# VARIATION IN THE EXTRACTIVES FROM LODGEPOLE PINE SAPWOOD AND HEARTWOOD

by

D. M. SHRIMPTON

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D.M. Shrimpton*

## ABSTRACT

Twenty-one turpentine components, eight fatty acids, and eight resin acids are consistantly present in lodgepole pine sapwood and heartwood. The neutral fraction consists predominantly of glycerides but waxes and unsaponifiables are also present. Sapwood and heartwood contain similar levels. Except for the sugars and phenols the composition of extractives is very similar in sapwood and heartwood of the same tree but differences in total fraction size do occur. Eight sugars are present in sapwood, and two in heartwood. Sapwood is characterized by higher sugar and turpentine levels than heartwood. Heartwood is characterized by the presence of phenols and higher levels of neutrals.

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* Research Scientist, Northern Forest Research Centre, Canadian Forestry Service, Department of the Environment, 5320 - 122 Street, Edmonton 70, Alberta, Canada.

## INTRODUCTION

Lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Englm.) is found throughout British Columbia, western Alberta, and parts of the Yukon. It extends southward through Washington and along the Rocky Mountains to Colorado. A coastal strain of lodgepole pine (var. *contorta*) is recognized that ranges from the Alaska panhandle to mid-California and merges completely with var. *latifolia* in British Columbia and northwestern Washington. A southern strain (var. *murrayana*) merges with var. *latifolia* in Oregon and extends into central California. Variety *bolandari* forms an isolated pocket in the Mendocino white plains area of California (Critchfield, 1957). Although four strains of lodgepole pine can be recognized on the basis of morphological characters, no obvious differences exist on the basis of chemical composition.

Lodgepole pine needle oils were studied earlier by Schorger (1915). He reported α-pinene, β-pinene, camphene, phellandrene, bornyl acetate, and cadinene. More recently, the terpenes of oleoresin collected from the stem have received considerable attention as a potential chemotaxanomic tool to measure hybridization with other species of pine (Anderson *et al*, 1969; Lotan and Joye, 1970; Mirov, 1967; Williams and Bannister, 1962; Zavarin *et al*, 1969), and because trees secrete resin following insect attack (Smith, 1967). The traditional concept was that the terpene fraction from lodgepole pine consisted almost entirely of β-phellandrene (Mirov, 1967; Smith, 1967; Williams and Bannister, 1962). More recently it has been shown that large variations exists in the terpene composition of this species and that β-phellandrene is frequently

not the major terpene (Lotan and Joye, 1970; Pauly and von Rudloff, 1971; Zavarin et al, 1969). Substituted terpenes and higher boiling components have previously been reported only from needle oils and in the turpentine recovered from sulphate pulp (Drew and Pylant, 1966; Pauly and von Rudloff, 1971; Rogers, 1971; Schorger, 1915).

Heartwood extractives reported are four phenolic compounds, pinobanksin, pinocembrin, pinosylvin and pinosylvin monomethyl ether (Erdtman, 1949; Lindstedt, 1949). Four fatty acids and eight resin acids have been reported (Anderson et al, 1969) for heartwood and sapwood of lodgepole pine in California, but variation in amount of these components from tree to tree is not indicated.

Flavonoids have been isolated from the bark of coastal lodgepole pine (Hergert, 1956). The most complete listing of extractives for the bark of this species is for trees from Colorado. Esterified wax and fatty acids, wax alcohols, parafins, sterols and diterpenes are reported (Rowe and Scroggins, 1964; Rowe, 1972 et al). Fatty acids have also been reported from bark of this species (Hartmann and Weenink, 1967) and from needles (Jamieson and Reid, 1972).

This report gives a more complete listing of extractives from the wood of lodgepole pine var. latifolia than is currently available. Variation in size of fractions and the relative composition of fractions is used as the basis for a study on changes occurring in the sapwood after insect attack. The trees sampled are from two locations in southeastern B.C. and one location in southwestern Alberta. The

fractions studied are the sugars, fatty acids and neutrals representing potential food requirements of invading organisms, and the resins and phenolics, which represent potential defence compounds of the tree.

