U. S. FOREST SERVICE RESEARCH NOTE PSW- 135

PACIFIC SOUTHWEST FOREST & RANGE EXPERIMENT STATION
1967 P.O. Box 245 Berkeley, California 94701

Monoterpene Composition of Pine Species and Hybrids. . .

some preliminary findings

RICHARD H. SMITH

ABSTRACT: Xylem resin samples, obtained from 72 freshly cut pine stumps at the Institute of Forest Genetics, Placerville, Calif., were analyzed for monoterpenes by gas-liquid chromatography. Very little or no qualitative or quantitative variation could be attributed to annual ring, time of securing sample, and period of storage of sample up to 1 year. The 34 hybrids sampled generally had resin properties that were intermediate between those of their parents. Several pines had terpenes whose presence hitherto has been unreported.

RETRIEVAL TERMS: Intraspecific variation; geographic variation; chemotaxonomy; gas chromatography; monoterpenes; *Pinus*. Line Project: 2201.

Until recently, little was known of the monoterpene and other resin characteristics of pine hybrids. The development of analytical procedures using gas-liquid chromatography has begun to fill this gap in knowledge.

Preliminary data from a study at the Institute of Forest Genetics, Placerville, Calif., indicates that monoterpenes can be used to determine the hybrid origin of a tree if the composition of the parents is qualitatively different. But difficulty may be encountered if only quantitative differences in monoterpene composition exist between the trees.

Early Studies

Data on the turpentine composition of pines have been compiled by Mirov (1961). These data were gathered by Mirov and others by the analytical procedures used at that time, largely extraction and reaction; Mirov briefly mentioned gas chromatography as a new method. Williams and Bannister (1962) update the information for 22 species of pine grown in New Zealand, by the use of gas chromatography. Since that time gas-liquid chromatography has been used for the analysis of other pine species.

Little is known, however, about the monoterpenes or other resin characteristics of pine hybrids. Mirov reports that certain resin properties of the *Pinus contorta X banksiana* hybrid (1956) and the *P. ponderosa X jeffreyi* hybrid (1961) were intermediate between the two parents. Zobel (1951) used physical resin properties as one means of determining the *P. jeffreyi X coulteri* hybrid in natural stands. Bannister et al. (1959) and Forde (1964) studied the inheritance of monoterpenes of the *P. attenuata X radiata* hybrid by using gas-liquid chromatographic analyses; they found a strong adherence to intermediacy in their studies. Most recently, Critchfield (1966) reports the use of gas chromatographic analysis of monoterpenes to verify hybrids of *P. sabiniana X coulteri* and *P. sabiniana X torreyana*.

Study Site and Procedures

The opportunity to gather preliminary data on the monoterpene composition of many pine hybrids developed during a partial thinning of a 10- to 25-year-old hybrid plantation at the Institute of Forest Genetics. At the same time, additional data could be obtained on inter-ring constancy of terpene composition that had been found in *P. ponderosa* (Smith 1964a). Many of the hybrids used were described by Little and Righter (1965).

Each tree was cut to an 18-inch stump in early February 1964. Resin flow does take place then, though at a greatly reduced rate. Each stump was recut to a 12-inch stump within a day or two to make the cut level. Each cross section was carefully scraped with a new razor blade to remove all debris and to eliminate the smearing effect of the saw.

By the next day resin was beginning to exude from the individual annual rings. A small sample of resin was obtained from the 1963 annual ring by carefully moving a thin glass rod along the annual ring. The rod with the drop of resin was immediately placed in a 2 ml. screwcap vial. From 0.1 to 0.05 ml. of pentane (chromatographic quality) was added to the vial and agitated to dissolve the resin from the rod; the vial was tightly sealed immediately with a teflon-gasketed screwcap. This procedure was repeated for the oldest ring from which resin could be obtained. No effort was made to secure both ring samples from the same radial segment.

The following day all resin that had collected on the stump surfaces was carefully scraped up and placed in corked vials. These samples were held at 35°F. until the resin could be distilled in a Hickman molecular still at 40°C. for 24 hr. at atmospheric pressure. If there was not enough resin for distillation--usually less than 1 or 2 cc.--we added an approximate equal volume of pentane. The pentane preparation or the distillate was transferred to the standard 2-ml. screwcap vial. The distillations were completed within 3 weeks after the collection of the resin. All prepared samples were held at 35°F. until analyzed.

A few stumps were resampled the second day after cutting to determine the effect of a 1-day delay.

The monoterpene analysis was made by a gas-liquid chromatograph with a thermal conductivity detector. The column was stainless steel, 8 feet by 1/4 or 1/8 inch; the solid support was 60/80 or 80/100 Chromosorb W acid-washed, respectively, for the two diameters. The liquid support was 7-1/2 or 10 percent β, β' oxydipropionitrile. Operational parameters were 130 to 140°C. on the injector, 55 to 65°C. on the column, and 140 to 150°C. on the detector, filaments at 200 ma., and helium at 40 to 50 ml. per min. Sample size ranged from 0.2 to 0.6 μl. for distillates and 1.0 to 3.0 μl. for pentane preparations. Variations in these parameters did not alter the analysis.

