THE RECOVERY AND ANALYSIS OF STEAM VOLATILE OILS OBTAINED FROM *JUNIPERUS VIRGINIANA*

By

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THE RECOVERY AND ANALYSIS OF STEAM VOLATILE OILS OBTAINED FROM *JUNIPERUS VIRGINIANA*

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SYMBOLS AND ABBREVIATIONS

appar	apparatus	l	liter
br	branches	m	meter
calcd	calculated	mg	milligram
cm	centimeter	min	minute(s)
co	county	mL	milliliter
°C	degree Centigrade	MS	mass spectrometry
DBH	diameter at breast height	na	not available
Fo	foliage	%	percent
g	gram	RT	room temperature
GC	gas chromatography	SFE	supercritical fluid extraction
hr	hour	vol	volume
Ht	height	wt	weight
kg	kilogram		

CHAPTER I

INTRODUCTION AND HISTORICAL

In Oklahoma there are between[1] 2.4 and 3.2 million hectares of land covered by *Juniperus Virginiana* L. Until recently these trees were considered to be a problem because the eastern redcedar decreases forage production on range land. Since measures used to control this infestation have not been effective and the acreage under eastern redcedar is increasing, the emphasis has changed to utilization of eastern redcedar. Lumber and oil production are the two primary ways of utilizing eastern redcedar in other states. Thus, eastern redcedar is now increasingly being viewed as a potentially valuable and renewable resource for Oklahoma. Because the eastern redcedar of Oklahoma is unique due to environmental pressures, studies are necessary to ascertain its potential for lumber and oil production. Oil may be collected from either the tree or the waste lumber resulting from manufacture of other products. Oil production in the tree begins concomitant with wood production, but reaches usable amounts long before the tree becomes useful for harvesting for lumber.

This study was undertaken to establish oil composition and yields from specifically selected *Juniperus Virginiana* L. These trees where selected to represent the geographic distribution and specific environmental conditions unique to Oklahoma. There are several problems that must be addressed when trying to establish oil yields from these trees. The quantity of oil producing mass, environment effects on its production, and which part of the biomass is producing the oil must be considered. Also of interest in any study which attempts to address the economic viability of a product is the identity of that product. In this case that equates to the quality and quantity of the oil produced under the various growth conditions that the tree experiences. These problems were addressed with the help of the Oklahoma State University Forestry department personnel, who carried out the

selection, identification, harvesting, rough production, and biomass weighing of the trees. Our contribution was to carry out a comprehensive study which would establish the oil quality and quantity isolated by various methods.

A survey of the literature revealed that while being extensive it inadequately addressed the qualitative and quantitative aspects of redcedar wood oil. Further, the specific trees of Oklahoma are only mentioned in a very few papers and receive rudimentary representation. The essential oils from *Juniperus Virginiana* L. have had a long history. In 1900 the source of cedarwood oil was reported[2] to be from the waste of pencil manufacturing. This oil was collected by steam distilling the shavings, with a reported yield of 2.5% to 5%. It is not known whether this is on a dry material weight basis also referred to as dry yield. The quality of the oil was expressed as its' optical rotation and color (brownish color). Cedrene and cedrol were the only constituents reported.

Between 1940 and 1950 cedarwood oil was obtained through pressurized steam distillation of the waste wood from the manufacture of cedar chests, closets, and closet linings. In one paper [3] the yields were reported to be from 1 to 3.5% depending on the heartwood to sapwood ratio, and in another[4] the yields reported in the 1900 paper were used. This paper[4] also reported that virgin cedar oil yield was about 3.5% and that the heartwood of virgin and sap cedar produced the same yield of oil. How the yields were obtained was not specified. Sapwood was reported to have almost no oil. A sample of commercially produced oil was said to have 12.5 % cedrol and 60 to 70% cedrene. Other constituents of the oil were cedrenol, and pseudocedrol.

In 1950 a review[5] reported the sapwood oil yield as 0.2% and virgin cedar sapwood yield at less than 1%. An overall yield of 2 to 2.5% with a theoretical yield of 3% was also reported. Again there was no information as to whether these are yields based on weight of fresh material (fresh yield) or on weight of dried material, and it was not reported how this 'theoretical' yield was obtained. The odor of a colorless sample was reported as soft and balsamic. Sawmill produced oil was pale yellow and had to be rectified before further use.

It was reported that old wood had 4.8% cedrol, and fresh wood had 12.5 to 14.71% cedrol in the oil. Overall the qualitative data showed 80% cedrene and from 3 to 14% cedrol in the oil.

By 1960 the yield of cedrol was accepted as 3.5%. The composition[6] of a 'dry' oil sample given in the table below to facilitate comparison with later information. This is the first time thujopsene was reported to be in the oil.

Table I.

SUMMARY OF 1960 DRY OIL COMPONENTS AND THEIR PERCENTAGES

Compound	% present	Compound found but no % given
α-cedrene	35%	β-cedrene
cedrol	4%	pseudocedrol
thujopsene	30%	cedrenol
cuparene	2%	dihydro-ar-curcumene
widdrol	2%	

Reviews of earlier information appeared in 1967[7] and 1971[8]. A paper[9] from 1968 presents no new information and seems to be a restatement in terms of information of a 1952[5] paper. In a 1985 paper[10], thin layer chromotography was used to identify and quantify some oxygenated compounds, but the method for arriving at these numbers was critically reviewed later[16].

A host of compounds are reported in a 1986 paper[11] but the origin of the oil sample was omitted. It was at this time that R. P. Adams began addressing the problem using

modern instrumental techniques. In his 1986 paper[12], for the first time, the collection of an oil sample from its' source is described. He reported that steam distillation of samples was carried out for 20 hours. The yields of oil were 3.18% based on dry weight and 2.56% based on fresh weight. His methods of sample drying, extraction, and solvent removal raises questions about the possibility of sample loss.

In 1987 Adams published a comparative study[13] of the *Juniperus* species of the United States. He did not recalculate yields. These appear to be based on his 1986 paper. He gives the following components and their percentages. The total % of these components makeup in the oil is 85.7.

Table II.

SUMMARY OF 1987 COMPARATIVE OIL COMPONENTS AND YIELD

Compound	% in oil
α-cedrene	27.2
β-cedrene	7.7
thujopsene	27.6
cuparene	6.3
cedrol	15.8
widdrol	1

In 1988 Adams and C. A. McDaniel jointly published a paper[14] on the termiticidal activity of the oils from the bark/sapwood, heartwood, and leaves of the *Juniperus* species of the United States. There is no information here about the quality, quantity, or source of

the oil. Although the title indicates that bark and sapwood oil data would also be represented, no data were reported.

A 1991 review further elaborates Adams' data. Herein[15] his method of steam distillation in a thimble is described. His GC/MS method of identification and quantitation is also described. Some 30 components are listed along with their relative percentages in the oil. The information given shows some difference with no explanation given. The percentages of the major components are given below.

Table III.

SUMMARY OF 1990 OIL COMPONENTS AND YIELD

Compound	% in oil
α-cedrene	21.1
β-cedrene	8.2
thujopsene	21.3
cuparene	1.6
cedrol	22.2
widdrol	2.3

A review paper[16] from 1991 in which Dr. Adams' aforementioned work figures prominently lists about 15 oxygenated constituents. The following table sums the extent of the papers information.

Table IV.

HYDROCARBONS AND OXYGENATED CONSTITUENTS OF CEDARWOOD OIL

Compound	% in oil
hydrocarbons	55.6
cedrol	24.2
widdrol	3.5
other oxygenated cmpds	37

Sometime prior to April 1992 Dr. E. J. Eisenbraun was contacted by Oklahoma State Forestry Department personnel regarding analysis of the steam volatile components in *Juniperus Virginiana* L. After a review of the journal articles provided by Forestry Department personnel, initial isolation experiments were undertaken. Preliminary experiments 1 and 2 deal with the volatility of cedrene and cedrol. These were successful enough to extend the work to preliminary experiments 3 and 4. These experiments gave tentative results on how to steam distill the sawdust and revealed that oil remained trapped in the wood. During discussion of these results with Forestry personnel it was learned that the oil is held in the ray cells of the wood. It was concluded that some method of disruption of the wood cells was necessary.

