TAXONOMY OF INFRASPECIFC TAXA OF *ABIES CONCOLOR*: LEAF ESSENTIAL OILS OF VAR. *CONCOLOR* AND VAR. *LOWIANA* - ERRATA

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ABSTRACT

Previously (Adams et al, 2011), the volatile leaf oils of *Abies concolor* were reported. Unfortunately, due to a sample-numbering error, the composition of the New Mexico population was incorrect. This paper reprints the original paper with the corrected data. The leaf essential oils of *Abies concolor* var. *concolor* and var. *lowiana* had large amounts of β-pinene (34-52%). The oils from central and northern California were very similar and were devoid of (E)-β-ocimene and 6-methyl-5-octen-one. Considerable differentiation was found among populations of var. *concolor*, confirming the work of Zavarin et al. (1970, 1975) of the existence of the Cuyamaca Race, and three sub-types of *A. c.* var. *concolor* oils: group A (Utah), B1 (New Mexico) and B2 (Arizona). *Phytologia 93(2): 208-220 (August 1, 2011).*

KEY WORDS: *Abies concolor* var. *concolor, A. c.* var. *lowiana, leaf* essential oils composition, geographic variation.

Abies concolor (Gord. & Glend.) Hilde. is a forest tree of western North America (Fig. 1) ranging from Oregon to northern Mexico (Zavarin et al. 1975). Eckenwalder (2009) recognized two varieties: var. *concolor* and var. *lowiana* (Gord.) Lemm. and noted that these have been treated as species by some authors. He also indicated that var. *lowiana* hybridizes with *A. grandis* (D. Dougl. ex D. Don in Lamb.) Lindl. but not with *A. lasiocarpa* (Hook.) Nutt. Recently, Xiang et al. (2009) examined nrDNA sequence data and found *A. concolor* most closely related to *A. grandis*, so hybridization seems possible. Zavarin et al. (1970, 1975) analyzed wood monoterpenes of *A. concolor* from 43 populations and found evidence that var. *lowiana* from n. and c. California formed a group (Fig. 1), but called var. *lowiana* from s. California, the Cuyamaca race. In addition, Zavarin et al. (1975) subdivided var. *concolor* into three groups (A, B1 and B2, Fig. 1).

There appears to be only one paper reporting on the leaf essential oil of *A. concolor* (Wagner et al. 1989) from a population in the North Kaibab Ranger District, AZ, and those data were reported on a ppm basis instead of the normal percent total oil data.

Previously (Adams et al, 2011) the volatile leaf oils of *Abies concolor* were reported to be highly differentiated in a Cimarron, NM population. Unfortunately, due to a sample numbering error, the results for the New Mexico population were incorrect. This paper reprints the original paper with corrected data.

MATERIALS AND METHODS

Plant specimens: *Abies concolor* var. *concolor*: *Adams 12405-12407*, Mill B trailhead, Big Cottonwood Canyon, Salt Lake City, UT, 40º 37.996' N, 111º 43.418' W, 6242 ft., *Adams 12481-12485*, (by D. Thornburg) 7 mi. nw of Pine, AZ along Rim Rd., 34º 26.844'N, 111º 21.520'W, 7597 ft., *Adams 12679-12683*, 13 mi. w of Cimarron, NM on US 64, 36º 31.509' N, 105º 10.932' W, 7872 ft.