Quantitative determinations were made by normalizing peak areas obtained with a disc integrator. Qualitative determinations were made by comparing relative retention times with knowns and known mixtures and by the introduction of knowns into the sample. The qualitative determinations were checked by analyzing at least one sample from each tree on a LAC-446 column at 90°C. A further check on qualitative determination was made by analyzing the resin from trees which represented groups of trees on an Apiezon-L column at 110°C. The qualitative determination of both α-thujene and terpinolene should be considered tentative because of the lack of relatively pure known standards. The distillate of *P. muricata* was used as a standard for identifying the terpinolene peak (Blight and McDonald 1963). There was agreement among the columns in the relative retention time for the peak described by Blight and McDonald as terpinolene with and without this distillate as a standard. The determination of α-thujene was based on the agreement of relative retention times on the oxydipropionitrile and Apiezon columns (Klouwen and ter Heide 1962).

Each of the three samples from each tree was analyzed at least once within 3 months after preparation on the 1/8-inch oxydipropionitrile column. At least one sample from each tree was analyzed on the LAC column within 6 months. One year after preparation one sample from each tree was analyzed on the 1/4-inch oxydipropionitrile column.

Results and Discussion

In interpreting these results it should be emphasized that all data pertain to the normalized monoterpene composition of xylem resin; other resin systems might be quite different. The term "monoterpene" has been liberally applied to include aliphatic hydrocarbons, such as heptane, nonane, and undecane, which volatilize before or along with the monoterpenes. In most cases only the generalized monoterpene composition of species is considered, since the resin of the actual parents was not obtained and in many cases could not be obtained if so desired. The interpretation of the analysis of hybrids must, therefore, be considered preliminary. The results from this study were as follows:

- No change occurred in the monoterpene samples during the 1-year period between the first and second series of analyses.

- Good agreement was obtained in comparing the first and second day's sampling of the recut stump surface (table 1). This finding indicates that the 1-day delay between stump preparation and sample collection had no apparent effect on the resin composition at this time of the year and was, therefore, a valid procedure.

- The three samples extracted from the same tree; i.e., the 1963 annual ring, the oldest ring with resin, and the total resin from the stump in all trees studied did not differ appreciably in monoterpene composition (table 2).

- There was a general qualitative intermediacy among all 34 hybrids (table 3).

- There was quantitative intermediacy in three out of seven pairs of full sibs; heptane was involved in three out of the four which were not intermediate (table 3).

- Evidence suggests that some of the natural hybrids used in breeding are not valid F_1 but apparently are the result of one or more backcrosses to one of the parents (table 3).

- Several terpenes, whose presence had not yet been reported, were found in some pines as follows (table 3): *P. engelmannii*--camphene, myrcene, β-phellandrene; *P. strobus*--camphene, myrcene, limonene; *P. monticola*--nonane, myrcene, β-phellandrene; *P. griffithii*--undecane, β-pinene, myrcene, limonene; *P. flexilis*, --nonane, β-pinene, 3-carene, sabinene, myrcene, limonene, β-phellandrene, terpinolene; *P. strobiformis* (reflexa)--camphene, sabinene, myrcene, limonene, β-phellandrene; *P. canariensis*--camphene, β-pinene, 3-carene, myrcene, β-phellandrene; *P. longifolia*--myrcene, limonene, β-phellandrene, γ-terpinene.

Acknowledgment

This study would not have been possible without the untiring efforts of many persons, particularly F. I. Righter, who was responsible for developing most of these hybrids; and the technical staff of the Institute of Forest Genetics, who performed the work necessary for producing them. Their efforts are gratefully acknowledged.

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The Author

RICHARD H. SMITH is in charge of this Station's research on the biology, ecology, and control of destructive forest insects, with headquarters in Berkeley. He holds B.S. (1942) and M.S. (1947) degrees from New York State University College of Forestry, and a Ph.D. degree (1961) from the University of California, Berkeley.