CHAPTER II

METHODS AND MATERIALS

Samples of wood from *Juniperus Virginiana* L., ground through a Wiley™ mill to either pass an 0.8 mm screen in the case of heartwood or a 2 mm screen in the case of sapwood, were supplied by the Oklahoma State University Forestry Department (Dr. Steve Anderson, Dr. Robert Wittwer, and Russell Lykins). Upon receipt, the samples were placed under argon and stored in a freezer at -29 °C.

Cedarwood samples were weighed followed by disruption in water with a Waring Blendor, cat. no. 700 model, fitted with a polypropylene sample bottle. The wood samples were sealed and allowed to soak in the water for approximately 15 hr Steam distillation of these samples was carried out in the apparatus shown in figure 1. It is a newer version of that described by Eisenbraun et al.[17] Several improvements have been incorporated. The addition of a second steam-generation pot allows for a greater volume of steam and longer operation. A 1-L splash bulb was introduced to prevent sawdust from being blown over with the steam distillate. Other changes include a one-piece all glass distillation head and the absence of the condensate and back-flow traps as part of the steam-generator. These back-flow traps have been replaced by Claisen heads fitted with glass stoppers. The last change is the addition of a steam inlet tube which fits through a standard taper threaded joint and is connected to the Claisen heads by a length of silicon tubing and a polypropylene "y". These changes enhance the performance and simplify dismantling and cleaning.

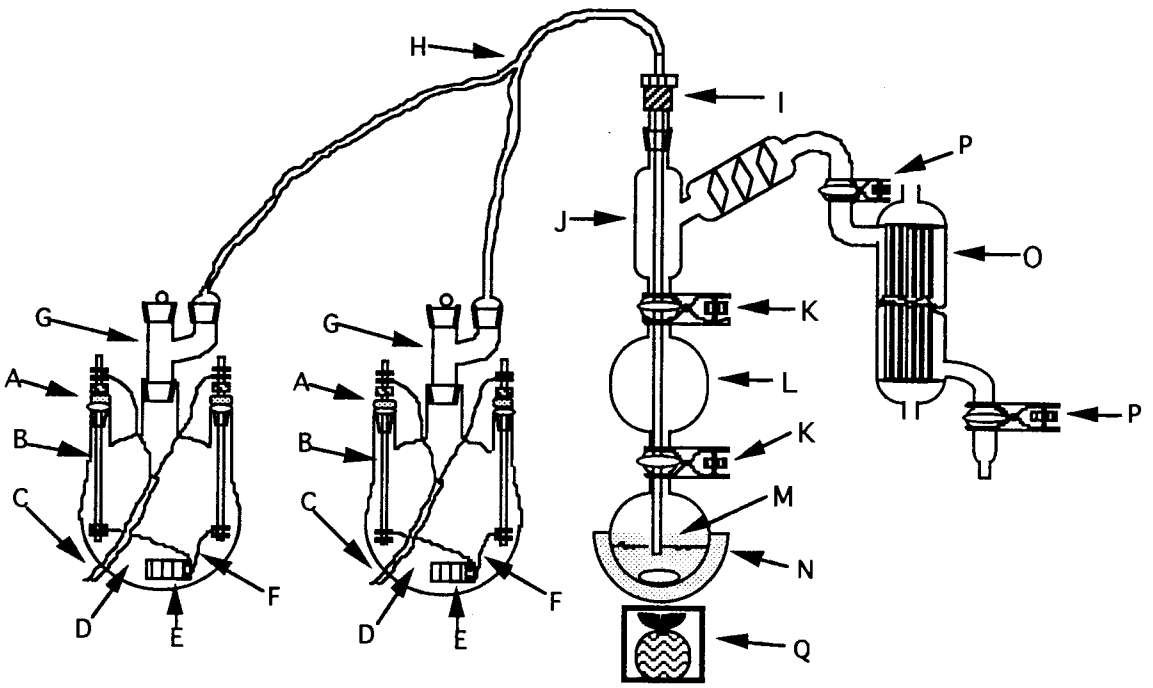

Figure 1. Revised Design of Steam Distillation Apparatus: **A,** Thermometer, adapter, 24/40. **B**, Copper or brass rod, 0.25 X 6-in. threaded at both ends and fitted at each end with two brass nuts. **C**, The electrical cord leading form the Variac to the brass support rods should withstand 110 V. AC. An 18-gauge, 2-strand, cord was used. **D**, Flask, round-bottom, 5 l, center neck 45/50 and side necks 24/40. **E**, Heating element, Nichrome, 12-amp. Master Appliance HAS-018K. **F**, Copper wire leads, 16-gauge. **G**, Claisen adapter 24/40. **H**, Polypropylene "y". **I**. #15 Ace Thread "Maxi" adapter 24/40, Ace Glass 030B. **J**, Still head fitted with a 24/40 joint at top, a 50/30 at the bottom, and a 35/20 joint at the condenser end. **K**, Clamp 50/30. **L**, Expansion bulb 50/30 joints top and bottom. **M**, Flask, round-bottom 50/30. **N**, Heating mantle. **O**, Condenser, glass with stainless steel cooling tubes. **P**, Clamp 35/20. **Q.** Magnetic Stirrer.

Following steam distillation, the steam distillation condenser was extracted with refluxing ether. The steam distillate was processed in a continuous ether/water extractor patterned after the one by Choney, Adkins, and Eisenbraun (1987)[18], Design modifications were minimum and only involved changes in flask sizes. Clamped o-ring spherical joints

are essential to prevent loss of sample. Salt was added to the extraction flask to decrease ether solubility in water. The device is shown in Figure 2.

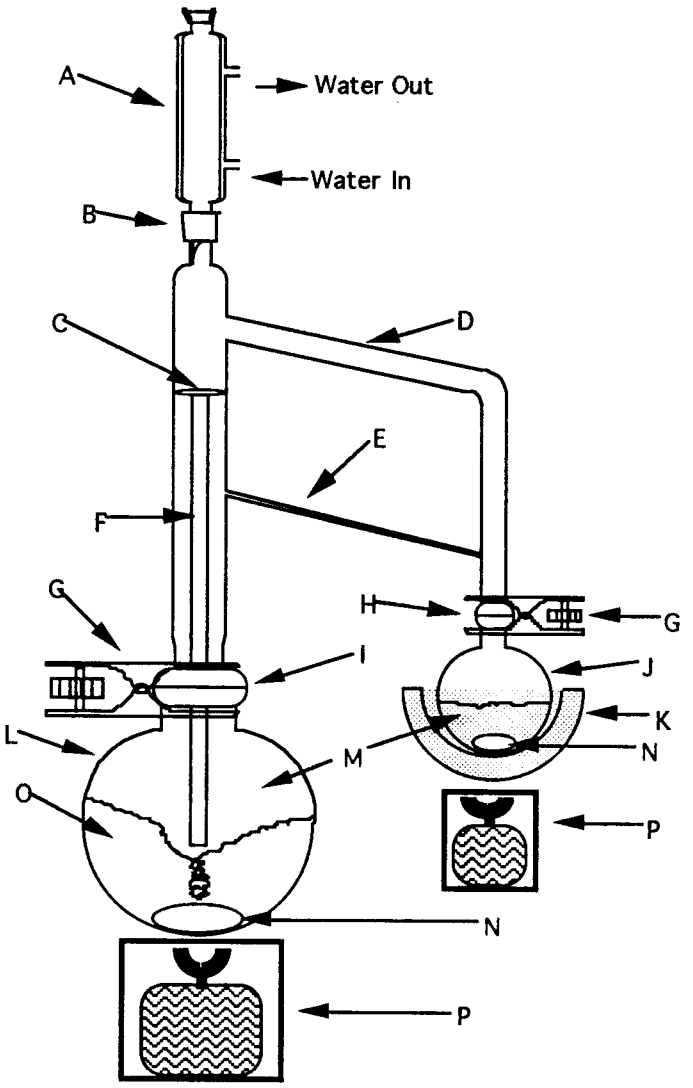

Figure 2. Continuous Ether/Water Extractor. **A**, Condenser, 24/40, water cooled, drip tip. **B**, Outer joint, 24/40. **C**, Ring seal funnel. **D**, Connecting sidearm to conduct solvent vapor from flask **J** to condenser **A**. **E**, Connecting sidearm to conduct solvent back to flask **J**. **F**, Drain tube. **G**, Clamp. **H**, Spherical joint, 35/25, O-ring. **I**, Spherical joint, 50/30, O-ring. **J**, Flask, 100 mL, 35/25. **K**, Heating mantle, 100 mL. **L**, Flask, 5 L, 50/30. **M**, Diethyl ether layer. **N**, Teflon-covered magnetic stirring bar. **O**, Water layer. **P**, Magnetic Stirrer.

