GEOGRAPHIC VARIATION IN THE LEAF ESSENTIAL OILS OF *JUNIPERUS GRANDIS* (CUPRESSACEAE) AND COMPARISION WITH *J. OCCIDENTALIS* AND *J. OSTEOSPERMA*

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ABSTRACT

The leaf essential oils of *Juniperus grandis* were examined from throughout its range. The oil of the Yolla Bolly Mtns. putative *J. grandis* population was found to be most similar to *J. occidentalis*. The disjunct San Bernardino Mtns., *J. grandis* population was found to be quite differentiated from *J. grandis* populations in the high Sierras of California. The oils from several populations of *J. occidentalis* and *J. osteosperma,* as well as the oils of *J. californica* (chemotypes A and B), are compared with *J. grandis*. The compositions of leaf essential oils of *J. grandis*, *J. occidentalis* and *J. osteosperma* are presented in detail. *Phytologia 92(2): 167-185 (August 2, 2010).*

KEY WORDS: *Juniperus grandis (= J. occidentalis* var. *australis), J. californica, J. occidentalis, J. osteosperma,* Cupressaceae, terpenes, geographic variation.

Juniperus grandis R. P. Adams (= *J. occidentalis var. australis* (Vasek) A. & N. Holmgren) is part of a complex of closely related serrate leaf-margined junipers (*J. californica* Carr.*, J. occidentalis* Hook.*, J. osteosperma* [Torr.] Little) of the western United States and Baja Calif., Mexico. Vasek (1966), in a classic study of *J. californica, J. occidentalis* and *J. osteosperma*, recognized a new variety of *J. occidentalis* (*J. o.* var. *australis*). Additional research utilizing leaf essential oils (Vasek and Scora, 1967) supported the new variety as well as the discovery of two chemical races of *J. californica* (chemotypes A and B).

Recently, DNA sequencing of nrDNA and trnC-trnD (Adams, et al., 2006) has shed new light on the relationships within this group. Firstly, the one-seeded, serrate leaf margined junipers were found to be paraphyletic. Secondly, *J. californica* was shown to be quite distinct (Fig. 1); however, analysis of nrDNA and trnC-trnD sequence data individually gives weak support that *J. californica* is sister to the *J. occidentalis* - *J. osteosperma* clade. Additional research will be needed to resolve this issue. Thirdly, all of the remaining species are divided into two large clades (Fig. 1), with *J. grandis* in a well-supported clade with *J. osteosperma*.

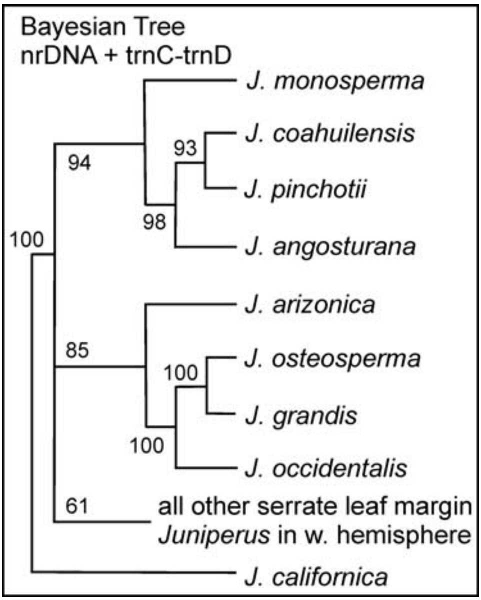

Figure 1. Partial phylogenetic tree derived from nrDNA + trnC-trnD sequence data (adapted from Adams et al., 2006). Values at the branch points are posterior probabilities.

Juniperus grandis has a major disjunction in its distribution, with populations in the high Sierras and the San Bernardino Mtns. (Fig. 2), and, according to Vasek (1966), with putative outlying