Abies concolor var. *lowiana*: *Adams 12427-12431* (by R. Lanner) 2 mi.
n of jct. US50 on White Meadows Rd., ca. 22 mi e of Placerville, CA,
38º 47' 00" N, 120º 29' 20" W, 3450 ft., *Adams 12432-12436* (by R.
Lanner) Mormon Emigrant Trail at jct. with Park Creek Rd., ca. 24 mi
ese of Placerville, CA, 38º 43' 30" N, 120º 28' 20" W, 4000 ft., *Adams
12438-12442* (by M. Kauffmann) Klamath Mtns., CA, 40º 50' 21.4" N,
123º 43' 11.09" W, 4820 ft., *Adams 12464-12468* (by B. Miller) Lee
Summit, CA on Hwy 70/89, 39º 52.674' N, 120º 45.736' W, 4414 ft.,
Abies concolor var. *concolor / lowiana*: *Adams 12522-12526*, on CA
Hwy 38 north side of Onyx Summit, CA, 34º 12.037' N, 116º 43.520'
W, 8490 ft. All specimens are deposited in the BAYLU herbarium.
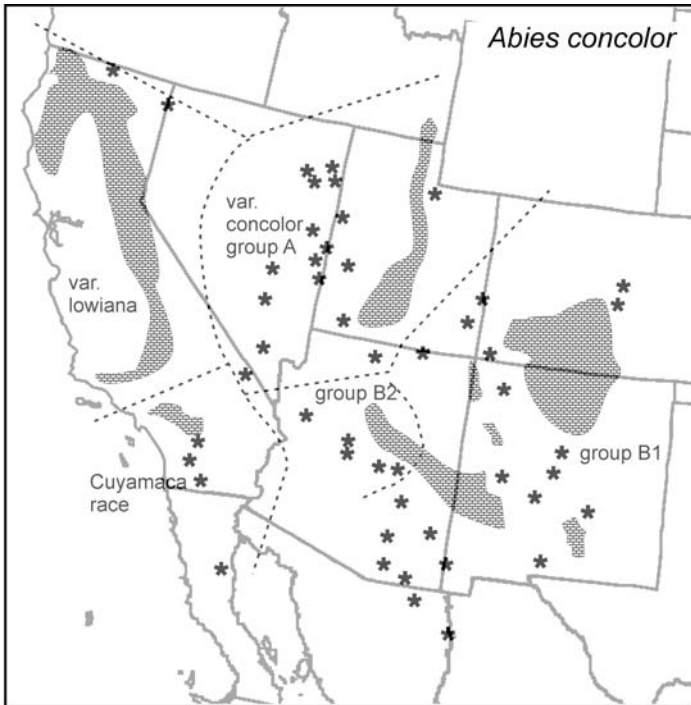

Figure 1. Distribution of *Abies concolor* (modified from Zavarin et al.
1975) with subgroups based on wood monoterpene data.

     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 percent total oil) were coded and compared among the species by the Gower (1971) metric. Principal coordinate analysis was performed by factoring the associational matrix using the formulation of Gower (1966) and Veldman (1967). Associational measures were computed using absolute compound value differences (Manhattan metric), divided by the maximum observed value for that compound over all taxa (= Gower metric, Gower, 1971; Adams, 1975). Principal coordinate analysis was performed by factoring the associational matrix based on the formulation of Gower (1966) and Veldman (1967).

RESULTS AND DISCUSSION

     In general, the leaf oils of *A. concolor* are dominated by monoterpenes with only small amounts of sesquiterpenes and diterpenes (Table 1). Each of the populations are high in β-pinene (Table 1). The populations from central and northern California (Lee S, Plac, Klam, Table 1) share several components at similar levels: linalool, α-terpineol, geranyl acetate, RI 1617 sesquiterpene alcohol, and eudesm-7(11)-en-4-ol and all are devoid of (E)-β-ocimene and 6-methyl-5-octen-one (Table 1).

The overall similarities of the oils are shown in figure 2. Notice *A. c.* var. *lowiana* from central and northwestern California have very similar oils (0.809, 0.888, Fig. 2). The major difference in the Klamath Mtns. oil is the presence of intermedeol that was only found in this oil and the New Mexico oil. The oils from Utah and Onyx Summit are the next most similar (0.734, Fig. 2), with the oils from Arizona and New Mexico being the least similar group (0.702, Fig. 2).
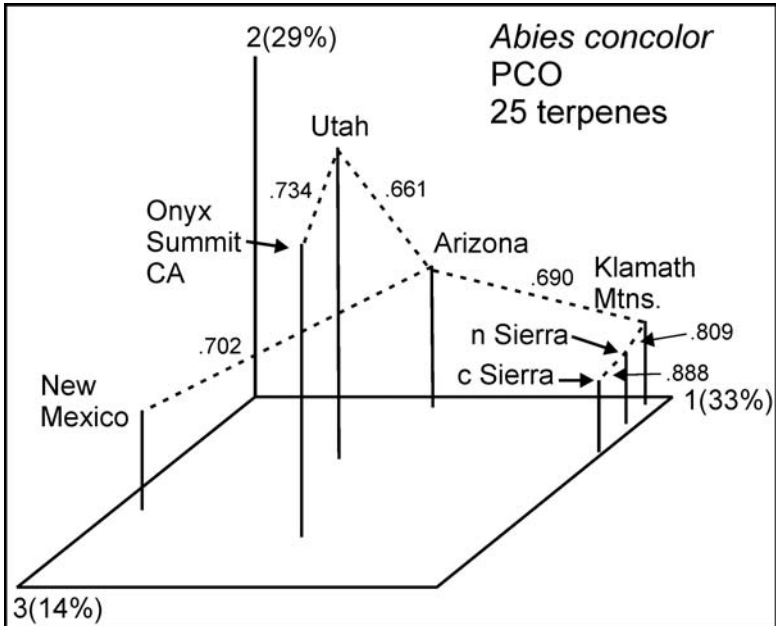
Figure 2. PCO based on 25 terpenes. The dotted lines are the minimum spanning network and the numbers next to the lines are the similarities.