Table 1.--*Monoterpene composition of resin samples taken at 24-hour intervals from cross section of five fresh-cut stumps*

Species or hybrid of *Pinus*	IFG No.	Heptane	Nonane	α-pinene	Undecane	Camphene	β-pinene	3-carene	Sabinene	α-phellandrene	Myrcene	Limonene	β-phellandrene	γ-terpinene	Unknown No. 2 (terpinolene)
		Percent													
ponderosa X *ponderosa* var. *scopulorum*	161	1.1	(1/)	28.0	--	0.7	33.4	24.2	--	--	3.4	6.7	1.1	--	1.5
		.5	(1/)	29.4	--	.5	34.8	23.1	--	--	3.3	6.2	1.0	--	1.0
ponderosa X *engelmannii*	18	--	--	39.3	--	(1/)	13.8	35.6	--	--	3.7	4.3	1.2	(1/)	2.1
		--	--	40.7	--	.3	13.2	35.8	--	--	4.1	3.6	.5	(1/)	1.6
[*jeffreyi* X (*jeffreyi* X *coulteri*)] X *ponderosa*	12	--	--	11.4	--	2.4	26.8	26.0	(1/)	--	3.2	13.8	16.2	--	(1/)
		--	--	8.2	--	1.9	26.9	26.5	(1/)	--	3.4	14.6	17.2	--	1.5
jeffreyi X (*jeffreyi* X *coulteri*)	95	83.4	0.1	4.8	--	1.4	2.5	.9	--	--	2.5	.3	4.2	--	--
		82.9	1.6	2.6	--	2.2	1.2	2.1	--	--	2.6	.6	4.2	--	(1/)
jeffreyi X (*jeffreyi* X *coulteri*)	75	85.3	1.0	1.3	--	1.0	(1/)	.3	(1/)	--	6.3	(1/)	4.7	--	--
		91.4	.9	.6	--	(1/)	(1/)	.5	--	--	3.7	--	3.4	--	--

[1] Trace.

Table 2.--*Monoterpene composition of resin of selected pines from three sources on fresh-cut stumps*

Species or hybrid of *Pinus*	IFG No.	Source of sample[1]	Heptane	Nonane	α-pinene	Undecane	Camphene	β-pinene	3-carene	Sabinene	α-phellandrene	Myrcene	Limonene	β-phellandrene	γ-terpinene	Unknown No. 2 (terpinolene)
			Percent													
ponderosa X wind	938	1	--	--	6.4	--	(2/)	23.2	43.4	--	--	4.9	19.6	0.6	(2/)	1.8
		12	--	--	6.7	--	.5	23.1	42.2	--	--	6.2	17.7	1.6	(2/)	1.9
		S	--	--	6.1	--	(2/)	21.9	42.5	--	--	5.9	20.2	.7	0.1	2.5
ponderosa var. *scopulorum* X *engelmannii*	25	1	--	--	54.3	--	1.9	13.1	25.8	--	--	2.0	1.0	.2	(2/)	1.7
		8	--	--	54.9	--	1.5	14.6	24.4	--	--	1.3	.9	.4	(2/)	2.0
		S	--	--	56.7	--	.8	13.2	25.3	--	--	1.4	.5	.4	(2/)	1.6
(*jeffreyi* X *ponderosa*) X *jeffreyi*	13	1	94.8	--	2.7	--	.2	.2	1.2	--	--	.7	(2/)	(2/)	--	--
		10	94.1	--	2.7	--	.7	.5	1.2	--	--	.7	--	--	--	--
		S	89.8	.8	3.7	--	.3	1.2	2.0	--	--	.8	.5	.9	--	(2/)
jeffreyi X (*jeffreyi* X *coulteri*)	82	1	93.4	(2/)	.7	(2/)	1.5	(2/)	.4	--	--	1.1	(2/)	2.9	--	--
		20	93.8	1.1	1.8	(2/)	.4	(2/)	--	--	--	1.5	--	1.5	--	--
		S	87.9	1.4	1.9	(2/)	1.5	.5	1.3	--	--	2.1	.3	3.1	--	--
monticola X (*strobus* X *peuce*)	3	1	(2/)	(2/)	52.4	--	2.8	42.1	1.4	--	--	.3	.3	.7	--	--
		8	(2/)	--	52.0	--	2.2	44.0	(2/)	--	--	.7	.4	.7	--	--
		S	2.5	.4	50.3	--	2.5	39.6	.6	--	--	1.2	1.0	1.6	--	.2

See footnotes at end of table.

Table 2.--*Monoterpene composition of resin of selected pines from three sources on fresh-cut stumps*, Continued