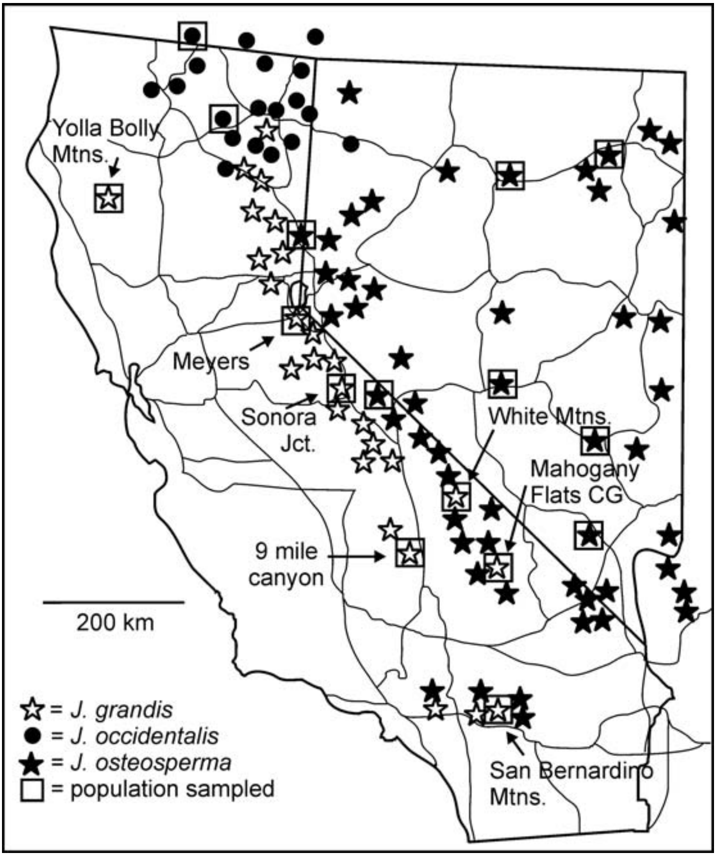

Figure 2. Distribution of *J. grandis* as per Vasek (1966) with populations sampled. Partial distributions of *J. occidentalis* and *J. osteosperma* are also mapped for this region. The putative (open stars) *J. grandis* populations (as per Vasek, 1966): Yolla Bolly Mtns., White Mtns. and Mahogany Flats represent the understanding prior to the present study, not the distribution of *J. grandis* as indicated by the terpene data in the present study.

populations in the Yolla Bolly Mtns., White Mtns., and Panamint Range (see Mahogany Flats CG, Fig. 2).

The leaf essential oils of *J. grandis* have been reported (as *J. occidentalis* var. *australis*) by Adams et al. (1983) and Adams (2000). However, both of these reports utilized samples taken only from the San Bernardino Mtns. Nothing has been published concerning geographic variation in the leaf essential oils of *J. grandis*.

The purpose of the present study is to present analyses of leaf essential oils of *J. grandis* from several populations and compare these with closely related species (*J. occidentalis, J. osteosperma*).

MATERIALS AND METHODS

Plant material:
J. californica, chemotype *A, Adams 10154-10156,* Victorville, CA, *Adams 8695-8697*, 13 km n of Amboy/Kelso exit on I40, on road to Kelso at Granite Pass, 34º 48.41N, 115º 36.54'W, 1280 m, San Bernardino Co., CA; *J. californica,* chemotype B *Adams 8698-8699*, 27 km se of SE of Yucca, on Alamo Road, 34º 44.91N, 113º 58.19'W, 920 m, Mojave Co., AZ;
J. grandis, Adams 11963-11967, Jct. US 50 & CA 89, 38º 51.086N, 120º 01.244'W, 1937 m, Meyers, El Dorado Co.; CA; *Adams 11968-11972*, 16 km w of Sonora Jct., on CA Hwy. 108, 38º 18.289'N, 111º 35.598'W, 2585 m, Tuolumne Co.; CA, *Adams 11984-11988*, Nine Mile Canyon Rd., 20 km w of Jct. with US 395, 35º 54.003'N, 118º 02.078'W, 2059 m, Tulare Co., CA; *Adams 11989-11993*, 5km n Big Bear City on CA 18, 34º 17.533'N, 116º 49.153'W, 2053 m, San Bernardino Co., CA;
J. occidentalis, Adams 11940-11942, 12 km e of Jct. WA 14 & US 97 on WA 14, 45º 44.392'N, 120º 41.207'W, 170 m, Klickitat Co.; WA, *Adams 11943-11945*, 2 km s of jct. US 97 & US 197 on US 97, 38 km ne of Madras, OR; 44º 53.676'N, 120º 56.131'W, 951 m, Wasco Co., OR; *Adams 11946-11948*, 3 km sw of Bend, OR; on OR 372, 44º 02.390'N, 121º 20.054'W, 1132 m, Deschutes Co., OR; *Adams 11949-11951,* 32 km e of Bend, OR on OR 20, shrubs, 0.5 - 1m tall, 43º 53.922'N, 120º 59.187'W, 1274 m, Deschutes Co., OR; *Adams 11952-11954,* 14 km e of Jct. OR66 & I5, on OR66, 42º 08.044'N, 122º

34.130'W, 701 m, Jackson Co., OR; *Adams 11957-11959*, on CA299, 10 km e of McArthur, CA, 41º 05.313'N, 121º 18.921'W, 1091 m, Lassen Co., CA; *Adams 11995-11998 (Kauffmann A1-A3, B1),* Yolla Bolly-Middle Eel Wilderness, 40º 06' 34"N, 122º 57' 59W, 1815- 2000 m, Trinity Co., CA;
J. osteosperma, Adams 10272-10276, on NV157, Charleston Mtns. 36º 16.246'N, 115º 32.604'W, 1795 m, Clark Co., NV; *Adams 11122-11124*, Hancock Summit, mile 38 on US375, 37º 26.404'N, 115º 22.703'W, 1675 m, Lincoln Co. NV; *Adams 11125-11127*, McKinney Tanks Summit on US6, 38º 07.005'N, 116º 54.103'W, 1933 m, Nye Co., NV; *Adams 11134-36*, 8 km s of Bridgeport, on US395, 38º 12.639'N, 119º 13.846'W, 2004 m, Mono Co., CA; *Adams 11141-11143,* 13 km w of Elko, on I80, 40º 45.598'N, 115º 55.942'W, 1535 m, Elko Co., NV; *Adams 11144-11146*, 8 km e of Wells, on I80, 41º 06.533'N, 114º 51.441'W, 1876 m, Elko Co., NV; *Adams 11960-11962,* 56 km n of Reno, NV; on US395, 39º 54.458'N, 120º 00.322'W, 1383 m, Lassen Co., CA; *Adams 11973-11977,* 10 km n of CA 168 on White Mtn. Rd., 37º 20.143'N, 118º 11.346'W, 2607 m, Inyo Co., CA; *Adams 11978-11982,* Mahogany Flats Campground, Panamint Mtns., 36º 13.783'N, 117º 04.102'W, 2477 m, Inyo Co., CA. Voucher specimens are deposited in the Herbarium, Baylor University (BAYLU).