## METHODS

Logs about 10 in. in diameter and 3 ft. long were cut from the butt of 70 - 80 year old lodgepole pine trees in late June 1969 from Kananaskis and June 1970 from Elk Creek and Horsethief Creek. Trees numbered 1 and 2 were obtained from Kananaskis, Alberta, 3 and 4 were from Elk Creek and number 5 from Horsethief Creek in the East Kootenay region of British Columbia. Trees chosen had no external damage and both sapwood and heartwood were free from stains. Processing of the logs started within 24 hours of cutting. Samples of heartwood and sapwood were removed from the mid-portion of each log and milled to pass a 2-mm screen. Sapwood was defined as that tissue which exudes oleoresin from a freshly cut surface.

The fractionation scheme used was essentially the same as von Rudloff and Sato (1963). Quantities used and changes from their methods are indicated below. Freshly prepared sawdust (about one litre volume) was steam distilled for 8 hours. The oil was recovered and the sawdust dried at 105°C for 72 hours. A further 2 litres of freshly prepared sawdust was extracted, in a soxhlet style extractor, first with acetone and then with methanol. Each extraction was for 48 hours with 2.5 litres of solvent. After extraction excess solvent was allowed to evaporate and the sawdust was dried at 105°C for 24 hours.

Steam Volatile Fraction

Steam volatiles were recovered (von Rudloff and Sato, 1963) and analyzed by gas liquid chromatography over apiezon L and carbowax 20 M as previously described (Shrimpton, D.M. and J.A. Watson, 1971). Terpene hydrocarbons, for samples with sufficient β-phellandrene to obscure the limonene peak on carbowax, were also analyzed on an 8 ft. X $\frac{1}{4}$ in. aluminum column of 10% β, β, oxydipropionitrile coated onto 80-100 mesh acid washed chromosorb W. The operating temperature was 60°C isothermally and the helium flow rate 50 ml/min. The vaporization inlet was set at 200°C and the thermal detector set at 300°C.

Individual components were identified from their relative retention times (r.r.t.) and were also enhanced with authentic samples*. Retention was corrected for the void volume of the column and expressed relative to the enhanced limonene peak for terpene hydrocarbons and relative to linalool for higher boiling components. Relative concentrations were determined by internal normalization and peak areas were calculated by triangulation. Repeated injection of standards indicated an error less than 3% in peaks of $\frac{1}{2}$ scale or more pen deflection and less than 10% in peaks of 1/20 scale or less pen deflection.

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* Standard compounds were purchased from Aldrich Chemical Company, Eastman Kodak Ltd., Sigma, Nutritional Biochemicals or provided by donors listed in the acknowledgements.

Acetone Soluble Fraction

Free acids and phenols were separated from neutrals by treatment with 1% aqueous sodium hydroxide. Sodium hydroxide solubles were recovered (von Rudloff and Sato, 1963) and the phenolic components analyzed qualitatively by thin layer chromatography (T.L.C.) (Loman, 1970). Acids were methylated with diazomethane (Nestler and Duane, 1967) and analyzed by G.L.C. over two different 8 ft. x $\frac{1}{4}$ in. aluminum columns, 3% OV-17 and 15% diethyleneglycol succinate both coated onto high performance acid washed silanized (DMCS) chromosorb W, 80-100 mesh. Operating temperatures of the columns were 180°C and 200°C respectively. Helium flow rate was 60 ml/min.

The inlet temperature was 275°C and the thermal detector set at 300°C. Retention was corrected for the void volume of the column and expressed relative to added methyl margarate (heptadecanoic acid) which also served as an internal standard. Quantities of each acid were determined from peak areas using the area correction factors of Nestler and Zinkel (1967). The identity of the resin acids was confirmed by T.L.C. (Zinkel and Rowe, 1964).