Species or hybrid of *Pinus*	IFG No.	Source of sample[1]	Heptane	Nonane	α-pinene	Undecane	Camphene	β-pinene	3-carene	Sabinene	α-phellandrene	Myrcene	Limonene	β-phellandrene	γ-terpinene	Unknown No. 2 (terpinolene)
			Percent													
contorta var. *murrayana* X *contorta* var. *contorta*	5	1	(2/)	--	6.1	--	0.5	7.5	2.3	1.9	1.4	2.8	1.9	75.5	--	--
		9	(2/)	--	6.6	--	.7	11.2	4.2	1.7	2.1	2.1	1.7	69.8	--	--
		S	(2/)	--	10.7	--	1.1	15.5	4.8	3.2		3.2	3.7	57.8	--	--
echinata X *taeda*	14	1	--	--	65.2	--	1.1	30.1	(2/)	--	--	.7	2.5	.4	--	--
		20	--	--	67.0	--	.5	29.9	(2/)	--	--	.5	1.5	.5	--	--
		S	--	--	62.7	--	.6	32.1	.4	--	--	1.0	2.7	.6	--	--
coulteri X wind	300	1	(2/)	--	53.1	1.6	1.5	1.9	(2/)	1.6	(2/)	1.6	1.4	36.2	--	1.0
		12	(2/)	--	56.6	3.5	2.5	2.8	--	2.8	.5	1.3	1.5	30.3	--	1.0
		S	(2/)	--	60.3	1.4	(2/)	2.8	--	2.3	.3	1.4	1.6	29.4	--	.4

[1] 1 = 1963 annual ring
>1= year of ring prior to 1963
S = scrape sample from whole stump.
[2] Trace.

Table 3.--*Data on the monoterpene composition of the resin from the 1963 annual ring of pine species and hybrids cut in the February 1964 thinning at the Institute of Forest Genetics, Placerville, California*

Species or hybrid[1] of *Pinus*	IFG No.	Heptane	Nonane	α-pinene	Unk. No. 1[2]	Undecane	Camphene	β-pinene	3-carene	Sabinene	α-phellandrene	Myrcene	Limonene	β-phellandrene	γ-terpinene	Unk. No. 2[2]	Remarks
		Percent[3]															
1. *jeffreyi* X *jeffreyi*	885	96	1	1	-	1	-	*	1	+	-	1	-	1	-	-	Similar to that reported.[4]
2. *jeffreyi* X *ponderosa* var. *scopulorum*	14	29	1	4	+	+	1	1	57	-	-	2	1	1	*	4	Quality intermediate: heptane, nonane, and camphene of *jeffreyi*; 3-carene myrcene, limonene, and terpinolene of var. *scopulorum*.[5] Remaining constituents in small amounts in both species. Quantity not intermediate; heptane at 29 percent far below the expected 47 percent, while 3-carene at 57 percent well above the expected 35-40 percent.

See footnotes at end of table.

Table 3.--*Data on the monoterpene composition of the resin from the 1963 annual ring of pine species and hybrids cut in the February 1964 thinning at the Institute of Forest Genetics, Placerville, California*, continued

Species or hybrid[1] of *Pinus*	IFG No.	Heptane	Nonane	α-pinene	Unk. No. 1[2]	Undecane	Camphene	β-pinene	3-carene	Sabinene	α-phellan-drene	Myrcene	Limonene	β-phellan-drene	γ-terpinene	Unk. No. 2[2]	Remarks
		Percent[3]															
3. *jeffreyi X washoensis*	5	32	-	2	+	+	*	2	45	+	-	12	1	1	-	4	Similarity to No. 2 not surprising, since var. *scopulorum* was found to be quite similar to *washoensis*;[4] trace amount of α-thujene may be found in both var. *scopulorum* and *washoensis*.
4. (a) (*jeffreyi X ponderosa*)● *X ponderosa*	13	+	+	8	-	+	1	21	47	-	-	6	13	2	+	2	Full siblings: the hybrid is a true F_1. Similar qualitative composition. However, < 5 percent heptane is far below expected 23 percent if there was intermediacy; γ-terpinene found in *ponderosa*.
(b) (*jeffreyi X ponderosa*)● *X ponderosa*	8	4	1	10	-	-	*	21	39	-	-	7	15	1	+	3	
5. (*jeffreyi X ponderosa*)● *X jeffreyi*	13	95	+	3	-	-	*	*	1	-	-	1	+	+	-	-	Half sib of No. 4; hybrid the common parent. Heptane at 95 percent far above the expected 71 percent. Note effect of changing one parent.
6. (a) *jeffreyi X (jeffreyi X coulteri)*○	20	72	1	12	-	+	+	1	1	+	-	2	1	11	-	-	Full sibs; however, only (c) and (d) are quantitatively similar; (a) and (b) differ considerably in heptane, α-pinene, and β-phellandrene. Small amount of α-pinene, myrcene, and β-phellandrene, components generally high in *coulteri*, suggests natural hybrid is not a true F_1 but has been backcrossed one or more times to *jeffreyi*.
(b) *jeffreyi X (jeffreyi X coulteri)*○	82	93	+	1	-	+	2	+	*	+	-	1	+	3	-	-	
(c) *jeffreyi X (jeffreyi X coulteri)*○	75	85	1	1	-	-	1	+	*	+	-	6	+	5	-	-	
(d) *jeffreyi X (jeffreyi X coulteri)*○	95	83	*	5	-	-	1	3	1	+	-	3	*	4	-	-	
7. (a) *jeffreyi X (jeffreyi X coulteri)*○	561	77	+	10	-	1	1	1	+	*	-	4	1	5	-	-	Full sibs, but not as similar as expected, differing appreciably in heptane, 77 and 69 percent; α-pinene, 10 and 16 percent. No common parentage with No. 6.