Isolation of Oils - Fresh leaves (200 g) were steam distilled for 2 h using a circulatory Clevenger-type apparatus (Adams, 1991). The oil samples were concentrated (ether trap removed) with nitrogen and the samples stored at -20ºC until analyzed. The extracted leaves were oven dried (100ºC, 48 h) for determination of oil yields.

Chemical Analyses - Oils from 10-15 trees of each of the taxa were analyzed and average values reported. The oils were analyzed on a HP5971 MSD mass spectrometer, scan time 1/ sec., directly coupled to a HP 5890 gas chromatograph, using a J & W DB-5, 0.26 mm x 30 m, 0.25 micron coating thickness, fused silica capillary column (see 5 for operating details). Identifications were made by library searches of our volatile oil library (Adams, 2007), using the HP Chemstation library search routines, coupled with retention time data of authentic reference compounds. Quantitation was by FID on an HP 5890 gas chromatograph using a J & W DB-5, 0.26 mm x 30 m, 0.25 micron coating thickness, fused silica capillary column using the HP Chemstation software.

Data Analysis - Terpenoids (as per cent total oil) were coded and compared among the species by the Gower metric (1971). Principal coordinate analysis was performed by factoring the associational matrix using the formulation of Gower (1966) and Veldman (1967).

RESULTS AND DISCUSSION

A minimum spanning network based, on 63 terpenes, revealed (Fig. 3) the taxa to be aligned in five groups: *J. osteosperma, J. californica, J. occidentalis, J. grandis* (San Bernardino Mtns.) and *J. grandis* (high Sierras). *Juniperus osteosperma* is the most uniform taxon, even though it includes populations that were putatively *J. grandis* (White Mtns, CA and Mahogany Flats campground, Panamint Mtns., CA). In figure 2, one can see that Vasek (1966) called plants from these areas *J. grandis.* Two *J. grandis* (filed as *J. occidentalis* var. *australis*) herbarium specimens were found from the White Mtns./ Inyo Mtns: UCR4254, *Vasek, Clarke & Kucera 650710-08*, 10 Jul 1965, Inyo Mtns., Seep Hole Springs (2800 m) near Waucoba Saddle, large trees with red bark; UCR99917, *G. K. Helmkamp 2460*, 30 Sept 1997, White Mtns., 6.1 mi. n of CA168 on White Mtn. Rd., 2622 m, abundant on steep rocky bank. Our population, 6.2 mi. n of CA168 on White Mtn. Rd., is very near the site of Helmkamp. The trees had a tendency to have a single axis, but were somewhat branched. Clearly, from the leaf oils (Fig. 3), our samples were typical oils of *J. osteosperma*. Of course, it may be that there are some *J. grandis* in the White Mtns. that were not sampled in this limited collection. I (RPA) was not able to visit Seep Hole Springs to collect from the Vasek et al. site, but the site seems to be in a micro-habitat at 2800 m and may well be a stand of *J. grandis* isolated from the high Sierra populations.

Two *J. grandis* (filed as *J. occidentalis* var. *australis*) specimens were found from the Panamint Mtns.: UCR1808, *Vasek 610909-06*, 09 Sept 1962, ca. 200 yds. s of Mahogany Flat, 2561 m and UCR 1812 *Vasek 620930-01*, 30 Sept 1962, s of Mahogany Flat, just below the new Mt. Rogers Rd., 2500 m. This area was visited (RPA) and appears to be where present day Mahogany Flat campground (CG) is located (2477 m). Several *J. grandis* - *osteosperma* trees were seen that had a strong central axis and the oils from these were extracted and examined. All had typical *J. osteosperma* oils (Fig. 3). This site is more mesic than the lower desert area where smaller, multi-stemmed