The concentrated oil from the continuous ether/water extracter and the oil from the steam distillation condenser were combined, dried over $MgSO_4$, filtered through Celite, placed in a volumetric flask, and the volume adjusted to the mark with ether. In the case of a heartwood sample this was 500 mL, and for sapwood this was 50 mL. A sample (1 microliter) was analyzed by gas chromatography (Varian™ 3700, fitted with a J & W™ DB-1ms 60 m X 0.25 mm column, gas flow He at 19.81 cm/sec.). The operating temperatures were; injecter, 270 °C , detecter , 300 °C, initial column temperature 60 °C with a ramp of 3 °/min to a final temperature of 300 °C. The signal was integrated with a Shimadzu™ CR601 integrator. Following initial analysis, a rough calculation of the quantity of cedrol in the sample was made and an equivalent amount of 2,2-dinaphthyl ether was introduced to the volumetric flask containing the oil sample. The flask contents were allowed to equilibrate overnight and a sample (1 microliter) was injected on the gas chromatograph. Sample injections were repeated three times. The injections being interspaced with injections of a reference solution containing a known ratio of cedrol to 2,2-dinaphthyl ether. Integrator data were processed, tabulated, and graphed using Excel™ 5.0A and KaleidaGraph™ 2.0. A modified Abderhalden drying apparatus fitted with air inlet/outlet and cooled collection trap was used to dry the wood samples. The cedarwood samples were dried at 65 °C, 100 °C, or 130 °C with the Abderhalden drying apparatus being charged with hexane, water, or 2-ethoxyethanol respectively. A preheated atmosphere of nitrogen or dry air with a flow rate of 13.4 mL/min was used as a carrier for the vaporized components. The preheating was necessary to prevent condensation of the volitilized materials at the gas inlet. The modified Abderhalden drying apparatus is shown in figure 3.

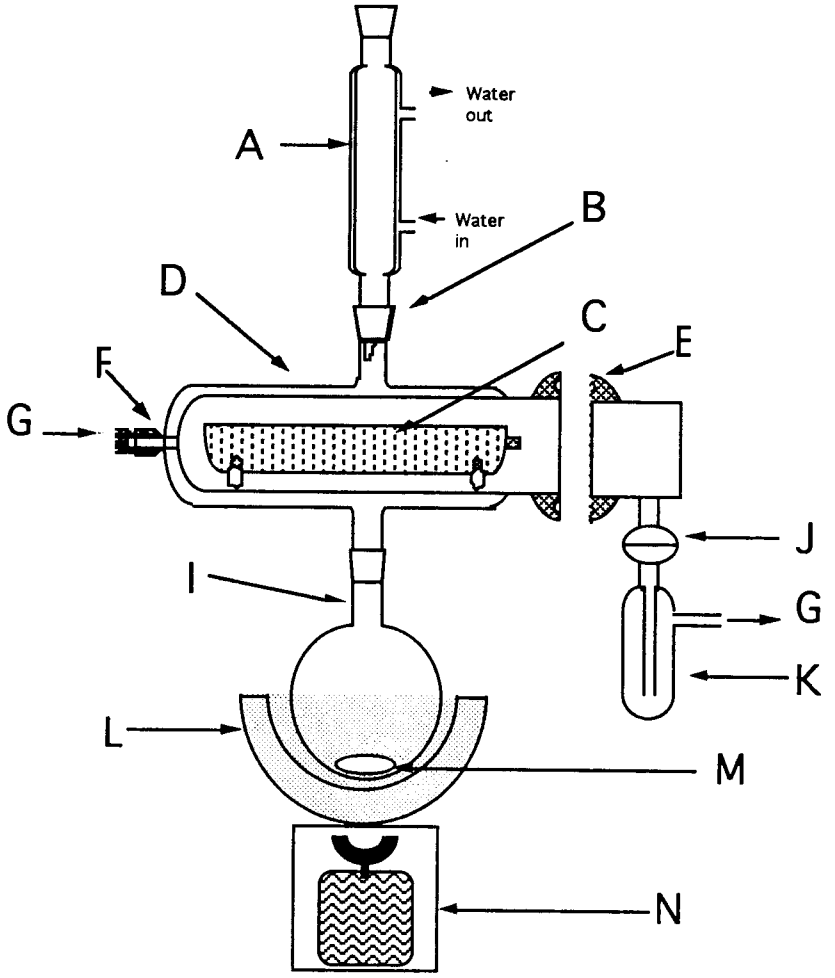

Figure 3. Modified Abderhalden Drying Apparatus. **A**, Condenser, 24/40, water cooled, drip tip. **B**, Outer joint, 24/40. **C**, Drying boat. **D**, Abderhalden. **E**, joint. **F**, Gas inlet. **G**, Direction of gas flow, **I**, Flask, 1 L, 24/40. **J**, Spherical joint **K**, Oil trap/bubbler. **L**, 1L Heating mantle. **M**, Teflon-encapsulated magnetic stirring bar. **N**, Magnetic Stirrer.

A flowchart, figure 4, showing the entire process is provided for convenience.

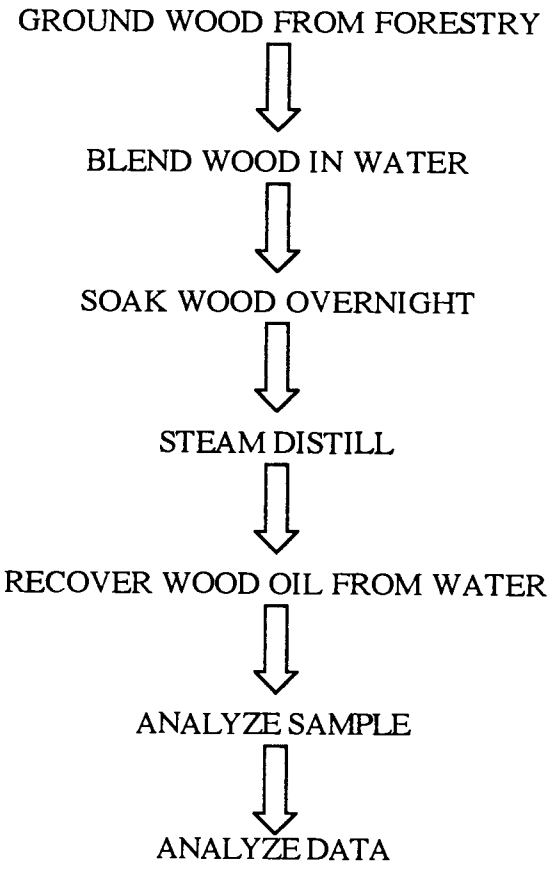

Figure 4. Process of *Juniperus Virginiana* L. Wood Analysis

CHAPTER III

RESULTS AND DISCUSSION

Data acquisition techniques

Subsequent experiments were carried out by Kirk Payne. The literature was reviewed and trial gas chromatography studies were carried out. The importance of sample size immediately became apparent, since overinjection (sample too large) caused the major peaks to split into several peaks. This was verified in trials using different size samples of a single compound. The sample size was optimized through trial studies. In this forest of peaks of a typical cedarwood gas chromatogram, often more than 120, it became obvious that sample size was critical with each injection. Too much sample and the peaks would split, causing loss of resolution. Too little and the minor components could not be seen. This problem of sample size would continue throughout initial attempts at analysis of the oil. Selection of injection port temperature also required optimization. Finally, the temperature of the column required selection. The choice was between an isothermal method or a temperature gradient method. Capillary columns utilizing temperature gradients are known to be highly effective at separating complex mixtures. The normal process of method development requires balancing the temperature gradient and the flow of carrier gas to obtain sharp and well separated peaks. Too low a temperature results in peak broadening and too high a temperature or too fast a carrier gas flow rate results in unseparated peaks. The method chosen used a temperature program with a 3°/min temp rise and an upper temperature limit of 300° to insure that none of the sample adhered to the column. A typical gas chromatogram is presented in figure 5. These techniques were tested on five samples of industrial processed oil taken at various times during the steaming process. The data are summarized in table V and figures 6 and 7.