See footnotes at end of table.

Table 3.--*Data on the monoterpene composition of the resin from the 1963 annual ring of pine species and hybrids cut in the February 1964 thinning at the Institute of Forest Genetics, Placerville, California,* continued

Species or hybrid[1] of *Pinus*	IFG No.	Heptane	Nonane	α-pinene	Unk. No. 1[2]	Undecane	Camphene	β-pinene	3-carene	Sabinene	α-phellandrene	Myrcene	Limonene	β-phellandrene	γ-terpinene	Unk. No. 2[2]	Remarks
		Percent[3]															
7. (b) *jeffreyi X (jeffreyi X coulteri)*°	559	69	1	16	-	1	+	3	2	1	+	2	1	3	-	1	
8. *jeffreyi X (jeffreyi X coulteri)*°	589	88	+	5	-	1	+	*	1	+	-	1	1	3	-	-	No common parentage with Nos. 6 and 7; shows expected differences and similarities between nonsibs. Considerable similarity among all six individuals of this hybrid presented in Nos. 6, 7, and 8 of this table.
9. [*jeffreyi X (jeffreyi X coulteri*°)] *X ponderosa*	12	-	+	11	-	2	+	27	26	+	-	3	14	16	-	4	Lack of heptane notable, since about 35 percent expected; 16 percent β-phellandrene considerably above expected 7-9 percent. Amounts of other components within expected range.
10. [*jeffreyi X (jeffreyi X coulteri*°)] *X* [*jeffreyi X ponderosa*]°	25	20	1	12	-	1	-	40	5	+	-	2	8	12	-	-	Little can be said about this complex hybrid. Composition within the expected limits, since both parents are or contain a natural hybrid which may not be a valid F_1.
11. (a) *coulteri X* wind	300	+	+	53	-	2	2	2	+	2	+	2	1	36	-	1	Composition[4] falls within reported range.
(b) *coulteri X* wind	57	1	1	43	-	4	+	3	+	+	+	15	5	28	-	-	
12. (a) *ponderosa X* wind	483	-	-	5	+	-	-	15	51	+	-	9	16	1	+	3	Half sibs through female parent. Compositions similar and within expected range, since great range has been found for this pine[5] (Mirov 1961; Smith 1964b).
(b) *ponderosa X* wind	938	-	-	6	+	-	+	23	43	-	-	5	20	1	+	2	
13. (a) *ponderosa X* wind	654	+	-	15	-	-	*	64	+	-	-	3	16	1	-	-	Similarity a coincidence, since derived from two different wind-pollinated parents. Interesting to note that both essentially lack 3-carene.
(b) *ponderosa X* wind	401	+	-	12	-	-	*	62	1	-	-	7	18	1	-	-	

See footnotes at end of table.

Table 3.--*Data on the monoterpene composition of the resin from the 1963 annual ring of pine species and hybrids cut in the February 1964 thinning at the* Institute *of Forest Genetics, Placerville, California*, continued

Species or hybrid[1] of *Pinus*	IFG No.	Heptane	Nonane	α-pinene	Unk. No. 1[2]	Undecane	Camphene	β-pinene	3-carene	Sabinene	α-phellandrene	Myrcene	Limonene	β-phellandrene	γ-terpinene	Unk. No. 2[2]	Remarks
		Percent[3]															
14. (a) *Ponderosa X (jeffreyi X coulteri)°*	28	69	2	13	-	2	+	2	1	1	-	3	+	8	-	-	Full sibs; (a) and (b) are quite similar, while (c) differs in the amount of heptane, α-pinene, and β-phellandrene. Heptan, > 66 percent, far above expected 25 percent, suggests nonapplicability of quantitative intermediacy or natural not true F_1. Same suggestion made for a different *jeffreyi X coulteri* in No. 6. Also some uncertainty about the *ponderosa* parent; in area where natural hybrids of *jeffreyi X ponderosa* are suspected.
(b) *ponderosa X (jeffreyi X coulteri)°*	32	66	2	15	-	+	1	1	1	1	-	4	1	10	-	-	
(c) *ponderosa X (jeffreyi X coulteri)°*	2	80	1	8	-	1	1	1	1	*	-	3	1	5	-	-	
15. *Ponderosa X montezumae*	4	5	5	41	-	3	-	26	-	-	-	4	16	1	-	-	Composition somewhat as expected --heptane and large amount of α-pinene from *montezumae* (Mirov 1961) and β-pinene, myrcene, and limonene from *ponderosa;* nonane and undecane probably from *montezumae* since neither found in the hundreds of *ponderosa* examined; composition of *montezumae* based on just a few trees. Lack of 3-carene of note, since lacking in wind-pollinated offspring of this same *ponderosa* (see No. 13a). Reported composition of *montezumae* quite variable, falling into two types--high α-pinene (Mirov 1961) and high 3-carene (Williams and Bannister 1962).
16. *Ponderosa X washoensis*	6	-	-	11	-	-	-	40	26	-	-	11	9	1	+	2	Composition well within range anticipated.[4]
17. (a) *ponderosa X ponderosa* var. *scopulorum*	115	-	-	5	+	-	+	27	50	-	-	7	7	1	*	4	Nonsibs; differ considerably but fall within expected limits, since both parent species very variable.
(b) *Ponderosa X ponderosa* var. *scopulorum*	161	1	+	28	-	-	1	33	24	-	-	3	7	1	+	2	