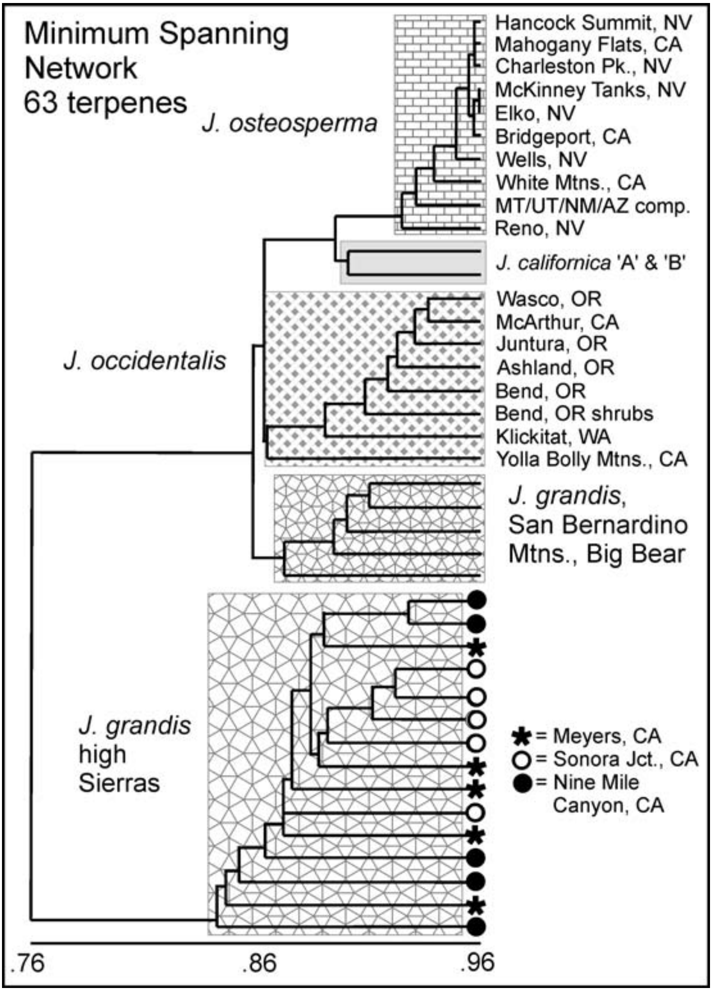

Figure 3. Minimum Spanning Network based on 63 terpenes.

J. osteosperma grow in profusion. It appears that when *J. osteosperma* grows in a more mesic site, it becomes more tree-like and as a result it may be confused with *J. grandis*. However, *J. grandis* has a characteristic trunk shape that (tapered from the base to the top of the tree). In older trees in the high Sierras such trunks are quite noticeable.

The putative *J. grandis* trees in the Yolla Bolly-Middle Eel Wilderness (Fig. 2), grow on sandy soil with Jeffery pine, sugar pine, Douglas fir, incense cedar and mountain mahogany at 1815- 2000 m. This site is very isolated from the high Sierra *J. grandis* populations and is in a quite mesic environment. The oils from the Yolla Bolly Mtns. junipers were most similar to the Juntura, OR and McArthur, CA *J. occidentalis* populations (links not shown in Fig. 3).

The major trend in figure 3 is the splitting of *J. grandis* into the high Sierras populations and San Bernardino Mtns. population. In fact, the oils of *J. grandis* from the San Bernardino Mtns. are more similar to *J. occidentalis, J. osteosperma* and *J. californica* than to the oils of the high Sierras populations. Notice, that among the three high Sierra populations, there appears to be little differentiation between the Meyers, Sonora Jct., and Nine Mile Canyon populations, as the individuals are interspersed in the cluster.

To further examine these groupings, Principal Coordinates Ordination (PCO) was performed using 63 terpenes. Factoring the similarity matrix resulted in eigenroots that appeared to asymptote after the first four eigenroots. These eigenroots accounted for 32.2, 12.46, 7.91 and 4.03 % of the variance among individuals. Ordination shows (Fig. 4) the five major groups. The oils of *J. grandis* from the San Bernardino Mtns. appear to be fairly similar to the oils of *J. occidentalis*. However, they were further separated from *J. occidentalis* by the fourth eigenroot (4.03%) (not shown in figure 4).

PCO of the 20 *J. grandis* individuals, plus *J. occidentalis* from McArthur, CA and Yolla Bolly Mtns., CA resulted in four eigenroots before they began to asymptote. These four eigenroots accounted for 35.05, 7.89, 6.40 and 5.89% of the variance. Ordination of the *J. grandis* individuals plus population averages from McArthur and Yolla Bolly Mtns., CA, shows (figure 5) the two groups of *J. grandis* (San

Bernardino Mtns. and high Sierras populations) plus *J. occidentalis* McArthur and Yolla Bolly Mtns. populations. Notice that the similarity between McArthur and Yolla Bolly Mtns. (0.82) is only slightly larger than between Yolla Bolly Mtns. and *J. grandis*, San Bernardino Mtns. (0.79), but much larger than the link to *J. grandis*, high Sierras (0.71). It should be noted that the Yolla Bolly Mtns. population is the most differentiated population of *J. occidentalis* (figure 3).