Infrared spectra of the neutral fractions were recorded for chloroform solutions in sodium chloride cells. Free sterols were precipitated as the digitonide, recovered, and analyzed by G.L.C. (Rowe and Scroggins, 1964). Neutrals were saponified and the acids and non-saponifiables recovered (von Rudloff and Sato, 1963).

The resultant acids were methylated and chromatographed as above. The non-saponifiables were taken up in a minimum volume of chloroform and chromatographed over a 10 ft. x $\frac{1}{4}$ in. column of 3% SE-30U coated onto silanized (DMCS) high performance 80-100 mesh chromosorb W. Operating temperatures were 230°C isothermal for the free sterols and 100 to 250°C at 1°/min for the non-saponifiable fraction. Glycerol was recovered and determined as the tri-acetate (von Rudloff and Sato, 1963).

Methanol Soluble Fraction

The methanol extract was evaporated to dryness and extracted first with acetone, then with ether and the fractions chromatographed on paper and T.L.C. (von Rudloff and Sato, 1963). A check on the quantity of sapwood sugars in each tree was obtained by immersing small chips (about 20 gm total) into a dry ice ethanol solution in the field. Sugars were extracted with ethanol, evaporated to dryness and acidic and basic components removed from an aqueous solution with ion exchange resins. Sugars were analyzed by paper chromatography (von Rudloff and Sato, 1963) and G.L.C. over SE-52 as the trimethylsilyl derivatives (Sweeley, et al, 1963).

## RESULTS

### Steam Volatile Fraction

The yield of steam volatile oil from heartwood of the 5 trees sampled was quite constant varying between 0.04 and 0.06% of the dried sawdust. The yield of oil from sapwood was considerably higher and more variable, between 0.3% and 0.9%. Table 1 gives the yield of oil from heartwood and sapwood of the individual trees.

β-phellandrene was the major terpene component in the heartwood and sapwood of three of the five trees. β-pinene was also the major terpene in both heartwood and sapwood of tree 2 and $\Delta$-3-carene in tree 4. In general, all trees contained significant amounts of α-pinene, β-pinene, Δ-3-carene, and β-phellandrene. Also present in heartwood and sapwood of all trees were camphene, myrcene, limonene, and $\gamma$-terpinene. Terpinolene was present in heartwood and sapwood of four trees, p-cymene, α-terpinene, and cis, and trans-ocimene were present in three trees. Also, consistantly present were terpinene-4-ol, α-fenchol, α-terpineol, borneol, isoborneol, estragole, cis-anethole, and β -caryophylene. Traces of linalool and citronellol were present in four of the trees. All samples contained between 3% and 4.5% of higher boiling unidentified components. Composition of the steam volatile fraction from individual trees is given in Table 2.

Acetone Soluble Fraction

The yield of acetone soluble material varied considerably in both heartwood (3.6 - 6.5% of dried extracted sawdust) and sapwood (2.7 - 7.0%). This variation in yield from both heartwood and sapwood of four of the five trees sampled was due to varying quantities of neutral components (0.6 - 4.7%). The percentage of free acidic components in these four trees was relatively constant (2.0 - 2.1% in sapwood and 2.3 - 2.8% in heartwood). Tree 4 yielded 3.5% free acids and 1.2% neutrals from heartwood. The yield of acetone solubles from individual trees are given in Table 1.

A small quantity of ether insoluble material present in the acetone solubles corresponded to material present in the methanol soluble fraction.

The free fatty acids present were predominantly oleic and linoleic acids in both sapwood and heartwood of all trees sampled. Lesser amounts of palmitic, palmitoleic, linolenic, arachidic, and behenic acids were consistantly present. Two peaks which corresponded to published retention for 5, 9, 12, octadecatrienoic acid, and henicosanoic acid were also consistantly present. Both of these fatty acids occur in lodgepole pine bark (Rowe and Scroggins, 1964). The fatty acid composition of individual trees is given in Table 3.