See footnotes at end of table.

Table 3.--*Data on the monoterpene composition of the resin from the 1963 annual ring of pine species and hybrids cut in the February 1964 thinning at the Institute of Forest Genetics, Placerville, California*, continued

Species or hybrid[1] of *Pinus*	IFG No.	Heptane	Nonane	α-pinene	Unk. No. 1[2]	Undecane	Camphene	β-pinene	3-carene	Sabinene	α-phellandrene	Myrcene	Limonene	β-phellandrene	γ-terpinene	Unk. No. 2[2]	Remarks
		Percent[3]															
18. (a) *ponderosa X ponderosa* var. *scopulorum*	153	+	-	32	-	-	1	26	26	-	-	6	6	2	+	2	Full sibs and quite similar. *Ponderosa* parent without 3-carene, noted with Nos. 13(a) and 15. Thus, the 3-carene in No. 18 came from var. *scopulorum*.
(b) *ponderosa X ponderosa* var. *scopulorum*	147	+	-	35	-	-	1	28	24	-	-	2	8	1	+	1	
19. (a) *ponderosa X engelmannii*	18	-	-	40	-	-	+	14	36	-	-	4	4	1	+	2	At least half sibs and could be full sibs with a common female parent and a pollen mixture. Quite similar except between 25 and 35 percent in 3-carene. High α-pinene expected, since about 80 percent reported for *engelmannii* (Mirov 1961).
(b) *ponderosa X engelmannii*	16	-	-	40	-	-	*	18	25	-	-	4	10	1	*	1	
20. (a) *ponderosa X engelmannii*	119	1	-	29	-	-	*	28	29	-	-	4	5	1	-	2	Nonsibs, and nonsibs to No. 19. Composition within expected range. Source of small amount heptane probably *engelmannii*, since slight traces of it rarely found in *ponderosa*.
(b) *ponderosa X engelmannii*	110	+	-	32	-	-	1	17	34	-	-	6	7	1	*	3	
21. (a) *ponderosa* var. *scopulorum X engelmannii*	25	+	-	54	-	-	2	13	26	-	-	2	1	*	+	2	Full sibs; composition nearly identical and well within anticipated range.
(b) *ponderosa* var. *scopulorum X engelmannii*	29	+	-	51	-	-	1	15	28	-	-	1	1	1	+	2	
22. *ponderosa* var. *scopulorum X ponderosa*	8	+	-	32	-	-	1	7	35	-	-	11	12	1	+	2	Half sib of No. 21. Change to *ponderosa* male parent in No. 22 readily apparent; decrease in α-pinene and increase in 3-carene, myrcene, and limonene. β-pinene could go either way, depending on *ponderosa* parent used.
23. *ponderosa* var. *arizonica X ponderosa*	12	-	-	28	-	-	*	22	39	-	-	3	4	1	+	2	Composition within expected range (Mirov 1961).[5]

See footnotes at end of table.

Table 3.--Data on the monoterpene composition of the resin from the 1963 annual ring of pine species and hybrids cut in the February 1964 thinning at the Institute of Forest Genetics, Placerville, California, continued