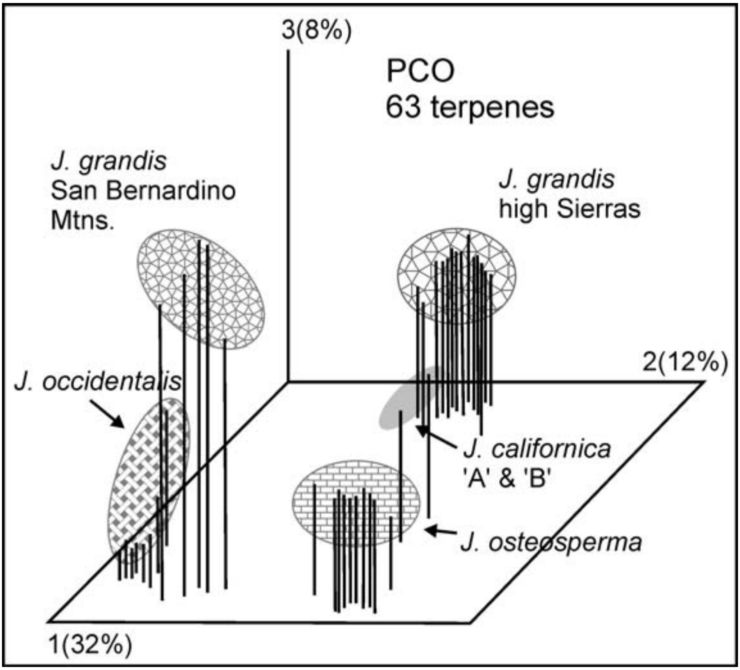

Figure 4. PCO based on 63 terpenes. See text for discussion.

Table 1 shows the leaf oil compositions for the four *J. grandis* populations and representative oils of *J. osteosperma* and *J. occidentalis*. The *J. grandis* (high Sierras vs. San Bernardino Mtns.) populations differ in many compounds: α-fenchene (1.4-1.5%, 0.2);

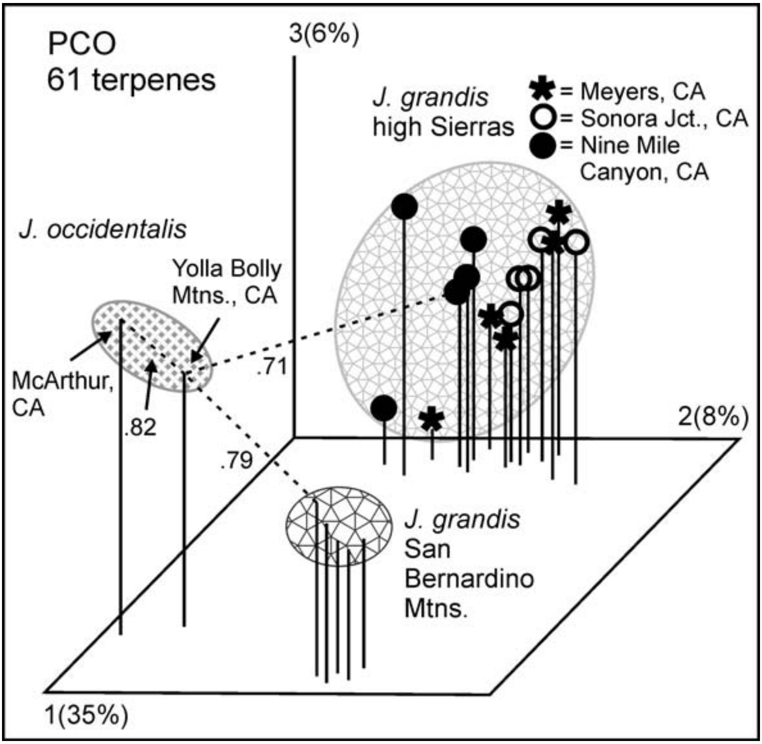

Figure 5. PCO based on 61 terpenes from *J. grandis* (20 individuals) and *J. occidentalis* populations (McArthur, Yolla Bolly Mtns., CA). The dotted lines are minimum links that connect the groups. The numbers by the dotted lines are the similarity (0.0 - 1.0 scale).

verbenene (1.7-2.9, 0.3), sabinene (0-trace, 24.3), α-phellandrene (1.3-2.3, 0.4), δ-3-carene (17.9-30.0, 2.8), p-cymene (1.4-1.6, 6.5), β-phellandrene (10.3-16.4, 1.5), γ-terpene (0.2-0.3, 4.9), cis-sabinene hydrate (0, 1.9), unknown 1092 (0.9-1.2, 0), trans-sabinene hydrate (0, 1.8), camphor (0, 1.2), neo-isopulegol (0.5-1.1, 0), sabina ketone (0, 0.9), terpinen-4-ol (0.4, 9.3), coahuilensol, methyl ether (0.4-1.8, 0), unknown 1230 (2.3-3.9, 0.4), piperitone (1.2-3.6, 0), methyl geranate (0, 1.8), trans-calamenene (0, 2.3), δ-cadinene (0.8-1.3, 0), elemol (0-trace, 0.9), germacrene-D-4-ol (0.7, 0) and α-eudesmol (0, 0.6). The oil of the high Sierra *J. grandis* is dominated by δ-3-carene (17.9-30.0%) whereas the oil of the San Bernardino Mtns. population is dominated by sabinene (24.3%).