TABLE V

QUALITATIVE TIME DEPENDENCE FOR STEAM DISTILLATION OF CEDARWOOD OIL OVER A SEVEN HOUR PERIOD

Sample #	% Composition of Selected Components							Total %
	α-Cedrene	β-Cedrene	Thujopsene	α-Selinene	β-Himachalene	Cedrol	Widdrol	
1	23.212	4.447	34.451	1.946	3.640	16.455	2.604	86.754
2	21.004	4.098	31.083	2.027	3.650	20.483	3.323	85.667
3	19.619	3.835	29.125	1.934	3.857	23.590	3.900	85.860
4	18.795	3.697	27.764	1.950	3.729	28.677	na[a]	na
5	18.942	3.736	27.952	1.901	3.886	24.868	4.431	85.717

[a]Integrator did not calculate this peak.
Compositional changes illustrated in Figures 6 and 7.

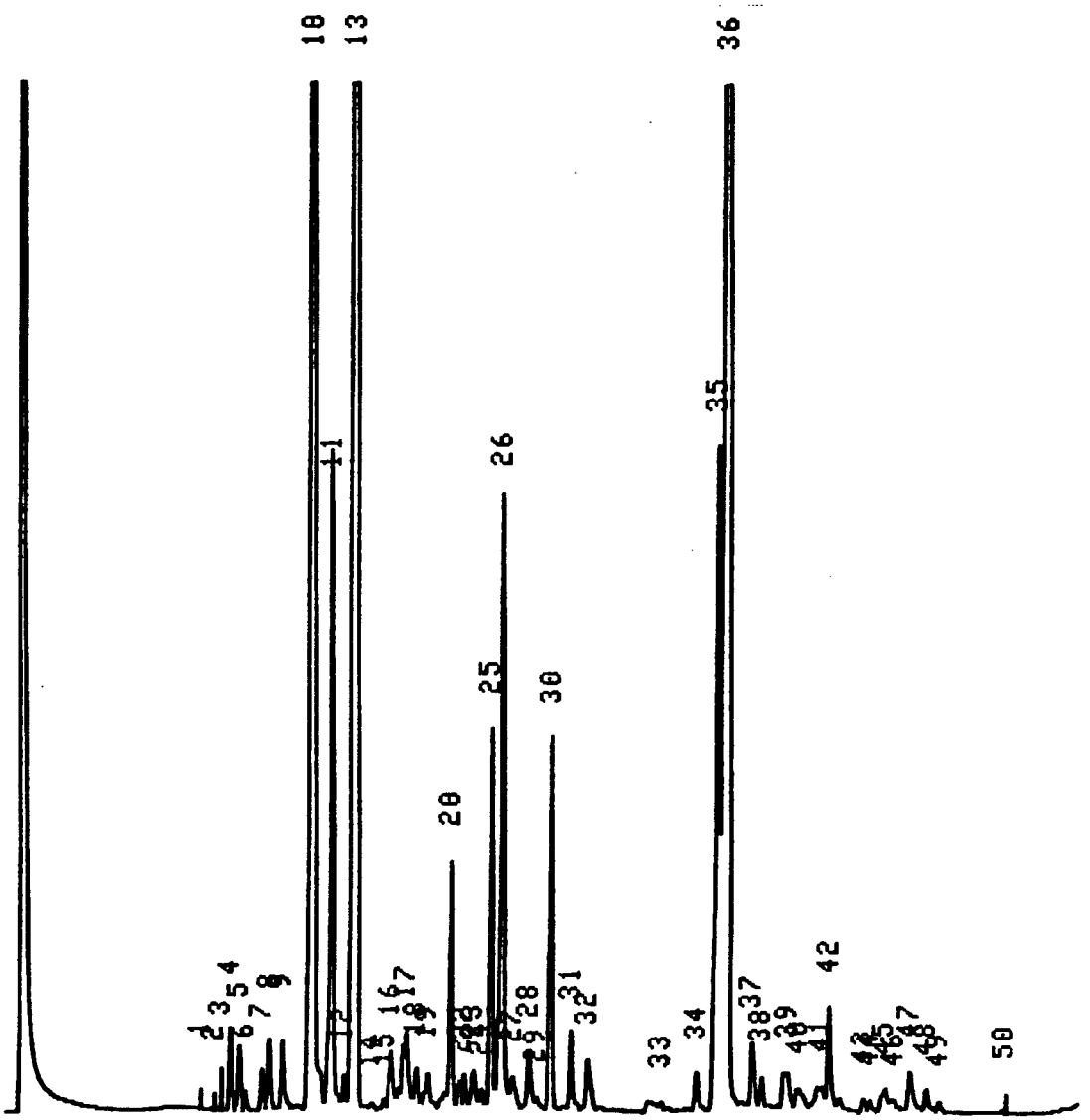

Figure 5. Typical Gas Chromatography Trace. Peak numbers and identification are as follows: #10 - α-cedrene, #11 - β-cedrene, #13 - thujopsene, #25 - α-selinene, #26 - β-himachalene, #35 - widdrol, #36 -cedrol.

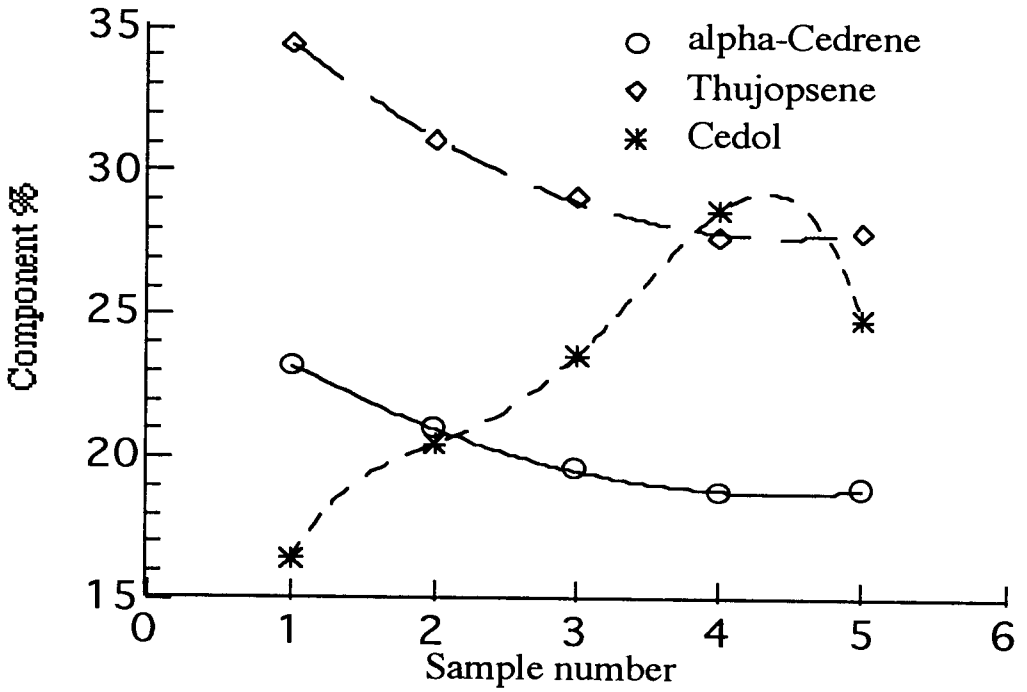

Figure 6. Heartwood Oil Composition Change During Steam Distillation for Components in Excess of 15 % in Cedarwood Oil. Part 1. Curves are polynomials of the form y=m0+m1*x+m2*^2...+m∞*x^∞. For (O) Cedrene curve: m0 = 26.175279236,m1 = -3.334544972, m2 = 0.3766141619, and r = 0.99968110906. For (◊) Thujopsene curve: m0 = 38.824240875, m1 =-4.9353004456, m2 = 0.55060005188 , and r = 0.99924961875. For (*) Cedrol curve: m0 = -5.1786060332, m1 = 39.443198681, m2 = 23.461239417, m3 = 6.2259583473, m4 = -0.57421247164, and r=1.

