pseudotsuda menziesii*) forests with some big-leaf maple in the overstory. In contrast, var. *alpestris* often occurs at mid- to high elevations (1100-5500 ft), often with *Abies* spp., Douglas-fir and incense cedar (*Calocedrus decurrens*), and without hardwood species in the forest canopy.

Table 1. Sample site locations for *Cimicifuga elata* populations included in the study. Pressed specimens were collected at each site in 2007.

Sample	Variety	Collection No.	Site_Name	Management/Ownership
0	alpestris	1633	Anderson Creek Road	BLM Medford District
1	alpestris	1632	Bald Mountain	BLM Medford District
2	alpestris	1634	Grizzly Peak	BLM Medford District
3	alpestris	1635	Shale City Road	BLM Medford District
4	alpestris	1637	Seven Mile Ridge	USFS Siskiyou NF
5	unknown	1647	Farmer Gulch[1]	BLM Medford District
6	alpestris	1651	Tenmile	BLM Roseburg District
7	elata	1661	Rock Creek Road	BLM Roseburg District
8	elata	1649	Cronemiller Lake	OSU McDonald Forest
9	elata	1650	Lewis and Clark State Park	State of Washington
10	elata	KW1, 2	Lake Mills	Olympic National Park

[1] This sample consisted of only one leaf and was not used in morphometric analyses.

Table 2. Specimens of *Cimicifuga elata* examined at the Oregon State University herbarium

collector	county	Collection no.	location
Halse	Skamania, Wa	2706	Skamania Co, WA T1N, R5E, Sec. 16 Hwy 14 at milepost 24, 2.3 miles east of Clark Co. line
Detling	Skamania, Wa	7335	Skamania Co, WA, Cape Horn, T1N, R5E, Sec. 16
Thompson	Multnomah, Or	4963	By Hwy east of Bonneville, Multnomah Co, OR
Helliwell	Douglas, Or	3234 (3224?)	Douglas Co, T31S, R1E, sec 10
Helliwell	Douglas, Or	3676	Douglas Co., T31S, R1E, Sec. 11. South of Bald Ridge, Rogue Umpqua Divide
Gorman	Skamania, Wa	4554	Skamania Co, WA, near base of Mt. Hamilton, open woods
Gorman	Skamania, Wa	5018	Skamania Co, WA, near base of Mt. Hamilton, open woods
Suksdorf	Skamania, Wa		Skamania Co, WA, in wet places in woods,
Henderson	Lane, Or	124	Shady banks of Triangle Lake, Lane Co.
Marttala	Multnomah, Or	5454	T1S, R2E, Sec 12, 1/3 mile E of W border
Thompson	Multnomah, Or	4963	By Hwy east of Bonneville, Multnomah Co.
Leach	Multnomah, Or	279	Corbett Rd. (only one node)
Delting	Lane, Or	18823	Moist opening in woods, Sec 23 N, Ford #5, Big Fall Creek, Lane Co, OR
Thompson	Multnomah, Or	3015	Beside road from HWY down to Corbett
Rader	Douglas, Or		Oakland, Douglas Co., OR
Helliwell	Douglas, Or	2666	Douglas Co., Along margin in wet meadow near Butler Butte, Rogue Umpqua Divide, T31S, R1E, Sec. 10 (elevation 5200 ft)
Crosby	Douglas, Or	276	Wolf Ridge, Pilot Rock Rd, (#3200) 4 miles east of HWY 227, 10 miles SE of Tiller. R1W, T32S, Sec 17
Henderson	Multnomah, Or		Open copses, Banks, Portland, OR
Chambers	Multnomah, Or	2266	Multnomah Co., Columbia Gorge scenic drive, 2.8 miles east of Bridal Veil, roadside bank at edge of woods
Halse	Polk, Or	2280	Polk Co., 1 mile east of Falls City along Rd to Black Rock, T85, R6W, Sec 17, elevation 135 meters
Foster	Marion, Or	1282	Wet Banks of Powers Creek near Silverton OR
Henderson	Lane, Or	17523	Moist wooded banks, Triangle Lake, Lane Co., OR
MWG	Multnomah, Or	2041	In coniferous woods, Barns Heights, Portland OR
Andrews	Lane, Or	148	Brushy logged-off land above Wendling, Lane Co, OR

Table 3. Morphological traits examined on specimens of *Cimicifuga elata* from field collections and herbarium specimens and their inclusion in PCA procedures 1 and 2. A total of 29 specimens were included in PCA procedure 1 and 9 specimens in procedure 2.

Trait	Explanation	PCA procedure 1	PCA procedure 2
seed length	mm		X
seed coat texture	1=ribbed (low ridges), 2=scaly (larger ridges), 3=flakey (high ridges, seed surface obscured).		X
follicle length	mm	X	X
follicle beak length	mm	X	X
mean # follicles/flower	measured on first three flowers at base of leading inflorescence	X	X
maximum # follicles/flower	Maximum number of follicles per flower from first three flowers at base of leading inflorescence		
follicle surface	0=glabrous, 1=glandular	X	X
pubescence of leaf veins (underside of leaves)	0=glabrous throughout, 1=pubescence on primary (major) veins, 2=pubescence reaches secondary veins, 3= pubescence reaches tertiary veins, 4=pubescence on smallest, reticulate veins.	X	X
pubescence on leaflet branch nodes.	On leaves that are compound, 0=glabrous, 1=pubescence on first branching node, 2=pubescence on second node.	X	X
pubescence on stem above scale	Are there hairs on the stem above the basal scale? 0=no, 1=y		X
pubescence on stem below inflorescence	Type of hairs and presence of glands on stem immediately below the inflorescence. 1=short hairs, 2=long hairs, 3=glands, 4=short hairs and glands, 5=long hairs and glands.	X	X
scale length	scale at base of stem, mm		X
lead inflorescence length	mm	X	X

Table 4. Morphological and habitat traits useful for differentiating the two varieties of *C. elata*.

trait	var. *elata*	var. *alpestris*
Leaf pubescence	Glabrous or pubescent	pubescent
No. pistils per flower	often ≤ 2	often ≥ 3
Scale at base of stem	< 20 mm	> 20 mm
No. reproductive stems	≤ 3	> 3
Habitat	Douglas-fir forest with local abundance of big-leaf maple in the canopy; 100-2250 ft elevation.	Mixed conifer forest (fir, Douglas-fir, incense cedar); 1100-5500 ft.