Mapping the minimum spanning network onto the distribution of *Abies concolor* (Fig. 3) clearly shows the geographic affinities. The unity of the central and northwestern California *A. c.* var. *lowiana* populations is clear. Zavarin et al. (1975) designated the southern California populations as the Cuyamaca race and this analysis confirms their observation. Zavarin et al. (1975) found an affinity (in the wood monoterpenes) of the Cuyamaca Race to var. *concolor*, group A, and

there is a moderate similarity in their oils (Figs. 2, 3), but they are rather distinct.

Zavarin et al. (1975) divided var. *concolor* into 3 sub-groups: A, B1 and B2. The present analysis (based on leaf essential oils) confirms the same pattern of differentiation (Figs. 2, 3).
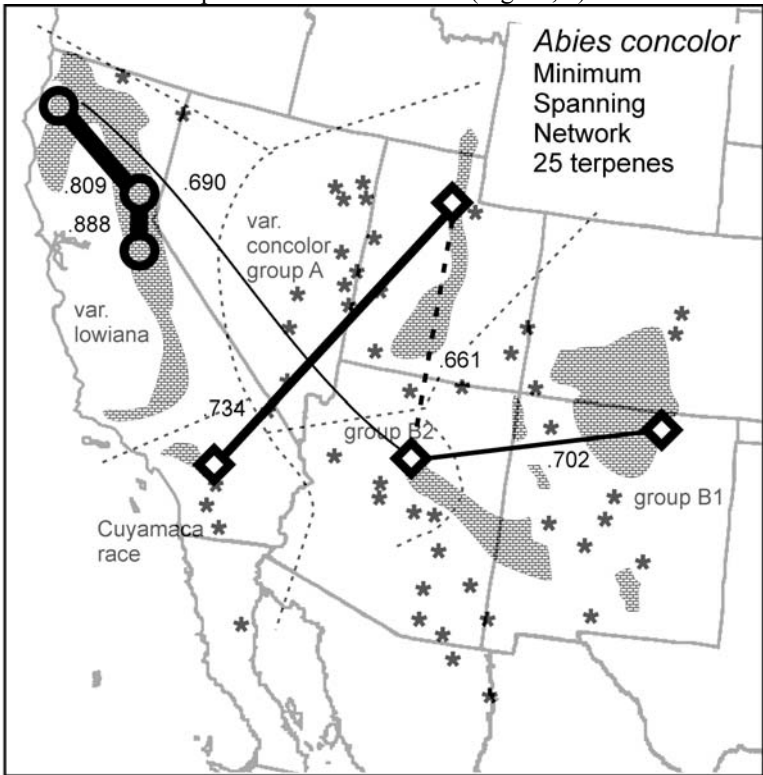
Figure 3. Minimum spanning network based on 20 terpenes. The open circles are *A. c.* var. *lowiana*, the open squares are generally treated as *A. c.* var. *concolor*. The numbers next to the lines are similarities.

A different perspective is obtained by geographically clustering the populations (Fig. 4). The differentiation of var. *lowiana* in northwest California is the dominant feature (Fig. 4). In addition, the differentiation of the other subgroups is clearly seen (Cuyamaca race - Utah, A) and (Arizona, B2 - New Mexico, B1).

Figure 4. Geographically clustering of populations of *Abies concolor* based on 25 terpenoids. The numbers next to the contour lines are the similarities.