The major resin acids were isopimaric, abietic, and dehydroabietic in sapwood and heartwood of all five trees. Also consistantly present were pimaric, sandracopimaric, levopimaric, palustric, and neoabietic acids. The resin acid composition of individual trees

is given in Table 3. No peaks corresponding to the breakdown products of levopimarate were observed (Nestler and Zinkel, 1967).

Total quantities of fatty acids and resin acids were calculated from corrected peak areas as in (Nestler and Zinkel, 1967) with margaric acid (heptadecanoic) as an internal standard. Total free fatty and resin acids in sapwood were relatively constant for all trees. The total of free fatty acids in sapwood expressed as a percentage of oven dried extracted sawdust were: tree 1, 0.4%; tree 2, 0.5%; tree 3, 0.4%; tree 4, 0.4%; tree 5, 0.3%. Total resin acids in sapwood were: tree 1, 1.6%; tree 2, 1.5%; tree 3, 1.6%; tree 4, 1.6%; tree 5, 1.8%. Total free fatty acids were greater in heartwood than in sapwood and the amount varied between trees. Total resin acids were about the same as sapwood with only slight variation between trees except for tree 5. The total of free fatty acids in heartwood was: tree 1, 0.6%; tree 2, 1.1%; tree 3, 0.9%; tree 4, 1.3%; tree 5, 1.1%. Total resin acids in heartwood were: tree 1, 1.6%; tree 2, 1.5%; tree 3, 1.6%; tree 4, 1.7% and tree 5, 1.1%.

The neutral fraction was a yellow oil from heartwood. Infrared spectra of the oil showed strong ester absorpition. The bulk of the fraction consisted of glycerides and waxes. No attempt was made to preserve the terpenes during concentration of the neutral fraction; however, gas chromatography of the oil over OV-17 at temperatures between 80-150°C revealed detectable amounts of the terpenes.

also present, in trace quantities, were the oxygenated terpenes and caryophyllene. The major component of the neutral fraction corresponded to manool over both OV-17 and SE-30U and was partially resolved from manool over DEGS. A mixture of manool and epimanool showed this same chromatographic behaviour. This component may, therefore, be epimanool as reported previously from the bark of lodgepole pine (Rowe and Scroggins, 1964). Other components consistantly present were farnesol, cadinenes, a trace of β - sitosterol, and three unknowns (r.r.t. 0.63, 1.78, 2.11; manool = 1.00 over 3% OV-17 at 200°C helium flow rate 60 ml/min). When the neutral oil was chromatographed on silicone columns at temperatures above 200°C several poorly resolved peaks were obtained, these were presumed to be waxes.

The use of manool as an internal standard indicated for sapwood, as a percentage of the neutral fraction, 1-2% of the components found in the steam volatile fraction, 0.5-1% farnesol, 1 - 3% cadinenes, 0.5 - 1% unknown (r.r.t. 63), 3 - 5% of the component corresponding to manool, 2 - 3% unknown (r.r.t. 1.78) and 1 - 2% unknown (r.r.t. 2.11) and a trace of β -sitosterol. Thus, free components in the neutral fraction from sapwood account for between 10 - 12% of the fraction. For the sapwood neutrals from tree 2 the free components amounted to 5% of the fraction, indicating that the unusually high yield of acetone solubles (Table 1) was due to an increased percentage of waxes and glycerides. For heartwood a similar

relative composition of the free components was found, but the total percentage of these components was 5 - 10% of the fraction.