Species or hybrid[1] of *Pinus*	IFG No.	Heptane	Nonane	α-pinene	Unk. No. 1[2]	Undecane	Camphene	β-pinene	3-carene	Sabinene	α-phellandrene	Myrcene	Limonene	β-phellandrene	γ-terpinene	Unk. No. 2[2]	Remarks
		Percent[3]															
24. *engelmannii X* wind	V31	-	-	95	-	-	2	2	-	-	-	1	*	+	-	-	Composition similar to that reported by Mirov. However, small amounts of camphene, myrcene, and β-phellandrene not reported.
25. *engelmannii X ponderosa* var. *scopulorum*	11	-	-	17	-	-	+	1	73	-	-	2	1	1	*	4	α-pinene considerably lower than expected and 3-carene considerably higher, if two parents typical. However, considerable 3-carene variation found in var. *scopulorum*, and *engelmannii* not extensively analyzed.
26. (a) *washoensis X* wind	35	-	-	17	-	-	+	27	37	-	-	12	4	2	+	2	Half sibs through female parent; exhibit considerable similarity.
(b) *washoensis X* wind	36	-	-	9	--	--	-	31	46	-	-	7	5	1	+	3	
27. (a) *contorta* var. *murrayana X* wind	39	+	-	7	-	-	+	11	2	2	1	1	1	75	-	-	Half sibs through female parent, but differ in β-pinene, 3-carene, and β-phellandrene. However, composition within expected range (Mirov 1961; Smith 1963).
(b) *contorta* var. *murrayana X* wind	75	-	-	6	+	-	*	14	16	3	1	3	1	55	-	1	
28. (a) *contorta* var. *murrayana X contorta* var. *contorta*	5	+	-	6	+	-	1	8	2	2	1	3	2	76	-	*	Half sibs through female parent; male a pollen mix. Quite different in 3-carene and β-phellandrene, but general composition about as expected. Half sibs of No. 27; related pairs quite similar.
(b) *contorta* var. *murrayana X contorta* var. *contorta*	3	+	-	8	+	-	1	4	18	2	1	3	2	59	-	1	
29. *contorta* var. *contorta X* wind	V11	-	-	9	-	-	1	4	5	2	1	2	2	73	-	1	Similar to var. *murrayana*; distinct terpene differences unlikely between var. *murrayana* and var. *contorta*.

See footnotes at end of table.

Table 3.--*Data on the monoterpene composition of the resin from the 1963 annual ring of pine species and hybrids cut in the February 1964 thinning at the Institute of Forest Genetics, Placerville, California,* continued

Species or hybrid[1] of *Pinus*	IFG No.	Heptane	Nonane	α-pinene	Unk. No. 1[2]	Undecane	Camphene	β-pinene	3-carene	Sabinene	α-phellandrene	Myrcene	Limonene	β-phellandrene	γ-terpinene	Unk. No. 2[2]	Remarks
		Percent[3]															
30. *contorta* var. *murrayana X banksiana*	12	-	-	55	-	-	1	23	2	+	+	2	1	18	-	-	Half sib of Nos. 27 and 28; α-pinene and β-pinene of *banksiana* (Williams and Bannister 1962); β-phellandrene of var. *murrayana*. Quantitative intermediacy not strong; α-pinene and β-pinene high, and β-phellandrene low. General intermediacy in resin properties of this hybrid noted some time ago by Mirov (1956).
31. *rigida X taeda*	7	-	-	75	-	-	2	9	-	-	-	4	2	9	-	-	Composition generally intermediate between two parent species (Williams and Bannister 1962).
32. *echinata X taeda*	14	-	-	65	-	-	1	30	+	-	-	1	3	*	-	-	Large percentage α-pinene expected; however, amount of β-pinene far exceeds that reported for either parent (Williams and Bannister 1962).
33. *attenuata X radiata*	89	-	-	59	-	-	2	38	+	-	-	1	1	1	-	-	Composition similar to that reported (Bannister et al. 1962; Forde 1964).
34. *attenuata X remorata*	10	-	-	44	-	-	1	3	+	34	-	1	1	1	+	16	Has expected composition--high α-pinene from *attenuata* and high sabinene and terpinolene from *remorata* (Forde and Blight 1964).
35. (a) *nigra* var. *cebennensis X nigra*	1	-	-	92	-	-	2	2	-	-	-	1	2	*	-	-	Composition of these, all hybrids of *nigra* and two of its varieties --*cebennensis* and *calabrica*--nearly identical and practically the same as that reported (Williams and Bannister 1962). First three half sibs, and last two half sibs. Only point of note is trace of 3-carene and sabinene in last three; indicates var. *calabrica* as source, since neither reported in *nigra*.
(b) *nigra* var. *cebennensis X* var. *cebennensis*	8	-	-	95	-	-	2	2	-	-	-	1	1	-	-	-	
(c) *nigra* var. *cebennensis X* var. *calabrica*	1	-	-	93	-	-	2	3	+	*	-	1	1	+	-	-	

See footnotes at end of table.