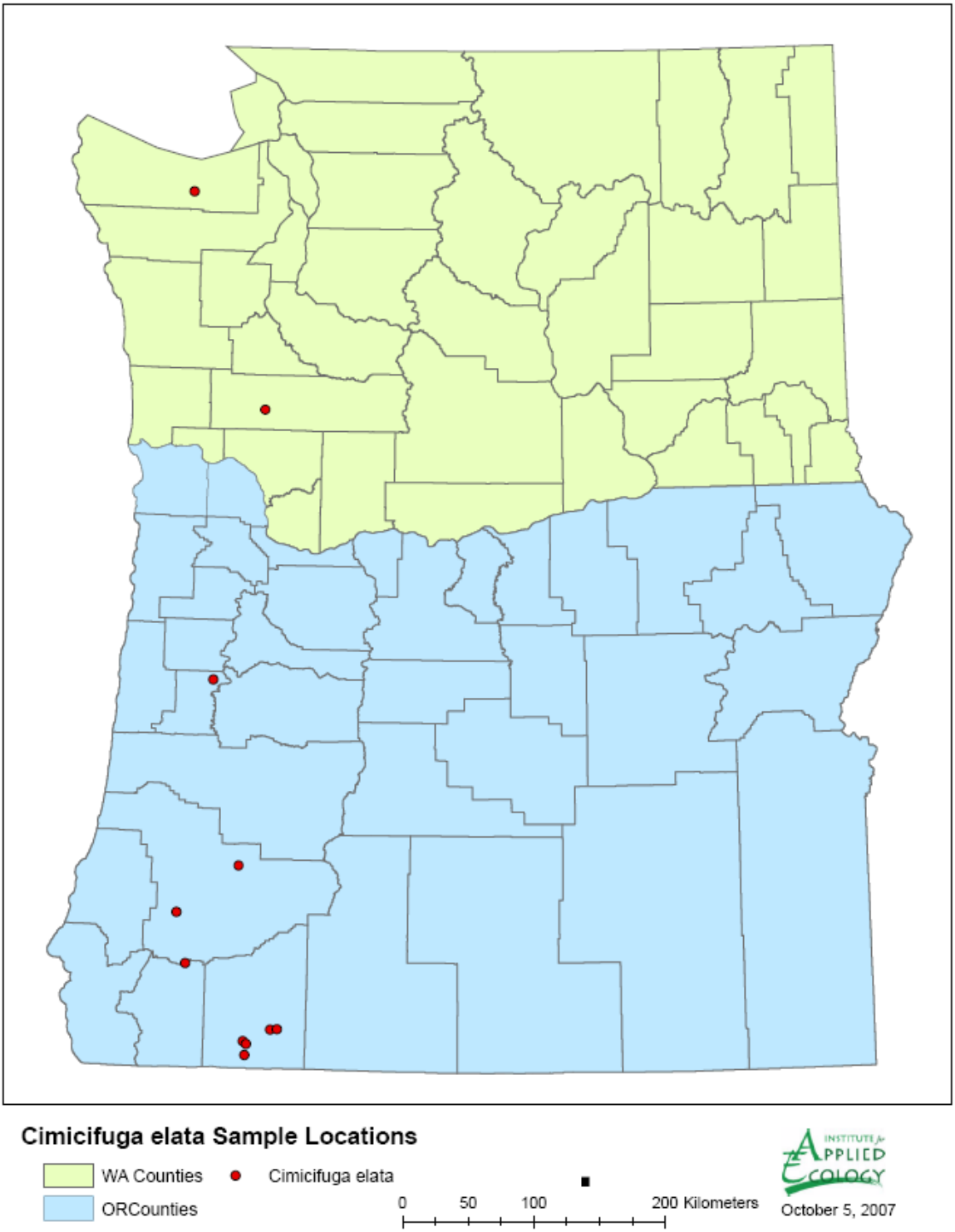

Figure 1. Sample locations for *Cimicifuga elata* populations in Oregon and Washington visited in 2007 and listed in Table 1.