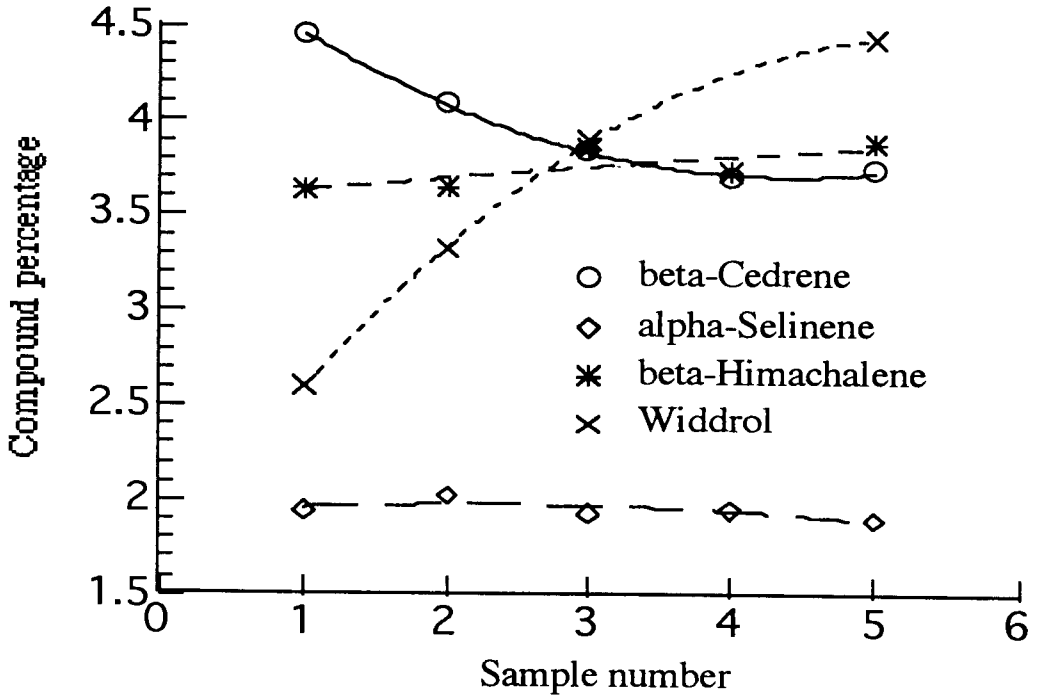

Figure 7. Heartwood Oil Composition Change During Steam Distillation for Components in Excess of 15 % in Cedarwood Oil. Curves are polynomials of the form y=m0+m1*x+m2*^2...+m∞*x^∞. For (O) beta-Cedrene curve: m0 = 4.9597800732, m1 = -0.56821141924, m2 = 0.064328568322, r = 0.99894179587, For (◊) alpha-Selinene curve: m0 = 1.9252599955, m1 = 0.048654333183, m2 = -0.010885724, r = 0.71840519079. For (*) beta-Himachalene curve: m0 = 3.5597799778, m1 = 0.075238565036, m2 = -0.0030214275633, r = 0.78949424341. For (X) Widdrol curve: m0 = 1.6733618433, m1 = 1.0184936632, m2 = -0.093304558234, r = 0.99990165189.

Since these data showed good precision, the next step was to apply the analysis to samples of known oil. Four different commercial samples and a sample supplied by Forestry were analyzed. The major constituents are compared in table VI on the next page.

TABLE VI.

COMPARISON OF COMMERCIALLY AVAILABLE OILS AND OIL SUPPLIED BY OSU FORESTRY DEPARTMENT

Oil sample	% Composition of Selected Components						Total %
	α-Cedrene	β-Cedrene	Thujopsene	α-Selinene	β-Himachalene	Cedrol + Widdrol	
Chinese	29.441	8.680	23.636	1.442	3.474	14.152	80.825
Texas	20.550	5.957	29.434	2.106	3.858	26.593	88.497
Perfumers	16.647	5.706	27.645	1.959	4.332	31.472	87.762
Virginiana	30.143	7.749	17.698	2.101	3.503	24.283	85.477
Forestry	36.718	8.720	21.193	1.492	4.375	14.234	86.731

Development of cedarwood oil recovery techniques

In an effort to establish the most efficient and timely method of recovering the steam volatile oils from a sample of cedarwood sawdust, several experiments involving isolation and analysis were carried out.

Cedarwood sawdust treated in a variety of procedures prior to steam distillation and subsequent hexane/ether extraction of the steam distillate resulted in the data shown in table VII (experiments 1-4) located on the next page. In all cases, 4 L of steam distillate were collected. From these results, experiment 4 (disruption of the sawdust with a Waring Blendor and presoaking overnight) was found to be the best procedure for optimum oil recovery. Experiment 4 represents a 31.2% increase over steaming without pre treatment.

This procedure was then utilized to determine the quantity of oil steam distilled in a succession of fractions, as shown in figure 8 (experiment 6, Cedarwood steam distillation-incremental fractions) located on the next page.

TABLE VII

OIL RECOVERY BASED ON TYPE OF PRE TREATMENT OF CEDARWOOD SAWDUST

Experiment number	Pre treatment	Grams of oil recovered
1	None	0.50[a]
2	Stored overnight in water	0.55
3	Blended with Waring blender	0.57
4	Blended and stored overnight	0.64
5	Sonication	0.47

[a]20.6 g of cedarwood sawdust was used in this case. In other runs, 20.0 g samples were used.