Free sterols in the neutral fraction from sapwood amounted to: tree 1 - 0.01%; 2 - 0.05%; 3 - 0.01%; 4 - 0.01%; 5 - 0.025% of dried extracted sawdust. For heartwood the free sterol percentages in the neutral fraction were: tree 1 - 0.015%, 2 - 0.025%, 3 - 0.02%, 4 - 0.15%, 5 - 0.03%. Chromatography of the recovered sterols on SE-30U showed about 90% β-sitosterol and 10% campesterol.

Glycerol was the major non-saponifiable component. Also recovered after saponification were α-terpineol and β-sitosterol. The major bound acids were oleic and linoleic. Also present were myristic, palmitic, palmitoleic, linolenic, 5, 9, 12, octadecatrienoic, arachidic, and behenic acids. The relative composition of bound acids recovered from the five trees is given in Table 4.

Phenolics were analyzed qualitatively. Heartwood of all trees contained, pinosylvin, pinosylvinmonomethyl ether, pinobanksin, and pinocembrin. No phenols could be detected in sapwood.

Methanol Soluble Fraction

Methanol solubles consisted mainly of sugars together with a brown amorphous material having Rf values comparable to the lignan and polylignan material prepared from jack pine by von Rudloff and Sato (1963). A portion of the acetone soluble fraction insoluble in ether was also comparable to this brown amorphous material. The

methanol soluble material and acetone soluble material and a mixture of the two were identical on T.L.C.

Total sugars from sapwood and heartwood of each tree are given in Table 1. Sapwood was very variable in the amount of sugar present (3.5% - 4.3%) for trees 1 to 4. Tree 5 had a very low level of sapwood sugars (0.9%). Ethanol extraction of sugars from samples frozen in the field gave yields about 10% higher than extraction of sawdust prepared from the logs. Sugars found were glucose, fructose, sucrose, galactose, xylose, mannose, raffinose, and stachyose. Yield of glucose and arabinose from heartwood varied between 0.2% and 0.4%.

## DISCUSSION

Thirteen terpene hydrocarbons, 9 oxygenated terpenes, and β-caryophyllene are consistantly present in the volatile fraction from both sapwood and heartwood of lodgepole pine. Most authors report far fewer components. These same components have, however, been consistantly found in oleoresin collected in a tapping device on the sapwood surface. The collected oleoresin was diluted with carbon disulfide and then chromatographed, thus indicating that components reported here were not artifacts of distillation and recovery procedures. Oil samples obtained with only 2 to 3 hours distillation time frequently contain the major terpenes, α-pinene, β-pinene, Δ-3 carene, β-phellandrene, myrcene, camphene, and terpinolene and only barely detectable amounts of the other components. The greater number of components reported here, than were reported by other authors, may be due

to the longer distillation time used.

Considerable variation occurred in the relative composition of the terpene fraction; β-phellandrene was the major terpene in three of the five trees, β-pinene in one, and Δ-3 carene in the other. Such variation is now generally accepted for terpenes from lodgepole pine growing in the Rocky Mountain area and the results of this paper are in good agreement with others for components found and the relative concentrations both within and between trees (Drew and Pylant, 1966; Lotan and Joye, 1970; Zavarin et al, 1969). The higher boiling volatile components agree with results from the needle oil (Pauly and von Rudloff, 1971) and for turpentine recovered from pulp (Drew and Pylant, 1966). However, the identification of borneol and isoborneol can only be considered tentative, since these components were not present in the needle oil (Pauly and von Rudloff, 1971) and were only tentatively identified in the turpentine (Drew and Pylant, 1966). When the volatile fractions from heartwood and sapwood were compared, for an individual tree the major component was always the same and other components followed the same general pattern of concentration.