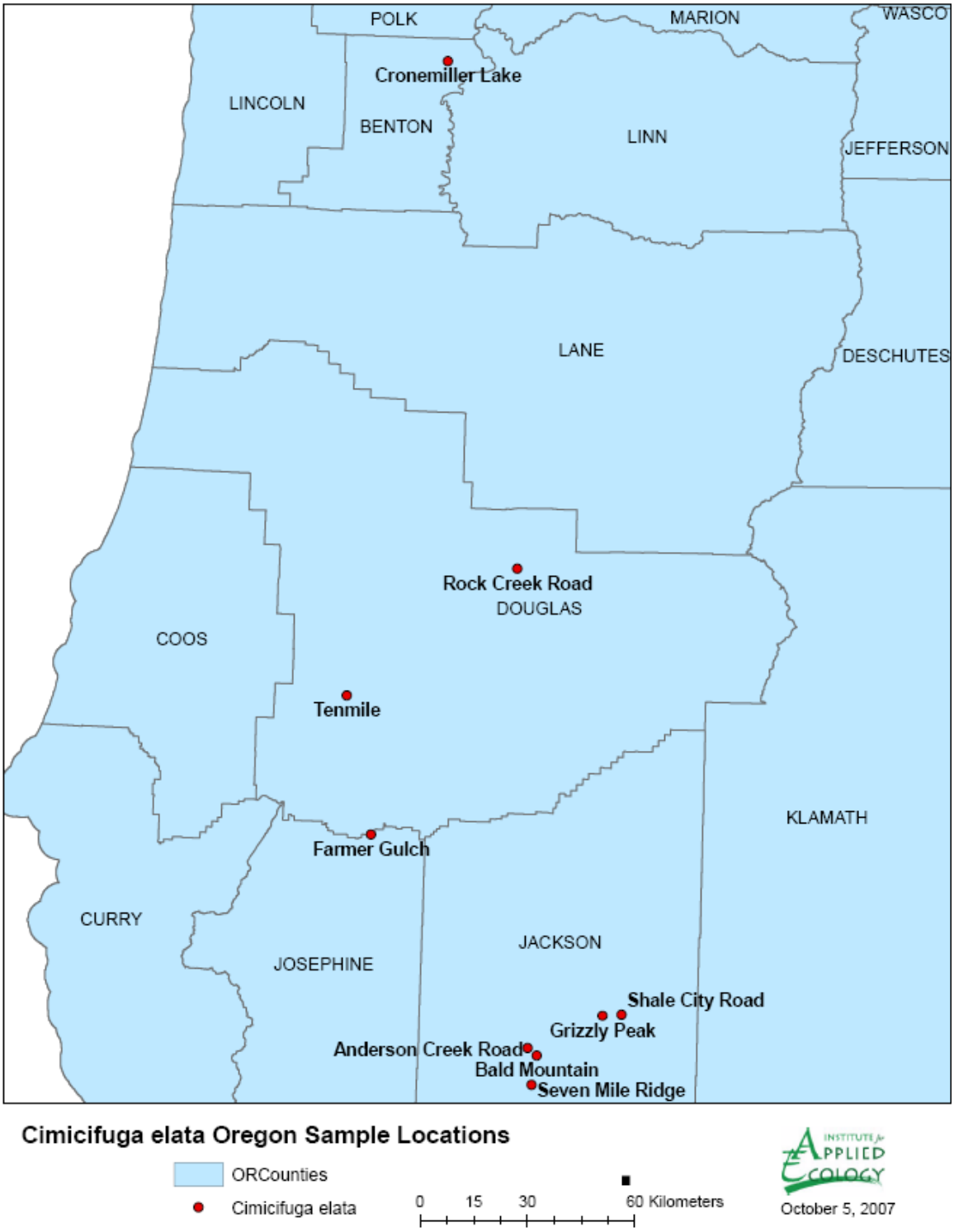

Figure 2. Sample locations for *Cimicifuga* populations in Oregon. See Table 1 for additional details of each site.

Figure 3. Sample locations for *Cimicifuga elata* populations in Washington. See Table 1 for additional details of each site.

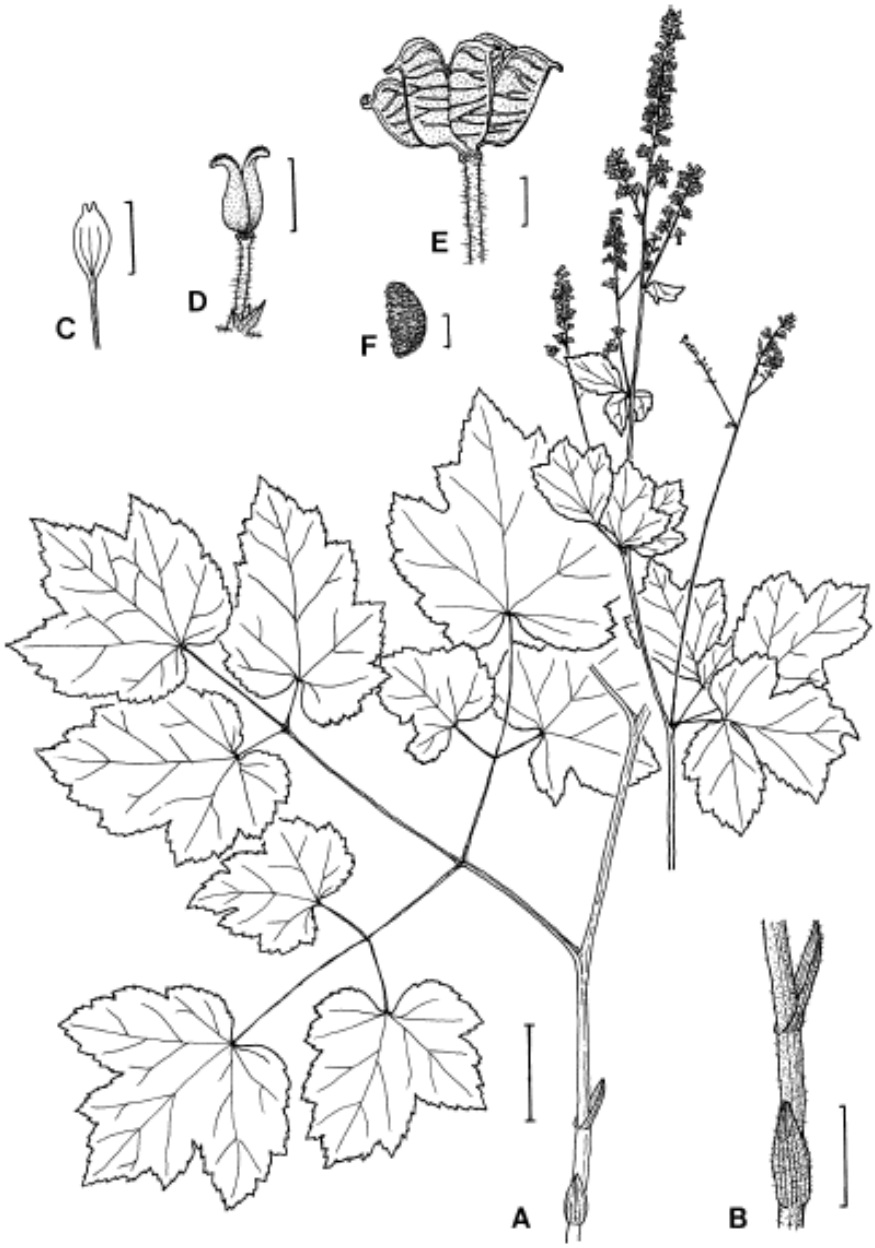

Figure 2. *Cimicifuga elata* var. *alpestris* H.-W. Lee & C.-W. Park. —A. Habit. —B. Stem with sheathing scales. —C. Petal. —D. Pistils and a pedicel with bracteoles. —E. Follicles. —F. Seed. Scale bars 10 cm (A), 5 cm (B), 5 mm (E), 2 mm (D), 1 mm (C, F). A, B, E, F drawn from the holotype (*Lee 1516*, SNU), and C, D from an isotype, by H.-W. Lee.

Figure 4. Line drawing of *Cimicifuga elata* var. *alpestris* from Lee and Park (2004).

Grizzly Peak (type locality of var. *alpestris*)

Bald Mountain (west of Ashland)

McDonald Forest (near Corvallis)

Figure 5. Sheathing scales surrounding the lower stem nodes on *Cimicifuga elata* from the type locality of var. *alpestris* (Grizzly Peak, Oregon), a nearby population west of Ashland (Bald Mountain, Oregon), and a population near Corvallis, Oregon (McDonald Forest). This characteristic was not unique to var. *alpestris*.

Grizzly Peak (type locality of var. *alpestris*)

Bald Mountain (west of Ashland)

McDonald Forest (near Corvallis)

Figure 6. Pistils in the inflorescences of *Cimicifuga elata* from the type locality of var. *alpestris* (Grizzly Peak, Oregon), a nearby population west of Ashland (Bald Mountain, Oregon), and a population near Corvallis, Oregon (McDonald Forest). Pistil number was found to be variable from plant to plant. High pistil numbers (3-5) were uncommon but more frequent at sites in Douglas County and southwestern Oregon.