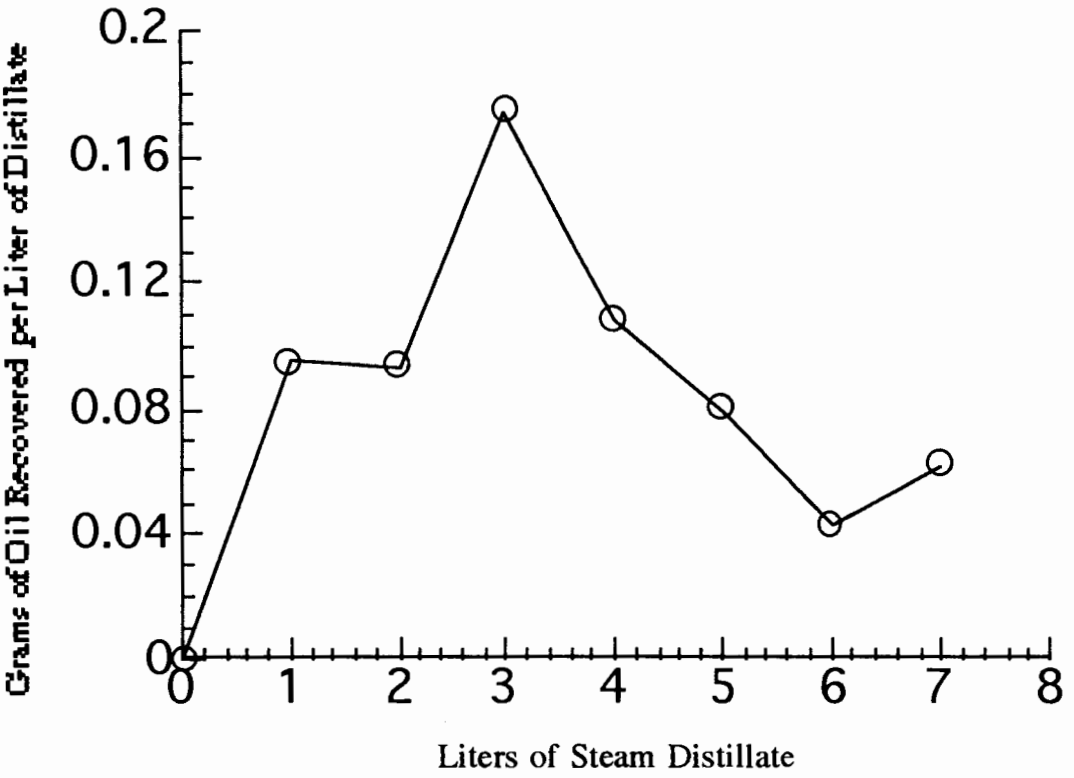

Figure 8. Experiment 6, Grams of Oil Recovered per Liter of Distillate vs Liters of Steam Distillate Collected.

In summary, a total of 0.655 g of oil was collected in this manner. In the first 4 L, the total is 0.470 g, which was a dismal return since it was 0.17 g less then that expected in 4 L of steam distillate (see experiment 4). This decrease was most likely due to increased manipulation and results from cumulative loss during the multiple steps in processing. The data acquired in this manner, however, suggested that the steaming process yields an increasing amount of oil up to the third liter collected and then a fall off in oil production. The last fraction collected showed an increase in oil return over the preceding fraction, and may be attributed to oil holdup in the condenser.

The utilization of a continuous ether/water extractor (procedure listed as experiment #8) came about after consideration of the errors inherent in the multi-step extraction process (separatory funnel) that was initially used for isolation of oil from the steam distillate. The use of the continuous ether/water extractor in oil recovery from the steam distillate surmounts several problems. Since this procedure involves only two steps in handling (transfer to the extractor and transfer of the extract to a volumetric flask), loss of oil during isolation is less likely. The continuous extractor also minimizes partial solubility of the oil in the water layer, conserves solvents, and overall conserves time. Following adoption of the continuous ether/water extractor, the apparatus for recovery of the steam volatile oil was considered complete and the entire assembly was tested on its' ability to recover a known amount of cedrol. This experiment (9) showed, by gas chromatography, an average efficiency for recovery of cedrol of 87.83%. However, direct isolation utilizing the rotary evaporator gave only a 72% recovery (0.360 g), the difference being due to loss of volatiles during concentration under vacuum.

To further determine the quantity of available oil from cedarwood sawdust, a direct extraction with dichloromethane was carried out. The dichloromethane extractables were found to be 0.767 g from a 20.0 g original sample. This is only 20 % more material than was obtained in experiment 4 (0.64 g). Furthermore, some of the weight of the dichloromethane extracted oil comes from colored material(s) that are not steam volatile.

Following extraction, the cedarwood sawdust weighed 18.392 g (1.608 g difference). This leaves 0.841 g of material unaccounted for. There may be two explanations for this. First; the missing weight is the water extracted from the sawdust and lost on the rotary evaporator, and/or second; some of the extracted oils are volatile enough to be removed in the rotary evaporator.

Prior to the adoption of the above experiments, test runs were undertaken to establish proper handling techniques and possible means of sawdust disruption. While the test runs did supply ample time to develop the handling techniques necessary for the types of experiments to be done, it is worth mentioning one of the test runs that ended in disappointment. This involved the use of a disintegrator. Several attempts were made to utilize this piece of equipment, some of which involved actual modification of the apparatus, but all ended in failure. During the processing of the sawdust at high speed, pieces of sawdust caught between the rotating shaft and the high speed Teflon bearing became charred, developed an odor, and likely contaminated the sample.

In conclusion, the selected pretreatment method (blending with water and storing overnight) followed by continuous ether/water extraction fit the criteria necessary for a continuation of the study of the cedarwood oil: the ability to recover a good percentage of the available oil in a timely fashion. It was further decided that to minimize oil loss, the oil/ether obtained from the ether/water extractor would be directly analyzed by gas chromatography using an internal standard for quantification.

Analysis of Trees for Biomass Study

The ground heartwood sawdust of trees harvested for the biomass study was subjected to the oil recovery and isolation techniques described. In all, data from nine trees were collected. These data make up appendices D and E.

The first question addressed was the reproducibility of the method of obtaining and analyzing the oil. Tree number seven was selected to demonstrate. The full results of this analysis may be found in appendices E7.1 and E7.2. Two batches of the sawdust from tree number seven were run through the process and analyzed. Table VIII is a summary of the variation that may be expected between two runs of identical samples. The lowest amount of precision is 76.5 % and this was a result of the difficulty that the integrator had distinguishing between alpha-cedrene and adjacent peaks. The other peaks had less of this type of interference and thus showed a higher precision.

TABLE VIII

VARIATION OF MAJOR CONSTITUENTS OF HEARTWOOD OIL FROM TREE NUMBER 7

Compound	% of Selected Components		Precision
	First Run	Second Run	%
α-Cedrene	6.99	5.35	76.5
β-Cedrene	1.04	0.956	91.9
Thujopsene	8.26	9.11	90.7
Cedrol + Widdrol	65.1	64.6	99.2

This difficulty with interfering compounds and overlapping peaks would plague us throughout our investigation. We utilized gas chromatography coupled with mass spectroscopy in an attempt to identify some of these unknown compounds. This was done through comparisons of retention times of peaks of interest with retention times of reference compounds, doping samples with reference compounds, and comparison of mass spectra of

library compounds with unknown compounds. In this we experienced only limited success. On the high side we established that a peak of interest that had a retention time slightly less than that of alpha-cedrene was italicene (mass spectra shown in appendix C1), and that a peak with a retention time slightly less than that of cedrol was alpha-longipinene. We were unable to identify the compounds in most of the mass spectra. This is due somewhat to the complexity of the mixture, the compounds being in such a small proportion compared to known compounds, and the limitation of the mass spectra library available to us. Confirmation of the major components in the heartwood samples was done, and some good mass spectra of unknown compounds were acquired. These are shown in appendices C2 and C3.

This GC, GC/MS work enabled us to select compounds out of the complex gas chromatograms of the oil. These were the components that we would track to establish qualitative and quantitative variations in the oils we would process. Specific components were chosen either because they were major constituents, defined as contributing more than 1% to the oil, or because they were marker compounds that would show us how well our GC/integrator couple was working. We chose, for tracking, 26 components of the steam distilled heartwood totaling between 92.3 % and 95.6 % of the total makeup of the oil. The identity of ten of these components are known to us at this time. For the sapwood, 26 components were also chosen. Three of these were different from those in the heartwood oil, but all together the components chosen totaled 92.3 % of the steam distilled sapwood. Only 10 of the components chosen for tracking in the sapwood are known.

At this time it became necessary for us to establish a method of arriving at a yield not only for the total amount of oil but for the individual components as well. As was mentioned in the introduction, investigators in the past have addressed this problem in various ways and achieved varying degrees of success. The main problem was variable moisture content. The obvious solution would be to base the yield on dried plant material, but we were convinced that oil is lost during the drying process. To establish the quantity

and quality of oil lost during drying, we trapped the oil released during the drying process and compared it with the oil collected during steam distillation. We used 100 °C as our drying temperature for comparison. Table IX compares the yields of some of the major components and the total oil yield of the two ways the oil was processed. These data clearly show that 17.2 % of the oil is lost in the drying process, and this oil is qualitatively different from that obtained by steam distillation. Because of this difference, uncorrected yields will be used in this paper but this does allow one to tentatively apply a correction factor to the yields obtained.