Free acids reported here and not previously identified from the wood of lodgepole pine were: palmitic, palmitoleic, 5, 9, 12, octadecatrienoic, heneicosanoic, and behenic acids. Anderson et al (1969) lists 16% unidentified acids in sapwood and 6% unidentified in heartwood of lodgepole pine from north central California. The free and bound acids found are quite similar qualitatively and quan-

titatively to acids from the wood (Anderson et al, 1969) and bark (Rowe and Scroggins, 1964) of lodgepole pine near the southern part of its range and also to jack pine (von Rudloff and Sato, 1963). Free acids, bound acids, and neutrals are qualitatively very similar between sapwood and heartwood for a single tree, but differences exist between trees. Differences in extractives between sapwood and heartwood of lodgepole pine are the absence of phenols in the sapwood. Other differences are higher levels of neutral components and higher levels of free oleic and linoleic acids in the heartwood. There are also lower levels of volatile compounds and sugars and absence of several individual sugars in the heartwood.

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TABLE I

Yield of Extractives from lodgepole pine sapwood and heartwood

| Tree Number | 1 | | 2 | | 3 | | 4 | | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | S* | H* | S | H | S | H | S | H | S | H |
| Steam Volatiles | 0.6+ | 0.05 | 0.7 | 0.06 | 0.9 | 0.05 | 0.6 | 0.04 | 0.3 | 0.04 |
| Acetone soluble | 2.8 | 3.6 | 7.0 | 5.6 | 2.7 | 5.5 | 2.7 | 4.9 | 5.0 | 6.5 |
| acids | 2.0 | 2.3 | 2.1 | 2.8 | 2.0 | 2.7 | 2.0 | 3.5 | 2.1 | 2.4 |
| neutrals | 0.6 | 1.2 | 4.7 | 2.5 | 0.6 | 2.5 | 0.6 | 1.2 | 2.6 | 3.9 |
| residue | 0.2 | 0.1 | 0.2 | 0.3 | 0.1 | 0.3 | 0.1 | 0.2 | 0.3 | 0.2 |
| Methanol soluble | 4.5 | 0.6 | 4.7 | 0.4 | 3.8 | 0.5 | 4.8 | 0.9 | 1.1 | 0.6 |
| sugars | 4.3 | 0.2 | 4.5 | 0.2 | 3.5 | 0.2 | 4.5 | 0.4 | 0.9 | 0.3 |
| residue | 0.2 | 0.4 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.5 | 0.2 | 0.3 |

* S - sapwood, H - heartwood.

+ Percentage of oven dried extracted sawdust.