Table 3.--*Data on the monoterpene composition of the resin from the 1963 annual ring of pine species and hybrids cut in the February 1964 thinning at the Institute of Forest Genetics, Placerville, California*, continued

Species or hybrid[1] of *Pinus*	IFG No.	Heptane	Nonane	α-pinene	Unk. No. 1[2]	Undecane	Camphene	β-pinene	3-carene	Sabinene	α-phellan-drene	Myrcene	Limonene	β-phellan-drene	γ-terpinene	Unk. No. 2[2]	Remarks
		Percent[3]															
35. (d) *nigra* var. *calabrica X nigra* var. *calabrica*	35	-	-	94	-	-	1	3	+	1	-	1	1	*	-	*	
(e) *nigra* var. *calabrica X nigra*	1	-	-	92	-	-	3	3	+	*	-	1	1	+	-	-	
36. *strobus X* wind	89	-	+	47	-	-	2	48	-	-	-	1	1	1	-	-	Composition resembles existing data only remotely (Mirov 1961). Camphene, myrcene, and limonene not reported; proportions of α-pinene and β-pinene quite different.
37. (a) *strobus X monticola*	12	-	+	48	-	-	1	48	-	-	-	1	1	1	-	-	Both about as expected; large amount α-pinene and β-pinene and smaller amount camphene, myrcene, limonene, and β-phellandrene. Terpenes not too suitable in determining hybridity of soft pines because of similarity between species.
(b) *strobus X griffithii*	28	-	+	57	-	+	5	36	-	-	-	1	+	+	-	-	
38. *monticola X monticola*	136	+	*	81	-	-	4	12	-	-	-	1	1	*	-	-	Mirov's (1961) data show much different proportions of α-pinene and β-pinene and do not report nonane, myrcene, and β-phellandrene.
39. (a) *monticola X strobus*	175	-	+	52	-	-	3	43	-	-	-	1	*	*	-	-	These four hybrids of *monticola* somewhat similar and about as expected; large amounts of α-pinene and β-pinene, small amounts of camphene, myrcene, limonene, and β-phellandrene. Two have measurable amounts of undecane; two others have measurable amounts of 3-carene.
(b) *monticola X strobus*	122	-	-	52	-	1	1	41	-	-	-	1	1	1	+	1	
(c) *monticola X (peuce X strobus)*⊕	3	+	+	52	-	-	3	42	1	-	-	*	*	1	-	-	
(d) *monticola X griffithii*	49	-	+	61	-	5	+	31	4	-	-	+	+	+	+	+	
(e) *monticola X peuce*	6	-	+	67	-	-	2	28	-	-	-	1	1	1	-	-	

See footnotes at end of table.

Table 3.--*Data on the monoterpene composition of the resin from the 1963 annual ring of pine species and hybrids cut in the February 1964 thinning at the Institute of Forest Genetics, Placerville, California,* continued

Species or hybrid[1] of *Pinus*	IFG No.	Heptane	Nonane	α-pinene	Unk. No. 1[2]	Undecane	Camphene	β-pinene	3-carene	Sabinene	α-phellan-drene	Myrcene	Limonene	β-phellan-drene	γ-terpinene	Unk. No. 2[2]	Remarks
		Percent[3]															
40. *griffithii X griffithii*	26	+	+	93	-	4	+	2	-	-	-	1	1	+	-	+	Undecane, β-pinene, myrcene, and limonene have not been previously reported (Mirov 1961).
41. *flexilis X flexilis*	12	+	4	28	-	8	+	5	35	13	-	2	1	1	-	6	Quite different from reported (Mirov 1961); α-pinene only terpene recorded. This is first reporting of nonane, undecane, β-pinene, 3-carene, sabinene, myrcene, limonene, β-phellandrene, and terpinolene. Large amount 3-carene suggests within-species variation. Mirov did not report it, and would have if it had been there.
42. *flexilis X griffithii*	4	+	+	85	-	8	+	2	+	3	-	1	*	+	-	1	Somewhat expected composition; large amount α-pinene and smaller amounts of other terpenes.
43. (a) *strobiformis* X wind	V13	-	+	69	-	+	2	10	-	17	-	+	+	+	-	3	Only data on these species (Mirov 1961) does not report a number of terpenes: for *strobiformis* no camphene, sabinene, myrcene, limonene, β-phellandrene; for *longifolia* no myrcene, limonene, β-phellandrene, γ-terpinene, terpinolene; for *canariensis* no camphene, β-pinene, 3-carene, myrcene, β-phellandrene.
(b) *longifolia X* wind	V55	-	-	18	-	-	-	18	56	-	-	3	1	1	+	4	
(c) *canariensis X* wind	81	-	-	90	-	-	2	7	+	-	-	1	1	*	-	-	

[1] ●= True F_1 hybrid.
○= Naturally occurring hybrid.
⊕= Origin of hybrid uncertain.

[2] Tentatively identified as α-thujene and terpinolene, respectively.

[3] * = from 0.1 to 0.4 percent.
+ = trace.
- = zero.
May not equal 100 percent for each tree because of rounding of decimals.

[4] Smith, R.H. *Variations in the monoterpene composition of Pinus jeffreyi, P. washoensis, P. coulteri, P. contorta.* 1967. (MS. submitted to Forest Sci.)

[5] Peloquin, R.L. *Geographic variation of the monoterpenes of Pinus ponderosa.* 1964. (Unpubl. master's thesis on file at Stanford Univ., Palo Alto, Calif.)