The percentages of several compounds of *J. grandis*, San Bernardino Mtns., are similar to *J. osteosperma* and *J. occidentalis* (Table 1): sabinene, camphene, myrcene, α-phellandrene, β-phellandrene, γ-terpene, cis- and trans-sabinene hydrate, sabina ketone, and terpinen-4-ol. It is easy to see why *J. grandis*, San Bernardino Mtns., oil was more similar to *J. occidentalis* and *J. osteosperma* than to *J. grandis* from the high Sierras (figure 3).

Leaf essential oils are extremely useful for the analyses of populational differentiation, hybridization and introgression and in assigning individual plants to a species. It is clear from the present study that some plants (Panamint Mtns. and White Mtns.) that resemble *J. grandis* are actually large, single stemmed *J. osteosperma* plants. The Yolla Bolly Mtns. upright junipers appear to be part of *J. occidentalis,* not *J. grandis*.

Terpenes are generally not as useful in making phylogenetic decisions because several terpenes may be controlled by a single enzyme (ex. a terpene alcohol synthase might add OH to several kinds of terpenes). Thus, adding up the number of terpene differences may or may not give a good estimation of divergence. However, the number and scope of terpene differences between the San Bernardino Mtns. and high Sierra *J. grandis* populations indicate considerable differentiation. Additional research, using DNA sequencing, should help in elucidating these relationships.

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Table 1. Leaf essential oil compositions for four populations of *J. grandis*, (Meyers, CA; 16 km w of Sonora Jct., CA; 9 Mile Canyon, CA and Big Bear City, CA) plus *J. osteosperma* (McKinney Tanks, NV) and *J. occidentalis* (Bend, OR). Compounds in boldface appear to separate taxa and were used in numerical analyses.

AI	Compound	grandis Meyers	grandis Son. Jct	grandis 9 mile	grandis Big Bear	osteo McKin	occid Bend
921	**tricyclene**	**-**	**-**	**0.3**	**0.3**	**0.8**	**1.1**
924	**α-thujene**	**-**	**-**	**-**	**2.3**	**0.5**	**1.0**
932	**α-pinene**	**14.0**	**7.3**	**12.0**	**7.1**	**4.4**	**5.0**
945	**α-fenchene**	**1.5**	**1.4**	**1.5**	**0.2**	**-**	**t**
946	**camphene**	**-**	**-**	**-**	**0.3**	**1.1**	**1.0**
953	thuja-2,4-diene	t	t	t	-	t	t
961	**verbenene**	**2.9**	**1.7**	**2.5**	**0.3**	**-**	**-**
969	**sabinene**	**-**	**t**	**t**	**24.3**	**10.2**	**12.0**
974	**β-pinene**	**1.3**	**0.6**	**1.0**	**0.5**	**0.2**	**0.4**
988	**myrcene**	**3.1**	**3.5**	**2.9**	**1.7**	**1.7**	**1.3**
1001	**δ-2-carene**	**1.1**	**0.2**	**0.8**	**0.1**	**-**	**t**
1002	**α-phellandrene**	**1.6**	**2.3**	**1.3**	**0.4**	**0.3**	**0.8**
1008	**δ-3-carene**	**27.3**	**30.0**	**17.9**	**2.8**	**-**	**1.0**
1014	**α-terpinene**	**0.4**	**0.4**	**0.1**	**3.0**	**1.3**	**1.7**
1020	**p-cymene**	**1.4**	**1.4**	**1.6**	**6.5**	**2.4**	**10.7**
1024	**limonene**	**1.2**	**1.8**	**1.2**	**1.6**	**2.1**	**0.9**

AI	Compound	grandis Meyers	grandis Son. Jct	grandis 9 mile	grandis Big Bear	osteo McKin	occid Bend
1025	**β-phellandrene**	**10.6**	**16.4**	**10.3**	**1.5**	**3.2**	**3.5**
1044	(E)-β-ocimene	t	t	0.2	0.3	t	0.1
1054	**γ-terpinene**	**0.3**	**0.2**	**0.3**	**4.9**	**2.1**	**3.0**
1065	**cis-sabinene hydrate**	**-**	**-**	**-**	**1.9**	**0.8**	**0.9**
1078	camphenilone	-	-	-	-	t	-
1086	**terpinolene**	**3.7**	**3.7**	**3.3**	**1.9**	**1.4**	**1.3**
1090	6,7-epoxymycene	-	-	-	-	0.1	-
1092	**96, 109,43,152, C10-OH**	**0.9**	**0.9**	**1.2**	**-**	**-**	**-**
1095	linalool	t	0.2	0.4	-	-	0.5
1098	**trans-sabinene hydrate**	**-**	**-**	**-**	**1.8**	**1.0**	**0.7**
1100	55,83,110,156, unknown	-	-	-	-	-	0.3
1102	isopentyl-isovalerate	-	-	-	-	0.2	-
1112	3-me-3-buten-methyl butanoate	-	-	-	-	0.4	-
1112	trans-thujone	-	-	-	0.2	-	t
1118	cis-p-menth-2-en-1-ol	0.8	1.2	0.6	0.7	0.6	0.7
1122	α-campholenal	t	t	t	-	0.3	-
1132	cis-limonene oxide (furanoid)	t	t	t	-	-	-
1136	**trans-p-menth-2-en-1-ol**	**0.9**	**1.0**	**0.7**	**0.8**	**-**	**0.9**
1141	**camphor**	**-**	**-**	**-**	**1.2**	**23.7**	**2.5**
1144	**neo-isopulegol**	**0.5**	**0.8**	**1.1**	**-**	**-**	**-**
1145	**camphene hydrate**	**t**	**t**	**0.2**	**0.2**	**1.5**	**0.2**