TABLE IX

QUALITATIVE AND QUANTITATIVE COMPARISON OF HEARTWOOD OIL OBTAINED FROM TREE #5 BY OVEN DRYING AT 100 °C AND STEAM DISTILLATION

Process	% Composition of Selected Components					Total oil
	α-Cedrene	β-Cedrene	Thujopsene	α-Selinene	Widdrol/ Cedrol	in mg
Oven drying	6.58	1.80	1.30	0.191	52.4	36.32
Steam distillation	9.75	2.45	12.4	1.05	50.5	211.34

Comparison of the oil constituents of the various trees was now possible. Following steam distillation of the heartwood samples and analysis of their oils, their individual major components were compared. This was done to show the variation in the individuals as well as to gain an insight on factors contributing to this variation. The range of composition of the major components is shown in table X located on the following page. The yield of heartwood oil varied from 1.06% to 3.44 %, with an average yield being

2.56%. This is based on a fresh or green weight. Sapwood oil was analyzed for the same purposes. While only one tree was done, it does give some idea of what can be expected as far as yields and composition are concerned. The sapwood showed a yield of 0.169% based on fresh weight, whereas the heartwood of the same tree had a yield of 1.06% based on fresh weight. The sapwood's major constituents along with their percentage in the oil are listed in table XI on the following page to facilitate comparison with the constituents of the heartwood.

TABLE X

QUALITATIVE COMPARISON OF MAJOR HEARTWOOD OIL CONSTITUENTS

Compound	Representative % in Oil		
	Low	Average	High
α- Cedrene	4.15	6.93	9.75
β-Cedrene	0.91	1.58	2.45
Thujopsene	6.94	10.08	12.42
Cuparene	0.80	1.29	2.13
Widdrol / Cedrol	50.46	59.84	64.84

Chart components represent on the average 79.72 % of the total oil sample.

TABLE XI

QUALITATIVE COMPARISON OF MAJOR SAPWOOD OIL CONSTITUENTS

Compound	Representative % in Oil
Limonene	1.69
Unknown 1s	4.53
L- Borneol	4.60
Thujopsene	1.59
Widdrol / Cedrol	71.05

Chart components represent on the average 83.46 % of the total oil sample.

Comparison of Laboratory and Commercial Processes

Various methods of heartwood oil isolation were undertaken on the heartwood of tree #10 and the results were compared. The steam distillation and extraction methods that we had developed served as a benchmark during this process as the other methods were developed and refined. Supercritical fluid extraction was one of the methods that was attempted. These experiments were carried out by Dr. Niels Maness of the OSU Horticulture and Landscape Architecture Department. They are described in the experimental section as #16. The oil obtained was analyzed as previously described. Another method resulted from our attempt to establish the type and quantity of oil that was being lost in the drying of the wood. This method (experiments 12 through 15) involved a modified Abderhalden drying apparatus fitted with gas inlet/outlet and oil collection trap. The Abderhalden drying apparatus allowed us to collect oil under precise conditions of temperature and atmosphere. We utilized two different temperatures, 100 °C and 134 °C,

and two different atmospheres, dry air and nitrogen, for these experiments. A comparison of the major components and overall oil yield for these different experiments is shown in table XII.

TABLE XII

QUALITATIVE AND QUANTITATIVE COMPARISON OF HEARTWOOD OIL OBTAINED FROM TREE #10 BY LABORATORY METHODS

Process	% Composition of Selected Components					Total oil
	α-Cedrene	β-Cedrene	Thujopsene	Cuparene	Widdrol/ Cedrol	in mg
Steam distillation	7.87	2.51	9.26	2.61	61.3	887
Supercritical Fluid Extraction	10.6	2.92	14.3	1.08	53.1	na
Abderhalden 100 °C, N_2	12.9	3.12	16.2	1.54	49.0	915
Abderhalden 100 °C air	12.9	3.01	16.2	1.44	49.2	812
Abderhalden 134 °C, N_2	13.4	4.88	17.2	1.86	42.2	716
Abderhalden 134 °C air	13.5	4.86	16.8	1.78	46.2	943

na This sample was not evaluated quantitatively because of time limitations

Several things become obvious when the data from table XII are compared. The first is that the material from SFE is richer in α-cedrene, and thujopsene. This may be due to some loss of the more volatile components under the conditions used. There is some basis for this assumption, since the experimenter used harsher conditions then may have been necessary for the extraction in an initial belief that the oil would be harder to extract than it was. These harsh conditions may also have catalyzed some rearrangement of cedrol to α-cedrene and widdrol to thujopsene.

When the samples subjected to the Abderhalden drying apparatus are considered something else becomes apparent. The atmosphere that the sample experiences does not matter as much as the temperature of treatment. The data indicate that at the higher temperatures some degradation of the sample is occurring. When degradation takes place, as previously explained, cedrol becomes alpha-cedrene and widdrol becomes thujopsene.

No careful evaluation of cedarwood oil would be complete without considering commercial methods and materials. We evaluated oil obtained from a commercial steam distillation unit, a commercial SFE process, a laboratory steam distillation, and from drying in the laboratory Abderhalden drying apparatus. All of these processes used the same starting material. For this study yields were not available on most of the samples, but a comparison of the components of the oils thus obtained was possible. Table XIII shows how the components of the oil differed from each other based on the method used. These data suggest that the commercial sample, in the form of wood chips, is not ideal for the method of steam distillation used in the current work. The material had a much higher ratio of internal area to surface area, and that is a likely cause of the low oil yield in the laboratory steam distillation process. This was overcome in the Abderhalden drying apparatus experiments by allowing a longer oil collection time. The quality of oil from the laboratory steam-distillation and Abderhalden apparatus drying are very similar. The commercial SFE was carried out by a company in England called Advanced Phytonics™. They use an exotic mixture of fluoroalkanes as their extraction fluid. It is impossible to tell whether their system is concentrating the hydrocarbon fraction of the oil at the expense of the alcohol fraction or if it has extracted all available material from the sample. From the % of other components in the sample (see appendix11.2) it seems that this is the case. If we knew the total oil yield, this would become clearer. One thing that does become clear during evaluation of these data is that the industrial steam distillation process produces oil which is not comparable to that produced by laboratory steam distillation. This is indicative of some deficiency in the industrial steam distillation process, and without quantitation it is

impossible to ascertain this deficiency. The data support the conclusion that this process is destroying the widdrol/cedrol fraction. It is information like this that is of the most value to the cedarwood oil industry.

TABLE XIII

QUALITATIVE AND QUANTITATIVE COMPARISON OF CEDARWOOD OIL OBTAINED FROM A COMMERCIAL WOOD SAMPLE BY VARIOUS METHODS

Process	% Composition of Selected Components					Total oil
	α-Cedrene	β-Cedrene	Thujopsene	Cuparene	Widdrol/ Cedrol	in mg
Steam distillation, laboratory	0.99	0.408	1.13	0.856	68.2	66.5
Steam distillation, commercial	13.3	3.32	22.7	2.63	39.4	na
Supercritical Fluid Extraction	5.70	1.94	6.24	2.26	54.5	na
Abderhalden 100 °C nitrogen, Run #1	3.81	1.83	5.43	2.49	67.2	113
Abderhalden 100 °C nitrogen, Run #2	4.05	1.83	4.96	2.31	66.8	105

na This sample was not evaluated quantitatively
A 20.00 g sample was used in all cases were yield of oil is given

This study of the oil of the Oklahoma Redcedar is far from comprehensive. The diverse environmental conditions and ages of the trees made it difficult to compare the production of the individual components between individual trees. As a preliminary evaluation of the type of oil produced and quantity that can be expected from a given tree, it does show validity. Before an industrial apparatus is put into place in Oklahoma, this study needs to be followed up with one that narrows the number of variables. A study of how tree age affects oil production would probably be the most valuable at this time. That study could be followed up by one of how competition with other trees affects oil production. Soil type will also eventually require evaluation concerning its contribution to the oil

production of the tree. In conclusion, there are many more studies that need to be done on the Oklahoma *Juniperus Virginiana* L. before the full value of a sustainable industry can be ascertained.