Grizzly Peak (type locality of var. *alpestris*)

Bald Mountain (west of Ashland)

McDonald Forest (near Corvallis)

Figure 7. Major leaf veins on the upper leaf surfaces of *Cimicifuga elata* from the type locality of var. *alpestris* (Grizzly Peak, Oregon), a nearby population west of Ashland (Bald Mountain, Oregon), and a population near Corvallis, Oregon (McDonald Forest). Scale is in centimeters. No pubescence was found on these leaf veins at any population.

Grizzly Peak (type locality of var. *alpestris*)

Bald Mountain (west of Ashland)

McDonald Forest (near Corvallis)

Figure 8. Major leaf veins on the undersides of the leaves of *Cimicifuga elata* from the type locality of var. *alpestris* (Grizzly Peak, Oregon), a nearby population west of Ashland (Bald Mountain, Oregon), and a population near Corvallis, Oregon (McDonald Forest). Scale is in centimeters. Pubescence was found on the leaf veins on the undersides of the leaves at many populations, and glabrous leaves were found on plants in Douglas County (Rogue-Umpqua Divide) and Washington.

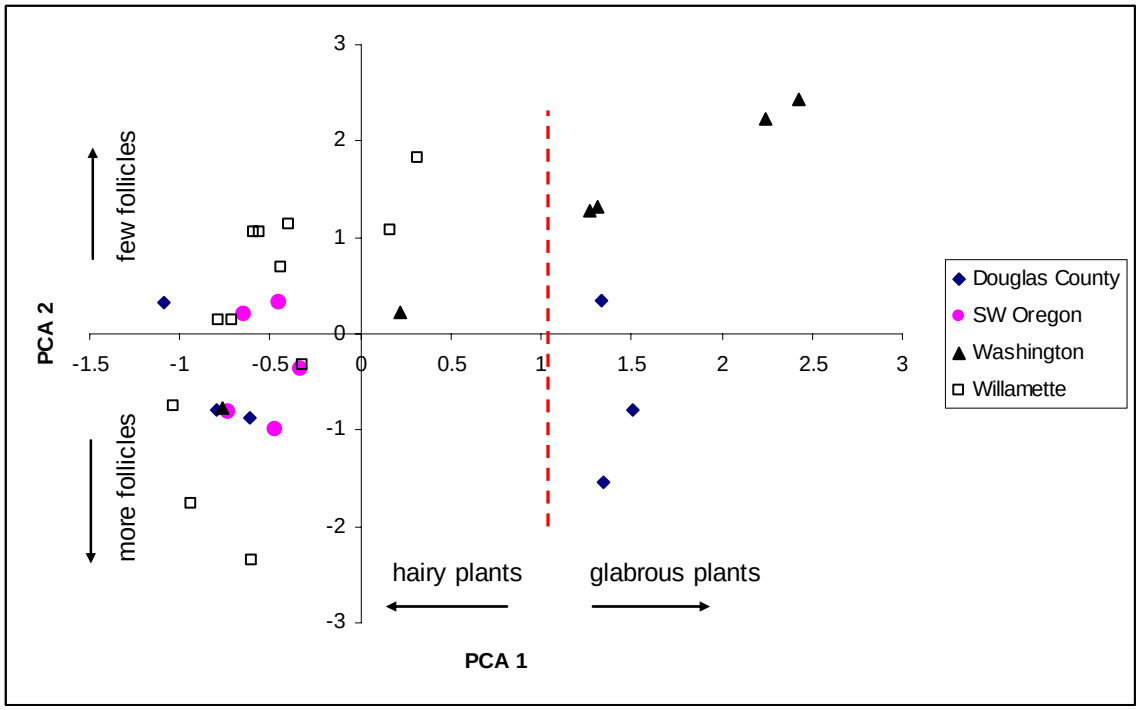

Figure 9. First PCA analysis with 29 samples and 8 traits. Vertical red line added to emphasize the discontinuity between plants with glabrous vs. pubescent leaves.