TABLE II

Steam volatile components of lodgepole pine sapwood and heartwood

| Tree Number | 1 | | 2 | | 3 | | 4 | | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | S* | H* | S | H | S | H | S | H | S | H |
| α-Pinene | 4.8+ | 6.1 | 4.9 | 5.7 | 5.6 | 5.1 | 4.5 | 2.5 | 9.5 | 6.5 |
| Camphene | 1.5 | 1.1 | 1.6 | 1.1 | 1.3 | 1.0 | 1.0 | 1.0 | 1.2 | 1.0 |
| β-Pinene | 13.3 | 15.6 | 38.5 | 42.6 | 10.4 | 9.5 | 16.6 | 20.5 | 10.2 | 10.5 |
| 3-carene | 15.2 | 16.3 | 9.5 | 10.8 | 22.6 | 15.2 | 34.4 | 25.1 | 12.6 | 15.3 |
| Myrcene | 1.1 | 1.0 | 1.2 | 0.9 | 2.1 | 1.0 | 2.2 | 2.0 | 1.8 | 1.5 |
| Limonene | 0.5 | 0.5 | tr | tr | 0.9 | 0.5 | 1.0 | 0.8 | 0.6 | tr |
| α-Terpinene | 1.3 | 1.0 | tr | tr | tr | 0.8 | 2.0 | 1.4 | 1.8 | 1.5 |
| β-Phellandrene | 45.7 | 42.9 | 25.7 | 16.8 | 32.9 | 38.9 | 17.2 | 23.0 | 31.1 | 34.2 |
| Cis-ocimene | tr | 0.5 | - | - | 0.5 | 0.6 | 0.5 | 0.6 | 0.6 | tr |
| ɣ-Terpinene | 2.5 | 2.1 | 2.0 | 1.9 | 3.1 | 2.5 | 1.5 | 1.1 | 4.8 | 2.5 |
| Trans-ocimene | tr | 0.7 | - | - | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.5 |
| p-cymene | 0.5 | 0.5 | tr | tr | tr | tr | 0.7 | 0.8 | 1.6 | tr |
| Terpinolene | 1.8 | 1.5 | 3.5 | 1.0 | 4.0 | 3.5 | 2.6 | 3.3 | 3.5 | 4.0 |
| Linalool | tr | tr | tr | tr | - | - | 0.5 | tr | tr | tr |
| α-Fenchol | 1.6 | 2.0 | 2.1 | 2.4 | 1.3 | 2.8 | 3.2 | 2.7 | 4.2 | 3.8 |
| Terpinene-4-ol | 2.3 | 2.1 | 1.5 | 2.6 | 1.8 | 2.0 | 1.6 | 2.1 | 2.4 | 2.0 |
| β-caryophyllene | tr | 0.5 | 0.5 | 1.6 | 1.0 | 1.5 | 0.7 | 0.5 | 1.8 | 2.5 |
| Estragole | 0.5 | 0.5 | 0.6 | 1.1 | 0.8 | 0.9 | 0.5 | 0.5 | 0.7 | 1.0 |
| Isoborneol | tr | tr | 0.5 | 0.5 | 0.5 | tr | tr | tr | 0.5 | tr |
| α-terpineol | 0.8 | 1.1 | 2.0 | 4.8 | 1.6 | 4.5 | 2.6 | 3.9 | 3.8 | 5.1 |
| Borneol | 1.5 | 1.0 | 1.3 | 1.5 | 2.1 | 2.5 | 1.2 | 1.0 | 1.2 | 1.0 |
| Citronellol | tr | tr | tr | tr | - | - | - | tr | tr | tr |
| Cis-anethole | 1.9 | 1.2 | 0.6 | 0.6 | 1.7 | 1.5 | 1.2 | 1.6 | 0.5 | 1.5 |
| Unidentified heavy | 3.0 | 3.5 | 4.0 | 4.0 | 4.5 | 4.5 | 3.0 | 4.0 | 4.0 | 4.5 |
| | 100.3 | 99.7 | 100.0 | 99.9 | 99.9 | 100.0 | 100.0 | 99.8 | 99.9 | 99.9 |