AI	Compound	grandis Meyers	grandis Son. Jct	grandis 9 mile	grandis Big Bear	osteo McKin	occid Bend
1154	**p-menth-1,5-dien-8-ol iso.**	**0.6**	**0.8**	**0.7**	**-**	**-**	**-**
1154	**sabina ketone**	**-**	**-**	**-**	**0.9**	**0.8**	**0.4**
1161	**p-menth-1,5-dien-8-ol iso.**	**0.3**	**0.3**	**1.3**	**-**	**-**	**-**
1165	**borneol**	**-**	**-**	**-**	**0.1**	**6.0**	**2.2**
1166	**coahuilensol**	**t**	**0.3**	**-**	**-**	**-**	**0.6**
1174	**terpinen-4-ol**	**0.4**	**0.4**	**0.4**	**9.3**	**8.3**	**6.7**
1176	**m-cymen-9-ol**	**0.4**	**0.5**	**1.2**	**-**	**-**	**-**
1179	p-cymen-8-ol	0.4	0.5	1.0	1.0	0.5	0.5
1186	α-terpineol	1.2	1.8	1.1	0.3	0.4	0.4
1195	myrtenol	-	-	-	0.2	0.2	-
1195	cis-piperitol	0.4	0.3	0.2	0.2	0.3	0.2
1204	verbenone	-	-	-	-	0.2	-
1207	trans-piperitol	0.9	1.0	0.8	0.6	0.3	0.3
1215	trans-carveol	-	-	-	-	0.6	-
1219	**coahuilensol, me-ether**	**0.4**	**0.5**	**1.8**	**-**	**0.2**	**1.1**
1223	**citronellol**	**t**	**0.6**	**0.3**	**0.2**	**8.3**	**8.4**
1230	43,119,152,194, unknown	**3.9**	**2.3**	**2.5**	0.4	**-**	**-**
1238	**cumin aldehyde**	**-**	**-**	**-**	**0.3**	**0.3**	**0.2**
1239	carvone	t	t	t	-	0.6	-
1249	**piperitone**	**1.2**	**1.2**	**3.6**	**-**	**t**	**0.2**
1253	trans-sabinene hydrate ac	-	-	-	0.6	-	-
1254	linalool acetate	-	-	-	-	-	0.1

AI	Compound	grandis Meyers	grandis Son. Jct	grandis 9 mile	grandis Big Bear	osteo McKin	occid Bend
1255	4Z-decenol	0.4	0.4	-	-	-	-
1257	methyl citronellate	0.2	0.4	-	0.1	-	-
1260	152,123,77,109, C10-OH	-	t	-	0.2	-	-
1274	**neo-isopulegyl acetate**	**0.3**	**1.4**	**0.2**	**-**	**-**	**-**
1283	α-terpinen-7-al	-	-	-	-	0.2	-
1284	**bornyl acetate**	**0.4**	**0.6**	**2.3**	**2.2**	**16.6**	**9.5**
1285	**safrole**	**0.3**	**0.5**	**2.3**	**-**	**-**	**-**
1298	carvacrol	0.2	0.2	0.4	0.2	t	0.4
1298	3'-methoxy-acetophenone	-	-	-	0.2	-	-
1319	**149,69,91,164, phenolic**	**0.8**	**0.7**	**3.2**	**-**	**0.4**	**-**
1322	**methyl-geranate**	**-**	**-**	**-**	**1.8**	**-**	**1.0**
1325	**p-mentha-1,4-dien-7-ol**	**-**	**-**	**-**	**0.7**	**0.5**	**t**
1332	**cis-piperitol acetate**	**0.4**	**0.2**	**t**	**-**	**-**	**-**
1343	trans-piperitol acetate	0.3	0.2	t	-	-	-
1345	α-cubebene	-	-	-	t	-	t
1350	citronellyl acetate	-	-	-	-	-	-
1374	α-copaene	-	-	-	0.2	-	1.0
1387	β-bourbonene	0.5	0.3	0.3	0.3	-	0.2
1387	β-cubebene	-	-	-	-	-	-
1388	**79,43,91,180, unknown**	**0.3**	**0.3**	**0.2**	**-**	**-**	**-**
1389	**111,81,151,182, unknown**	**1.0**	**0.9**	**0.9**	**0.4**	**-**	**-**
1403	methyl eugenol	t	0.2	t	-	-	-