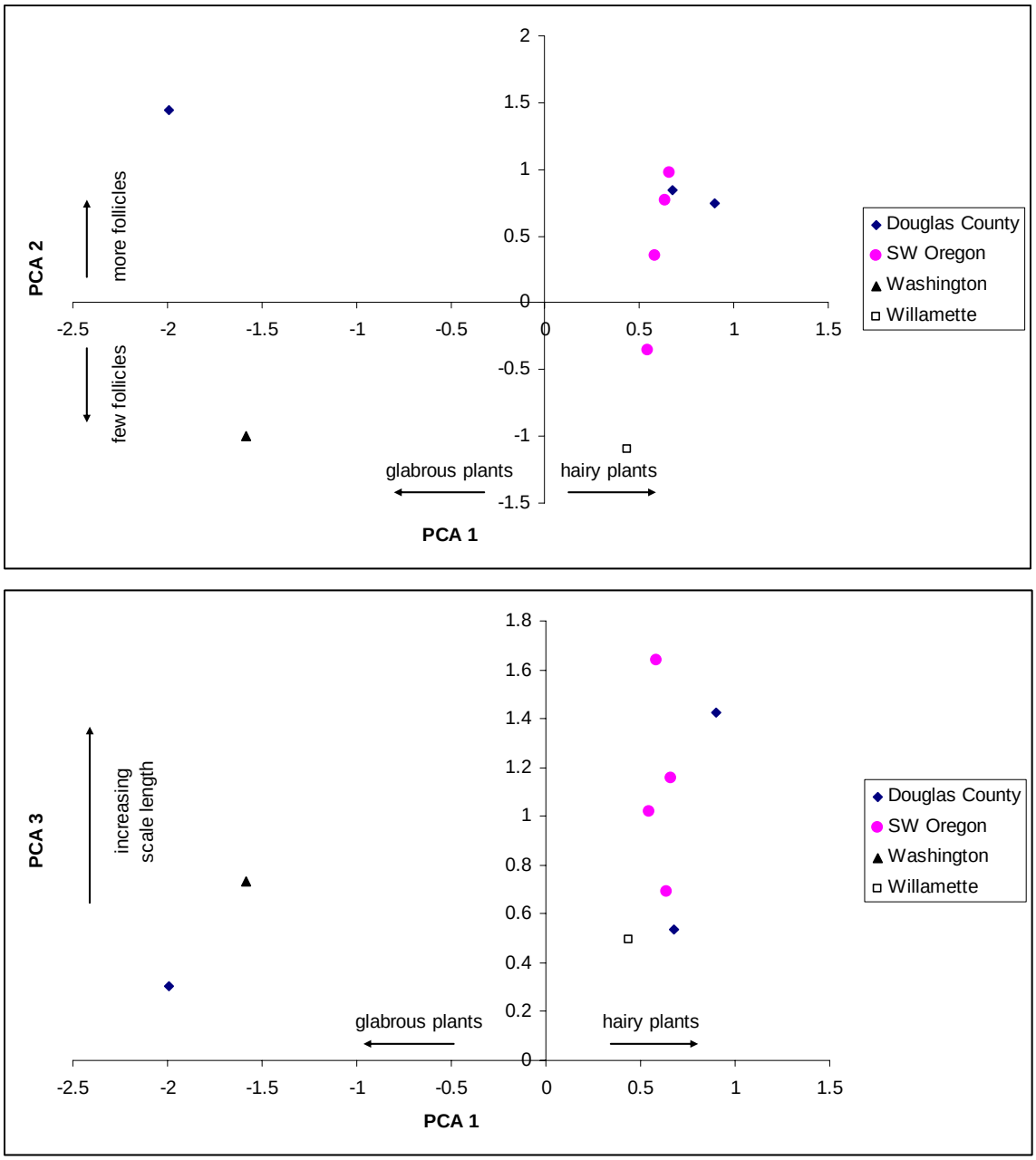

Figure 10. Second PCA analysis with 9 samples and 13 traits. Top panel shows axis 1 against 2, and the bottom panel shows axis 1 against 3.

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Appendix A. Raw data used in the morphometric analyses.

Data taker	date of measur	samplenun	collector	county	specimen#	date	location	seed lengtl	seed coat	follicle_len	follicle_bea	follicles/flo	max_follicles	follicle_ves	hairy_vein	hairy_node	hairy_stem	hair_stem_	scale_lengi	infl_length
TN Kaye	10/15/2008	1	TN Kaye	Douglas, O	1661	2007	Rock Cr.	2.8	3.0	7.7	1.2	2.3	3	1	4	2	1	2	52	131
TN Kaye	10/15/2008	2	TN Kaye	Lewis and	1650	2007	L+C	2.2	1.0	7.5	1.2	1.0	1	0	0	0	0	1	10	78
TN Kaye	10/15/2008	3	TN Kaye	Jackson, C	1634	2007	Grizzley	2.5	3.0	10.7	1.2	2.7	3	1	4	2	1	4	52	135
TN Kaye	10/15/2008	4	TN Kaye	Jackson, C	1633	2007	Anderson	2.5	3.0	10.3	1.2	1.7	2	1	4	2	1	4	31	150
TN Kaye	10/15/2008	5	TN Kaye	Jackson, C	1632	2007	Bald	2.7	3.0	11.3	1.4	2.3	3	1	4	2	1	4	49	210
TN Kaye	10/15/2008	7	TN Kaye	Benton, Or	1649	2007	Crone	2.2	1.0	9.3	1.1	1.0	1	1	4	2	1	4	16	90
TN Kaye	10/15/2008	8	TN Kaye	Douglas, O	1651	2007	Tenmile	2.5	2.0	10.0	1.1	2.3	3	1	4	2	1	3	23	114
TN Kaye	10/15/2008	9	TN Kaye	Jackson, C	1635	2007	Shale			10.3	0.9	1.7	2	1	4	2	1	3	62	125
TN Kaye	10/15/2008	10	TN Kaye	Jackson, C	1637	2007	Seven	2.1	3.0	9.0	1.2	2.3	3	1	4	2	1	5	34	122
TN Kaye	10/15/2008	11	K Ward	Jefferson, \	KW1	2007	Whiskey	1.8	3.0	11.3	1.2	1.0	1	1	3	2	1	4		120
TN Kaye	10/15/2008	12	K Ward	Jefferson, \	KW2	2007	Whiskey			10.0	1.0	2.0	2	0	0	0	0	4		119
Denise Gile	10/16/2008	13	Halse	Skamania,	2706	7/15/1983	Skamania			9.0	1.1	1.7	2	1	0	0		3		133
Denise Gile	10/16/2008	14	Detling	Skamania,	7335	7/3/1953	Skamania			8.7	0.8	1.3	2	1	0	0		3		144
Denise Gile	10/16/2008	15	Thompson	Multnomah	4963	6/23/1928	By Hwy			8.2	0.8	3.0	2	1	4	2		3		135
Denise Gile	10/16/2008	16	Helliwell	Douglas, O	3234 (3224	8/14/1998	Douglas			6.0	0.8	1.7	2	1	1	0	0	4	29	134
Denise Gile	10/16/2008	17	Helliwell	Douglas, O	3676	9/2/2004	Douglas	2.8	2.0	11.3	1.0	3.0	4	1	0	2	0	4	31	161
Denise Gile	10/16/2008	18	Gorman	Skamania,	4554	6/7/1919	Skamania					1.7	2	1	3	2		3		131
Denise Gile	10/16/2008	19	Gorman	Skamania,	5018	7/3/1920	Skamania					1.7	2	1	4	2		3		124
Denise Gile	10/16/2008	20	Suksdorf	Skamania,	Wa	7/7/1894	Skamania			8.3	1.0	1.0	1	1	4	2		3		85
Denise Gile	10/16/2008	21	Henderson	Lane, Or	124	7/7/192?	Shady	2.4	1.0	10.3	0.8	1.0	1	1	4	2		3		92
Denise Gile	10/16/2008	22	Marttala	Multnomah	5454	10/10/2004	T1S, R2E,			8.3	1.2	1.0	1	1	3	1		4		240
Denise Gile	10/16/2008	24	Thompson	Multnomah	4963	6/23/1928	By Hwy			10.0	0.5	1.3	2	1	3	2		3		173
Denise Gile	10/16/2008	27	Leach	Multnomah	279	7/17/1927	Corbett			11.0	0.6	2.0	3	1	3	2		3		169
Denise Gile	10/16/2008	28	Delting	Lane, Or	18823	7/17/1938	Moist	2.8	3.0	12.0	1.0	3.7	5	1	4	2		4		222
Denise Gile	10/17/2008	29	Thompson	Multnomah	3015	7/17/1927	Beside					1.0	1	1	4	2		3		128
Denise Gile	10/17/2008	30	Rader	Douglas, Or		7/1951	Oakland,	2.0	3.0	8.3	0.6	1.7	2	1	4	2		3		156
Denise Gile	10/17/2008	31	Helliwell	Douglas, O	2666	8/7/1995	Douglas			8.3	0.6	2.3	3	1	1	0		3		111
Denise Gile	10/17/2008	32	Crosby	Douglas, O	276	7/23/1975	Wolf					3.3	4	1	0	0		3	21	159
Denise Gile	10/17/2008	33	Henderson	Multnomah, Or		6/3&22/1882	Open			8.0	1.1	1.7	2	1	4	2		3		116
Denise Gile	10/17/2008	34	Chambers	Multnomah	2266	8/5/1964	Multnoma	2.8	2.0	12.0	0.8	1.0	1	1	4	2		3		110
Denise Gile	10/17/2008	35	Halse	Polk, Or	2280	7/8/1980	Polk Co.,	2.0	3.0	10.0	0.9	2.0	2	1	4	2		4		164
Denise Gile	10/17/2008	36	Foster	Marion, Or	1282	7/5/1910	Wet	1.8	3.0	9.3		2.7	3	1	4	1		1.5		138
Denise Gile	10/17/2008	37	Henderson	Lane, Or	17523	7/4/1935	Moist					1.7	2	1	3	2		3		121
Denise Gile	10/17/2008	39	MWG	Multnomah	2041	6/30/1904	In	0.9	1.0	7.7	1.2	3.0	4	1	4	2		3		139
Denise Gile	10/17/2008	40	Andrews	Lane, Or	148	6/22/1934	Brushy	1.9	3.0	10.7	1.2	1.0	1	1	3	2		3		93