CONCLUSIONS

In general, the leaf volatile oils gave a very good agreement with the pattern of differentiation Zavarin et al. (1975) found using wood monoterpenes. The volatile leaf oils support the recognition of var. *concolor* and var. *lowiana*. The differentiation of the Cuyamaca race, and three sub-types of *A. c.* var.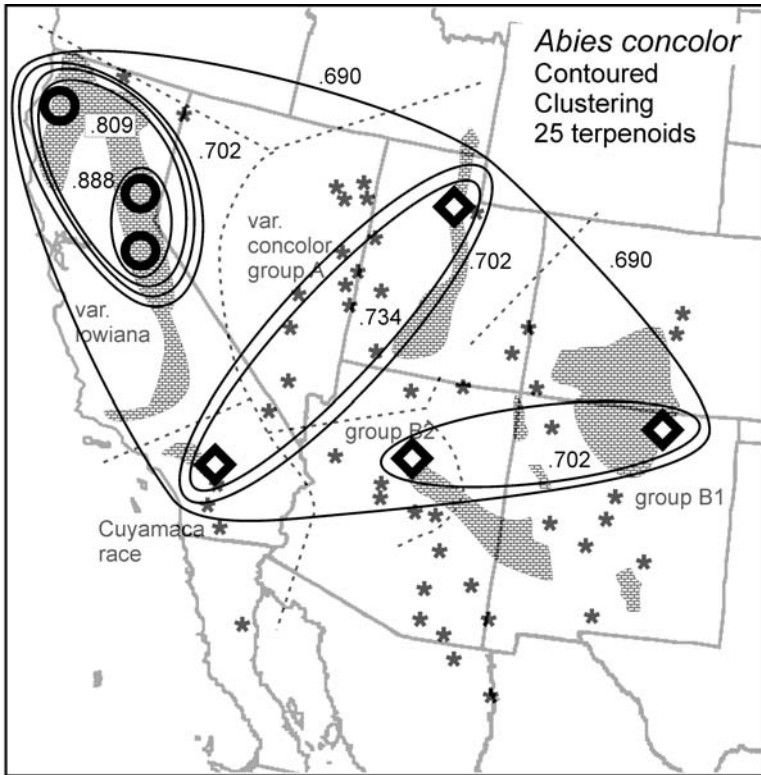 *concolor* oils: group A (Utah), B1 (New Mexico) and B2 (Arizona) suggests that these populations might be incipient varieties.

ACKNOWLEDGEMENTS

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Table 1. Comparison of leaf oil compositions of *Abies concolor* populations. Klam = Klamath Mtns., NW CA, Lee S = Lee Summit, CA, Plac = Placerville, CA, AZ = Pine, AZ, NM = Cimarron, New Mexico, UT = Wasatch Mtns., UT, Onyx = Onyx Summit, CA. Compounds in bold face appear to separate the taxa. Compositional values less than 0.1% are denoted as traces (t). Unidentified components less than 0.5% are not reported. RI is the Kovat's Index using a linear approximation on DB-5 column. *= cpds used for PCO (30 cpds.)

RI	compound	Plac	Klam	Lee S	AZ	NM	UT	Onyx
884	**santene***	**0.2**	**0.3**	**0.2**	**-**	**-**	**t**	**t**
921	tricyclene*	0.1	0.2	0.2	0.3	0.6	0.2	t
924	α-thujene	t	t	t	t	-	t	t
932	α-pinene*	4.4	4.7	5.1	7.9	6.6	8.9	7.8
946	**camphene***	**1.4**	**2.7**	**2.5**	**4.3**	**9.0**	**2.9**	**0.5**
969	sabinene	t	t	t	t	0.1	t	t
974	**β-pinene***	**47.1**	**45.2**	**42.0**	**52.2**	**34.0**	**43.9**	**41.5**
988	myrcene*	2.2	1.4	2.0	2.2	1.2	2.1	1.7
1002	α-phellandrene	0.4	0.3	0.4	0.3	0.1	0.2	0.4
1008	δ-3-carene*	0.1	0.2	0.1	0.5	1.8	1.6	1.1
1014	α-terpinene	0.2	0.2	0.2	0.1	t	0.1	0.2
1020	p-cymene	t	t	t	t	t	t	t
1024	**limonene***	**23.0**	**17.6**	**23.0**	**9.0**	**1.6**	**9.3**	**21.2**
1025	**β-phellandrene**	**2.5**	**2.0**	**2.5**	**1.1**	**6.5**	**1.1**	**2.5**
1032	(Z)-β-ocimene	-	t	t	0.3	0.1	0.2	0.1