* S - Sapwood H - Heartwood

\+ Percentage of the fraction

TABLE III

Free acids of lodgepole pine sapwood and heartwood

| Tree Number | 1 | | 2 | | 3 | | 4 | | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | S* | H* | S | H | S | H | S | H | S | H |
| Palmitic | 1.9+ | 2.2 | 1.3 | 1.7 | 1.6 | 1.8 | 2.4 | 2.6 | 1.8 | 2.2 |
| Palmitoleic | 0.8 | 1.0 | tr | 1.1 | 0.7 | 0.8 | 1.3 | 1.3 | 0.5 | 1.3 |
| Oleic | 8,0 | 8.1 | 5.5 | 12.5 | 5.9 | 10.4 | 5.2 | 14.6 | 3.9 | 17.2 |
| Linoleic | 10.0 | 17.7 | 10.4 | 18.8 | 10.5 | 18.2 | 9.6 | 20.2 | 4.3 | 21.6 |
| 5,9,12 octadeca-trienoic | tr | tr | tr | tr | - | - | - | - | - | tr |
| Arachidic | 0.9 | 4.4 | 0.6 | 6.3 | 1.1 | 1.5 | 0.5 | 2.3 | 0.5 | 4.8 |
| Linolenic | tr | 0.5 | - | 1.5 | 0.5 | tr | tr | 0.5 | tr | tr |
| Heneicosanoic | tr | tr | - | tr | - | - | - | - | tr | tr |
| Behenic | tr | 2.8 | 5.2 | 3.4 | 2.6 | 3.6 | 2.2 | 3.4 | 1.1 | 4.0 |
| Pimaric | 5.5 | 4.5 | 3.2 | 5.1 | 3.8 | 4.4 | 2.5 | 3.8 | 10.0 | 3.6 |
| Sandracopimaric | 0.9 | 1.1 | 1.9 | 1.2 | 2.6 | 1.1 | 1.6 | 1.3 | 1.7 | 0.9 |
| Levopimaric/ Palustric | 9.6 | 7.1 | 12.4 | 2.8 | 8.8 | 4.5 | 5.4 | 4.2 | 8.4 | 4.7 |
| Isopimaric | 10.9 | 7.0 | 16.1 | 11.2 | 10.3 | 8.4 | 18.6 | 9.6 | 18.5 | 8.7 |
| Abietic | 19.0 | 21.6 | 15.2 | 22.7 | 19.5 | 14.6 | 18.6 | 12.8 | 17.6 | 13.2 |
| Dehydroabietic | 23.1 | 16.2 | 18.0 | 10.5 | 25.2 | 25.8 | 22.5 | 18.4 | 22.4 | 13.0 |
| Neoabietic | 9.1 | 5.4 | 9.7 | 1.1 | 6.3 | 4.8 | 9.4 | 4.9 | 7.2 | 4.4 |
| | 99.7 | 97.6 | 99.5 | 99.9 | 99.4 | 99.9 | 99.8 | 99.9 | 97.9 | 99.6 |

* S - Sapwood
H - Heartwood

\+ Percentage of the fraction

tr - trace quantities less than 0.05%

\- indicates not found

TABLE IV

Bound acids of lodgepole pine sapwood and heartwood

| Tree Number | 1 | | 2 | | 3 | | 4 | | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | S* | H* | S | H | S | H | S | H | S | H |
| Myristic | tr | 2.0+ | - | - | 1.5 | 2.0 | 0.6 | 1.8 | tr | 1.3 |
| Palmitic | 3.6 | 7.5 | 7.8 | 9.6 | 8.0 | 9.1 | 2.8 | 4.3 | 5.6 | 7.1 |
| Palmitoleic | 1.6 | 3.2 | 3.1 | 3.8 | 1.8 | 2.3 | 1.0 | 2.7 | 1.5 | 1.9 |
| Oleic | 19.7 | 14.9 | 44.3 | 42.3 | 30.0 | 25.6 | 16.5 | 20.1 | 36.8 | 39.2 |
| Linoleic | 62.3 | 60.0 | 35.5 | 38.5 | 47.8 | 54.6 | 68.6 | 65.7 | 48.7 | 47.0 |
| 5,9,12, octadeca-trienoic | tr | 0.5 | - | - | - | - | - | - | tr | tr |
| Arachidic | 7.9 | 9.5 | 7.0 | 5.8 | 7.1 | 4.3 | 6.5 | 3.1 | 6.1 | 1.1 |
| Linolenic | 1.3 | 0.5 | 1.5 | tr | 1.2 | 0.5 | 1.0 | 0.5 | 0.5 | tr |
| Behenic | 3.0 | 1.5 | - | tr | 2.5 | 1.6 | 2.8 | 1.7 | 0.5 | 2.3 |
| | 99.4 | 99.6 | 99.2 | 100.0 | 99.9 | 100.00 | 99.8 | 99.9 | 99.7 | 99.9 |

* S - Sapwood H - Heartwood

\+ Percentage of the fraction

tr - trace quantities less than 0.05%

\- indicates not found

Shrimpton, D. M.

1972. Variation in the extractives from lodgepole pine, sapwood and heartwood.

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Information Officer,
Northern Forest Research Centre,
Canadian Forestry Service,
Department of the Environment,
5320 - 122 Street,
Edmonton 70, Alberta, Canada.