Appendix B. PCA results.

All variables but with fewer samples (procedure 1)

Principal Components Report

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Database

Robust and Missing-Value Estimation Iteration Section

No.	Count	Trace of Covar Matrix	Percent Change
0	9	1793.147	0
1	35	4534.419	152.87
2	35	4140.107	-8.7
3	35	4391.245	6.07
4	35	4610.058	4.98
5	35	4794.153	3.99
6	35	4951.104	3.27

Descriptive Statistics Section

Variables	Count	Mean	Standard Deviation	Communality
seed_length	35	2.819922	0.959715	1
seed_coat	35	8.185243	8.721095	1
follicle_length	35	9.496495	1.39996	1
follicle_beak_length	35	0.983947	0.205274	1
follicles_flower	35	1.876476	0.754064	1
max_follicles	35	2.228571	1.031439	1
follicle_vestiture	35	0.942857	0.235504	1
hairy_vein	35	2.942857	1.551903	1
hairy_node	35	1.542857	0.81684	1
hairy_stem_base	35	0.734463	0.431059	1
hair_stem_below_infl	35	3.242857	0.770518	1
scale_length	35	-13.3808	59.72975	1
infl_length	35	136.3428	36.04078	1

Correlation Section

	Variables				
Variables	seed_length	seed_coat	follicle_length	follicle_beak_length	follicles_flower
seed_length	1	0.884024	-0.20084	-0.43683	-0.01766
seed_coat	**0.884024**	1	-0.43835	-0.42616	0.054957
follicle_length	-0.20084	-0.43835	1	0.075095	0.024701
follicle_beak_length	-0.43683	-0.42616	0.075095	1	0.016735
follicles_flower	-0.01766	0.054957	0.024701	0.016735	1

max_follicles	0.031988	-0.00968	0.086327	-0.00319	0.931704
follicle_vestitur e	0.164834	0.123991	0.133188	-0.12093	0.124704
hairy_vein	-0.42986	-0.41359	0.248913	0.192556	-0.03922
hairy_node	-0.4794	-0.54969	0.487348	0.177696	-0.01463
hairy_stem_ba se	-0.52713	-0.49798	0.319157	0.263754	-0.08858
hair_stem_belo w_infl	0.035434	0.0205	0.307283	0.194857	0.12056
scale_length	0.238355	0.156319	-0.04704	0.672486	0.056255
infl_length	0.206714	0.150379	0.202603	-0.01659	0.405603

Phi=0.342622 Log(Det|R|)=-24.713673 Bartlett Test=712.58 DF=78 Prob=0.000000

Principal Components Report

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Database

Correlation Section

Variables

Variables	max_follicles	follicle_vestitu re	hairy_vei n	hairy_node	hairy_stem_ base
seed_length	0.031988	0.164834	-0.42986	-0.4794	-0.52713
seed_coat	-0.00968	0.123991	-0.41359	-0.54969	-0.49798
follicle_length	0.086327	0.133188	0.248913	0.487348	0.319157
follicle_beak_le ngth	-0.00319	-0.12093	0.192556	0.177696	0.263754
follicles_flower	**0.931704**	0.124704	-0.03922	-0.01463	-0.08858
max_follicles	1	0.176434	-0.08347	-0.01197	-0.13602
follicle_vestitur e	0.176434	1	0.47365	0.471782	0.425584
hairy_vein	-0.08347	0.47365	1	0.83725	0.98302
hairy_node	-0.01197	0.471782	0.83725	1	0.868662
hairy_stem_ba se	-0.13602	0.425584	**0.98302**	**0.868662**	1
hair_stem_belo w_infl	0.131643	0.24081	0.098035	0.204947	0.073972
scale_length	0.091964	0.005928	-0.24864	-0.21726	-0.21505
infl_length	0.464635	0.262266	0.045584	0.047441	-0.0221

Phi=0.342622 Log(Det|R|)=-24.713673 Bartlett Test=712.58 DF=78 Prob=0.000000

Variables

Variables	hair_stem_belo w_infl	scale_length	infl_lengt h
seed_length	0.035434	0.238355	0.206714
seed_coat	0.0205	0.156319	0.150379
follicle_length	0.307283	-0.04704	0.202603
follicle_beak_le ngth	0.194857	**0.672486**	-0.01659
follicles_flower	0.12056	0.056255	0.405603
max_follicles	0.131643	0.091964	0.464635
follicle_vestitur	0.24081	0.005928	0.262266

e			
hairy_vein	0.098035	-0.24864	0.045584
hairy_node	0.204947	-0.21726	0.047441
hairy_stem_base	0.073972	-0.21505	-0.0221
hair_stem_below_infl	1	0.147355	0.355954
scale_length	0.147355	1	-0.17565
infl_length	0.355954	-0.17565	1