AI	Compound	grandis Meyers	grandis Son. Jct	grandis 9 mile	grandis Big Bear	osteo McKin	occid Bend
1417	(E)-caryophyllene	-	-	-	0.2	-	-
1429	**cis-thujopsene**	**-**	**-**	**-**	**-**	**0.7**	**0.9**
1448	cis-muurola-3,5-diene	t	t	-	0.2	-	-
1451	trans-muurola-3,5-diene	-	-	-	-	-	0.1
1452	α-humulene	-	-	-	-	-	-
1465	cis-muurola-4,5-diene	-	-	t	0.1	-	0.1
1468	**pinchotene acetate**	**-**	**-**	**-**	**-**	**0.5**	**0.6**
1471	**121,105,180,208,phenol**	**0.3**	**0.4**	**2.0**	**0.3**	**-**	**-**
1471	dauca-5,8-diene	-	-	-	0.2	-	-
1475	trans-cadina-1(6),4-diene	-	-	-	-	-	0.3
1478	**γ-muurolene**	**-**	**t**	**t**	**0.2**	**-**	**0.8**
1484	germacrene D	0.2	0.2	t	0.3	-	0.3
1491	43,207,161,222, C15-OH	-	-	-	0.3	-	-
1493	trans-muurola-4(14),5-diene	-	-	-	0.2	-	0.4
1493	epi-cubebol	-	t	-	0.5	-	0.4
1500	α-muurolene	0.3	0.2	0.4	-	t	1.1
1513	**γ-cadinene**	**1.3**	**0.8**	**1.2**	**1.2**	**t**	**3.7**
1518	**epi-cubebol**	**0.4**	**0.4**	**1.1**	**1.5**	**-**	**0.4**
1521	**trans-calamenene**	**-**	**-**	**-**	**2.3**	**-**	**-**
1522	**δ-cadinene**	**1.1**	**0.8**	**1.3**	**-**	**0.2**	**4.1**
1533	trans-cadina-1,4-diene	-	-	-	0.1	-	0.1

AI	Compound	grandis Meyers	grandis Son. Jct	grandis 9 mile	grandis Big Bear	osteo McKin	occid Bend
1537	α-cadinene	t	-	t	0.2	-	0.4
1544	α-calacorene	-	-	-	-	-	0.3
1548	**elemol**	**-**	**t**	**-**	**0.9**	**0.9**	**-**
1555	**elemicin**	**1.5**	**1.4**	**-**	**-**	**-**	**-**
1559	germacrene B	-	-	-	0.1	-	-
1561	**1-nor-bourbonanone**	**-**	**-**	**-**	**1.1**	**-**	**-**
1561	(E)-nerolidol	-	t	-	-	-	-
1574	**germacrene-D-4-ol**	**0.7**	**0.7**	**0.7**	**-**	**t**	**0.6**
1582	caryophyllene oxide	t	t	t	0.3	t	-
1586	gleenol	-	-	-	-	-	0.3
1587	trans-muurol-5-en-4-α-ol	-	-	-	t	-	-
1607	**β-oplopenone**	**0.4**	**0.3**	**-**	**0.8**	**-**	**0.4**
1608	humulene epoxide II	-	-	-	-	t	-
1618	1,10-di-epi-cubenol	t	t	-	-	-	0.2
1627	1-epi-cubenol	t	t	0.3	0.5	-	1.6
1630	γ-eudesmol	-	-	-	t	0.2	-
1638	**epi-α-cadinol**	**0.7**	**0.7**	**0.7**	**0.6**	**t**	**1.1**
1638	epi-α-muurolol	0.7	0.7	0.8	0.6	t	1.2
1644	α-muurolol	t	0.2	t	0.1	-	0.7
1649	β-eudesmol	0.4	t	-	0.2	0.2	-
1652	**α-eudesmol**	**-**	**-**	**-**	**0.6**	**0.2**	**-**
1652	**α-cadinol**	**1.6**	**1.4**	**1.7**	**0.7**	**0.2**	**1.8**

AI	Compound	grandis Meyers	grandis Son. Jct	grandis 9 mile	grandis Big Bear	osteo McKin	occid Bend
1670	bulnesol	-	-	-	-	t	-
1675	cadalene	-	-	-	0.1	-	0.3
1687	43,167,81,238, unknown	-	-	-	0.3	-	-
1688	shyobunol	0.2	0.2	t	-	-	-
1699	epi-nootkatol	-	t	t	-	-	-
1739	oplopanone	t	t	t	0.2	t	-
1987	**manoyl oxide**	**t**	**0.1**	**t**	**t**	**-**	**3.2**
2009	epi-13-manoyl oxide	-	-	-	-	-	t
2056	manool	t	-	t	-	-	-
2055	abietatriene	t	t	-	-	-	-
2298	4-epi-abietal	t	0.1	t	-	-	-
2312	abieta-7,13-dieen-3-one	-	-	-	-	0.1	-

AI = Arithmetic Index on DB-5 column. Compositional values less than 0.1% are denoted as traces (t). Unidentified components less than 0.5% are not reported.