RI	compound	Plac	Klam	Lee S	AZ	NM	UT	Onyx
1038	2-heptyl acetate	-	-	-	-	-	t	-
1044	**(E)-β-ocimene***	-	-	-	**0.3**	**0.2**	**0.3**	**0.1**
1054	γ-terpinene	0.2	0.1	0.2	0.2	0.2	0.2	0.2
1077	(6-methyl-5-octen-2-one)	-	-	-	0.1	0.1	0.1	0.1
1086	terpinolene*	1.7	1.0	1.4	0.7	0.6	1.7	1.4
1087	2-nonanone*	0.4	0.1	0.3	0.5	0.2	0.6	0.4
1095	**linalool***	**0.2**	**0.1**	**0.4**	**1.4**	**1.9**	**1.8**	**1.4**
1118	endo-fenchol*	0.4	0.3	0.4	0.2	t	1.8	1.6
1118	cis-p-menth-2-en-1-ol	0.4	0.3	0.4	0.1	t	0.2	0.4
1122	α-campholenal	0.1	t	0.1	0.1	t	0.2	0.2
1136	trans-p-menth-2-en-1-ol	0.3	0.1	0.3	t	t	0.1	0.3
1141	camphor	t	t	0.1	t	0.2	0.1	t
1145	**camphene hydrate***	**0.2**	**0.1**	**0.3**	**1.8**	**3.4**	**4.1**	**0.5**
1148	citronellal*	0.1	0.3	0.1	0.6	0.5	0.3	0.2
1155	iso-borneol	t	t	t	t	t	0.1	t
1165	borneol*	0.3	0.2	0.5	0.2	0.2	0.6	0.8
1172	cis-pinocamphone	t	t	t	t	t	-	t
1174	terpinen-4-ol*	0.4	0.3	0.4	0.3	0.4	0.6	0.7
1183	cryptone	t	t	t	t	-	-	t
1186	**α-terpineol***	**6.9**	**4.8**	**6.5**	**2.2**	**1.2**	**3.5**	**4.5**
1195	cis-piperitol	0.2	0.1	0.2	t	t	t	0.1
1201	n-decanal	0.3	-	0.1	0.2	t	0.1	0.2
1207	trans-piperitol	0.1	t	0.2	t	-	t	0.1

RI	compound	Plac	Klam	Lee S	AZ	NM	UT	Onyx
1218	endo-fenchyl acetate	t	t	-	0.1	t	t	t
1223	citronellol*	0.2	0.3	0.5	0.4	0.2	0.6	1.0
1235	neral	0.1	-	0.3	-	-	t	t
1249	**piperitone***	**0.1**	**t**	**0.4**	**t**	-	**1.1**	**1.7**
1264	geranial	0.4	-	0.6	t	t	0.2	0.2
1287	**bornyl acetate***	**1.2**	**6.6**	**2.8**	**8.8**	**20.2**	**6.4**	**0.6**
1289	**thymol***	**t**	-	**t**	**t**	-	**1.3**	**0.6**
1293	2-undecanone	0.3	0.2	0.1	0.4	0.3	0.1	0.4
1300	tridecane*	0.1	t	0.2	0.3	0.8	0.2	0.8
1350	citronellyl acetate*	0.2	0.2	0.2	0.5	0.2	t	0.1
1379	geranyl acetate*	0.8	0.4	0.5	0.2	0.6	t	t
1395	sesquiterpene,43,55,86,206	0.1	-	0.1	0.3	t	t	-
1408	dodecanal	t	-	t	t	t	t	0.1
1417	(E)-caryophyllene	t	t	t	t	-	0.2	0.3
1478	γ-muurolene	t	0.2	0.1	-	-	-	t
1496	valencene	0.2	0.3	0.2	t	-	-	0.2
1500	α-muurolene	-	-	-	-	t	-	-
1514	γ-cadinene	-	-	-	-	0.3	-	-
1514	cubebol	-	0.2	-	-	0.3	-	0.3
1522	δ-cadinene	-	t	-	0.1	0.3	-	0.4
1559	germacrene B	t	-	0.1	0.1	0.5	-	t
1561	(E)-nerolidol	t	-	0.1	t	t	0.1	t

RI	compound	Plac	Klam	Lee S	AZ	NM	UT	Onyx
1617	**sesquiterpene,<u>81</u>,161, 189,222***	**0.3**	**0.4**	**0.5**	**t**	**t**	**t**	-
1627	1-epi-cubenol	t	-	0.1	t	0.4	-	0.3
1649	β-eudesmol	0.1	-	0.2	-	-	t	-
1652	α-eudesmol	0.1	-	0.2	-	-	t	-
1652	α-cadinol	0.1	-	0.2	-	t	t	-
1665	**intermedeol***	-	**6.4**	-	-	**2.5**	-	-
1700	eudesm-7(11)-en-4-ol	0.1	0.1	0.1	-	-	t	-
1987	manoyl oxide	-	t	t	0.1	0.2	t	t
2014	palustradiene(=abieta-8, 13-diene) *	t	t	0.1	t	-	t	0.3
2056	manool	0.1	t	0.1	t	-	t	t
2149	abienol	0.1	t	0.1	t	-	t	0.2