Phi=0.342622 Log(Det|R|)=-24.713673 Bartlett Test=712.58 DF=78 Prob=0.000000

Principal Components Report

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Database

Eigenvalues after Varimax Rotation

No.	Eigenvalue	Individual Percent	Cumulative Percent	Scree Plot
1	2.916875	22.44	22.44	|||||
2	2.001755	15.4	37.84	||||
3	1.670985	12.85	50.69	|||
4	2.095946	16.12	66.81	||||
5	1.025151	7.89	74.7	||
6	1.095673	8.43	83.13	||
7	0.976551	7.51	90.64	||
8	0.915566	7.04	97.68	||
9	0.155575	1.2	98.88	|
10	0.094068	0.72	99.6	|
11	0.051056	0.39	99.99	|
12	0.000772	0.01	100	|
13	0.000026	0	100	|

Factor Loadings after Varimax Rotation

	Factors				
Variables	Factor1	Factor2	Factor3	Factor4	Factor5
seed_length	-0.30899	-0.02305	-0.01408	0.919601	0.005384
seed_coat	-0.27359	0.010102	-0.06688	0.892854	0.044188
follicle_length	0.189236	0.027826	-0.00325	-0.16595	0.150686
follicle_beak_length	0.173407	-0.02131	**0.87936**	-0.38688	0.097197
follicles_flower	-0.01005	**0.97938**	0.016976	0.010336	0.042966
max_follicles	-0.07904	**0.958637**	0.031026	-0.02172	0.031183
follicle_vestiture	0.394473	0.109757	-0.02545	0.185892	0.11302
hairy_vein	**0.96827**	-0.03308	-0.03508	-0.1714	0.028682
hairy_node	**0.804239**	0.002924	-0.04326	-0.28784	0.112371
hairy_stem_base	**0.945324**	-0.08175	0.015564	-0.26097	0.001538
hair_stem_below_infl	0.062534	0.063735	0.11729	0.029349	0.961649

scale_length	-0.19083	0.065057	**0.931543**	0.209347	0.058627
infl_length	0.019966	0.305932	-0.0791	0.125363	0.183755

Principal Components Report

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Database

Factor Loadings after Varimax Rotation

	Factors				
Variables	Factor6	Factor7	Factor8	Factor9	Factor10
seed_length	0.004089	-0.10086	0.12133	0.019487	0.177282
seed_coat	0.263824	-0.05209	0.072535	-0.0553	-0.19785
follicle_length	-0.9505	-0.09246	0.029256	0.017203	0.003653
follicle_beak_length	0.041164	-0.11234	-0.12842	-0.0202	-0.05434
follicles_flower	0.015607	-0.10894	0.005962	-0.01502	-0.07851
max_follicles	-0.04909	-0.17413	0.095113	0.018306	0.084588
follicle_vestiture	-0.03566	-0.10028	0.879016	0.019002	0.001403
hairy_vein	-0.02896	-0.03785	0.136259	-0.08292	0.041438
hairy_node	-0.27159	0.0035	0.201836	0.375723	0.012284
hairy_stem_base	-0.1019	0.004134	0.123022	-0.04744	-0.05648
hair_stem_below_infl	-0.14407	-0.15522	0.087716	0.009728	-0.00101
scale_length	-0.03181	0.181335	0.078361	0.011111	0.046348
infl_length	-0.10121	-0.91204	0.090624	-0.00021	-8.6E-05

	Factors		
Variables	Factor11	Factor12	Factor13
seed_length	0.037146	0.001363	-0.00012
seed_coat	-0.04063	-0.00032	0.000232
follicle_length	0.00155	0.000206	0.00067
follicle_beak_length	-0.05371	0.003483	0.003589
follicles_flower	-0.14107	-0.00607	-1E-06
max_follicles	0.151862	0.005491	0.000796
follicle_vestiture	0.002706	0.00006	0.000291
hairy_vein	-0.01198	0.018765	-0.00105
hairy_node	0.003563	0.00005	0.000047
hairy_stem_base	0.004157	-0.01828	0.000779
hair_stem_below_infl	-0.00027	0.000106	0
scale_length	0.044665	-0.00223	-0.00325
infl_length	-5.8E-05	0.000217	0.000058

Factor Structure Summary after Varimax Rotation

Factors

Factor1	Factor2	Factor3	Factor4	Factor5	Factor6
hairy_vein	follicles_flower	scale_length	seed_length	hair_stem_below_infl	follicle_length
hairy_stem_base	max_follicles	follicle_beak_length	seed_coat		
hairy_node					

Principal Components Report

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Database

Factor Structure Summary after Varimax Rotation

	Factors				
Factor1	Factor7	Factor8	Factor9	Factor10	Factor11
hairy_vein	infl_length	follicle_vestiture			
hairy_stem_base					
hairy_node					

Factor Structure Summary after Varimax Rotation

	Factors	
Factor1	Factor12	Factor13
hairy_vein		
hairy_stem_base		
hairy_node		

Factor Score after Varimax Rotation

	Factors				
Row	Factor1	Factor2	Factor3	Factor4	Factor5
1	0.8986	0.7502	1.4262	-0.1353	-1.8025
7	0.6769	0.8444	0.5386	-0.1733	-0.4007
16	-1.9897	1.439	0.3053	-0.8531	0.7065
3	0.6587	0.9705	1.1548	-0.1173	0.7774
4	0.5438	-0.3592	1.0174	-0.2887	0.7752
5	0.5862	0.3576	1.6386	-0.1504	0.3014
9	0.6383	0.7639	0.6917	-0.6091	2.5228
2	-1.5813	-0.9975	0.7355	-0.9858	-2.4659
6	0.4367	-1.1007	0.4967	-0.6631	1.2412
8					
10					
11					
12					
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Subset of variables to include more samples (procedure 2)

Principal Components Report

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Database

Robust and Missing-Value Estimation Iteration Section

No.	Count	Trace of Covar Matrix	Percent Change
0	29	1548.98	0
1	35	1306.345	-15.66
2	35	1306.311	0
3	35	1306.303	0
4	35	1306.301	0
5	35	1306.3	0
6	35	1306.3	0

Descriptive Statistics Section

Variables	Count	Mean	Standard Deviation	Communality
follicle_length	35	9.496328	1.400516	1
follicle_beak_length	35	0.977334	0.208159	1
follicles_flower	35	1.876476	0.754064	1
max_follicles	35	2.228571	1.031439	1
follicle_vestiture	35	0.942857	0.235504	1
hairy_vein	35	2.942857	1.551903	1
hairy_node	35	1.542857	0.81684	1
hair_stem_below_infl	35	3.242857	0.770518	1
infl_length	35	136.3428	36.04078	1

Correlation Section

Variables	Variables follicle_len	follicle_beak_le	follicles_flower	max_follicl	follicle_vesti

	gth	ngth		es	ture
follicle_length	1	0.079674	0.023767	0.08545	0.133105
follicle_beak_length	0.079674	1	-0.01631	-0.0269	-0.12719
follicles_flower	0.023767	-0.01631	1	0.931704	0.124704
max_follicles	0.08545	-0.0269	0.931704	1	0.176434
follicle_vestiture	0.133105	-0.12719	0.124704	0.176434	1
hairy_vein	0.249676	0.173045	-0.03922	-0.08347	0.47365
hairy_node	0.48801	0.197079	-0.01463	-0.01197	0.471782
hair_stem_below_infl	0.3072	0.257705	0.12056	0.131643	0.24081
infl_length	0.202216	-0.0184	0.405603	0.464635	0.262266

Phi=0.307932 Log(Det|R|)=-4.909418 Bartlett Test=148.10 DF=36 Prob=0.000000

Principal Components Report

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Database

Correlation Section

Variables

Variables	hairy_vein	hairy_node	hair_stem_below_infl	infl_length
follicle_length	0.249676	0.48801	0.3072	0.202216
follicle_beak_length	0.173045	0.197079	0.257705	-0.0184
follicles_flower	-0.03922	-0.01463	0.12056	0.405603
max_follicles	-0.08347	-0.01197	0.131643	0.464635
follicle_vestiture	0.47365	0.471782	0.24081	0.262266
hairy_vein	1	0.83725	0.098035	0.045584
hairy_node	0.83725	1	0.204947	0.047441
hair_stem_below_infl	0.098035	0.204947	1	0.355954
infl_length	0.045584	0.047441	0.355954	1

Phi=0.307932 Log(Det|R|)=-4.909418 Bartlett Test=148.10 DF=36 Prob=0.000000

Eigenvalues after Varimax Rotation

No.	Eigenvalue	Individual Percent	Cumulative Percent	Scree Plot
1	1.839432	20.44	20.44	|||||
2	1.968482	21.87	42.31	|||||
3	1.009374	11.22	53.53	|||
4	1.006118	11.18	64.7	|||
5	1.057086	11.75	76.45	|||
6	0.967554	10.75	87.2	|||
7	0.963103	10.7	97.9	|||
8	0.12938	1.44	99.34	|
9	0.059472	0.66	100	|

Factor Loadings after Varimax Rotation

Factors

Variables	Factor1	Factor2	Factor3	Factor4	Factor5
follicle_length	-0.20376	-0.02458	0.021226	-0.1418	0.964161
follicle_beak_length	-0.11425	0.010723	**0.981174**	-0.1282	0.021293
follicles_flower	-0.00021	**-0.976**	-0.00818	-0.04531	-0.01791
max_follicles	0.053797	**-0.959**	-0.00592	-0.03277	0.052223
follicle_vestiture	-0.32232	-0.09132	-0.10173	-0.11783	0.023594
hairy_vein	**-0.95679**	0.051775	0.079539	-0.00805	0.050737
hairy_node	**-0.8716**	0.005309	0.097176	-0.08492	0.302237
hair_stem_below_infl	-0.05381	-0.05991	0.14034	-0.95675	0.145476
infl_length	-0.00804	-0.2844	-0.01747	-0.17299	0.091302

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Factor Loadings after Varimax Rotation

Factors

Variables	Factor6	Factor7	Factor8	Factor9
follicle_length	0.08508	0.019447	-0.00975	-0.00198
follicle_beak_length	-0.01509	-0.08366	-0.00389	0.00089
follicles_flower	0.128803	0.016655	0.020802	0.166399
max_follicles	0.184853	0.085088	-0.02417	-0.17778
follicle_vestiture	0.116168	0.921637	-0.00794	-0.00234
hairy_vein	0.028814	0.188919	0.190567	0.008925
hairy_node	-0.02138	0.199793	-0.30304	-0.00928
hair_stem_below_infl	0.161582	0.105557	-0.00623	0.000204
infl_length	0.931899	0.109748	0.002164	-0.00134

Factor Structure Summary after Varimax Rotation

Factors

Factor1	Factor2	Factor3	Factor4	Factor5	Factor6
hairy_vein	follicles_flower	follicle_beak_length	hair_stem_below_infl	follicle_length	infl_length
hairy_node	max_follicles				

Factors

Factor1	Factor7	Factor8	Factor9
hairy_vein	follicle_vestiture		
hairy_node			

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Factor Score after Varimax Rotation

Row	Factors Factor1	Factor2	Factor3	Factor4	Factor5
1	-0.7996	-0.7977	1.4646	1.8431	-1.325
7	-0.614	-0.8626	0.4239	0.3953	0.3503
15	1.3316	0.3351	-0.8215	-1.5828	-2.5138
16	1.3419	-1.5459	0.1849	-0.6896	1.4561
26	-1.0906	0.3325	-1.8084	0.0358	-1.1119
27	1.5023	-0.7848	-1.6238	-0.1299	-0.4519
28					
3	-0.4698	-0.9983	1.0966	-0.7642	0.6638
4	-0.4535	0.3325	1.1082	-0.7364	0.372
5	-0.3276	-0.374	1.8546	-0.2259	1.038
8	-0.6471	0.1948	-0.5898	0.3069	0.5726
9	-0.7311	-0.8065	0.6755	-2.5149	-0.8316
2	1.2718	0.8763	1.1208	2.5235	-0.7366
10	0.2241	1.225	1.0059	-0.7827	1.3251
11	1.3091	-0.1451	-0.3063	-1.58	0.5477
12	2.431	0.3604	0.8856	0.4638	0.1865
13	2.2374	0.6622	-0.3144	0.2768	-0.1294
17					
18					
19	-0.7675	1.0054	-0.1332	-0.0167	-0.9049
6	-0.5576	1.0469	0.5372	-1.2184	-0.2951
20	-0.5881	1.0466	-0.7803	0.1183	0.6506
21	0.318	1.8167	0.9675	-0.5631	-1.1744
22	-0.4438	0.6966	-2.2118	0.2286	0.2534
23	-0.3227	-0.3302	-1.859	0.3793	1.0548
24	-0.606	-2.3423	-0.0292	-0.4043	1.4792
25					
29	-0.7825	0.1445	0.738	0.2413	-1.2239
30	-0.3946	1.1415	-0.9089	0.3557	1.9323
31	-0.7146	0.1479	-0.4358	-0.9617	0.0404
32					
33					
34	-0.9409	-1.7631	0.9089	0.3503	-1.5538
35	0.1608	1.0801	1.0132	0.4661	1.0474
14	-1.0334	-0.76	-0.9729	0.0724	-1.1712