CHAPTER IV

Experimental

Preliminary Experiment 1, Volatility of Cedrene. A 3-l round-bottomed flask containing a stir bar was charged with cedrene (4 g). The flask was connected to the steam distillation apparatus and the contents were steamed for 3 hr. Two 1-L and two 2-L fractions were collected. These fractions were extracted with low boiling petroleum ether followed by ether. Sodium chloride (15% solution) was used to facilitate extraction.

Preliminary Experiment 2, Volatility of Cedrol. A 3-l round-bottomed flask containing a stir bar was charged with cedrol (4 g) and 200 mL water. The flask was connected to the steam distillation apparatus and the contents were steamed until three 1-L and two 2-L fractions were collected. The first fraction which took approximately 20 minutes to collect was extracted with low boiling petroleum ether (2 X 100 mL). Most of the cedrol was recovered in this fraction.

Preliminary Experiment 3, Cedarwood sawdust steam distillation. A 3-l round-bottomed flask containing a stir bar was charged with red cedar sawdust (100 g) . The flask was connected to the steam distillation apparatus and the contents were steamed until 2 L of distillate had been collected. The distillate was extracted with petroleum ether (2 X 100 mL). 850 mg was isolated.

Preliminary Experiment 4, Cedarwood sawdust steam distillation. A 3-l round-bottomed flask containing a stir bar was charged with red cedar sawdust (100 g) and the sawdust covered with water . The flask was connected to the steam distillation apparatus and the contents were steamed until 1 L of distillate had been collected. The distillate was extracted with petroleum ether (100 mL) followed by diethyl ether (100 mL). This resulted in the collection of 720 mg of oil. Oil stuck on the interior of the condenser was washed down with acetone and extracted with petroleum ether (3 X 200 mL). This resulted in a

further 490 mg of oil. Further steam distillation of the sample and work-up resulted in an additional 580 mg of oil.

Experiment 1, Cedarwood steam distillation. A 1-l round-bottomed flask containing a Teflon® coated stir bar was charged with cedarwood sawdust (20.6 g) and water (300 mL). The flask was connected to the steam distillation apparatus and the contents were steamed until 4 l of condensate were collected (80 min). Sodium chloride (1.2 kg) was dissolved in the steam distillate which was placed in a 6-l separatory funnel, extracted with hexane (200 mL) and diethyl ether (2 X 100 mL). The combined organic layers were washed with water, dried ($MgSO_4$), filtered through Celite, and concentrated by rotary evaporation to a yellow oil (0.5 g)

Experiment 2, Cedarwood steam distillation-with prior soaking. Carried out as above except as follows: Prior to steam distillation, cedarwood sawdust (20.0 g) and water (200 mL) were placed in a closed bottle overnight. When the contents were transferred in the 1-l round-bottomed flask for steam distillation, only 100 mL water was added. The yellow oil thus recovered weighed 0.55 g.

Experiment 3, Cedarwood steam distillation-immediately after Waring Blender treatment. Done as in experiment 1 with the following revisions. Prior to steam distillation, cedarwood sawdust (20.0 g) and water (130 mL) was treated in a Waring Blender (66% power for 15 min). This material was transferred to a 1-l round-bottomed flask with water (170 mL) and steam distilled. The resulting yellow oil weighted 0.57 g.

Experiment 4, Cedarwood steam distillation after Waring Blender treatment and overnight soaking. Done as in experiment 3 except as follows. After treatment with the Waring Blender, water (70 mL) was added and the whole placed in a tightly closed jar overnight. When the soaked sawdust was transferred in the 1-l round-bottomed flask for steam distillation, 100 mL of water was added. The yellow oil obtained weighed 0.64 g.

Experiment 5, Cedarwood steam distillation-sonication. In a 1-l round-bottomed flask cedarwood sawdust (20.0 g) and water (300 mL) was sonicated for 1 hr. The sonicated material was transferred to the steam distillation flask and then steamed as in experiment 1. The resulting yellow oil weighed 0.47 g.

Experiment 6, Cedarwood steam distillation-incremental fractions. The cedarwood sawdust was treated before steam distillation as in experiment 4. During the steam distillation 1-l fractions were treated as follows: Sodium chloride (300 g) was dissolved in the fraction which was introduced to a 2-l separatory funnel, extracted with hexane (50 mL), diethyl ether (2 X 25 mL), washed with water, dried ($MgSO_4$), filtered through Celite, and concentrated by rotary evaporation. In all 7 fractions were collected and treated in the manner described. The weights of the fractions are as follows (in order of collection): 0.095 g, 0.093 g, 0.174 g, 0.108 g, 0.080 g, 0.043 g, and 0.062 g (total recovered weight was 0.655 g).

Experiment 7, Available extractables and recovery-Soxhlet extraction. A Soxhlet extractor was charged with cedarwood sawdust (20.0 g) and extracted with dichloromethane for 4 hrs. The dichloromethane extract was concentrated by rotary evaporation to yield a red oil weighing 0.767 g. The extracted cedarwood was air dried to a constant weight of 18.392 g.

Experiment 8, Standard continuous ether/water extraction procedure. A 5 l r.b. flask containing a stir bar, 0.5 l water, and 300 g NaCl was charged with 4 l of steam distillate and the apparatus was assembled. The mixture was stirred vigorously until a clear solution was achieved and then 750 mL of ether was added. Following boil up, the extraction was carried out for 4 hr. The resulting extract was dried ($MgSO_4$), filtered through Celite, and placed in an appropriate sized volumetric flask for subsequent gas chromatography analysis.

Experiment 9, Apparatus efficiency in recovery of steam volatile oil (cedrol). A weighed amount of cedrol (0.500 g) was placed in the apparatus and steamed

until 4 l of steam distillate were collected. This was transferred to the continuous ether/water extractor with 750 mL ether and 300 g NaCl. Extraction was carried out for 3 hr. The ether extract was dried ($MgSO_4$), filtered through Celite, and concentrated by rotary evaporation to a white solid (0.360g).

Experiment 10, Steam Distillation Condenser Holdup of Cedrol. A weighed amount of cedrol (0.300 g 99.4% purity) was placed in the apparatus and steamed until 4 l of steam distillate were collected. The steam distillate was set aside, and the steam distillation condenser was drained. A second condenser was mounted on top of this and the steam distillation condenser extracted with refluxing diethyl ether (50 mL) for four hours. The diethyl ether extract was dried over magnesium sulfate (2.16 g), filtered through Celite™ (1.48 g), and concentrated by rotary evaporation to colorless crystals (0.172 g, 57.3% recovery).

Experiment 11, Typical Wood Drying (Tree #10) at 65 °C with the Abderhalden Drying Apparatus. Ground Cedarwood (22.181 g) was weighed out in the Abderhalden apparatus glass boat. This was placed in the apparatus and the apparatus sealed. A stream of nitrogen (13.4 mL/min) was started. After 15 minutes the flask containing the solvent (hexane bp. 67 °C) was heated. The apparatus reached a temperature of 65 °C within 1/2 hr. Following a 24 hr period, the apparatus was allowed to cool to room temperature and the glass boat weighed. The steps of starting the stream of nitrogen 15 min before heating, heating, cooling to room temperature, and weighing were continued until no weight lose could be detected over a 24 hr period. This proved to be on the tenth day and the final weight was 18.121 g (81.696% weight retention, 4.060 g oil/water loss).

Experiment 12, Typical Wood Drying (Tree #10) at 100 °C with the Abderhalden Drying Apparatus. Done as in experiment 11 except as follows: Ground Cedarwood (23.480 g) was weighed into the Abderhalden apparatus glass boat. Water was used as the heat transfer medium and a temperature of 100 °C was achieved within 0.5 hr. On the second day, the final weight was achieved (18.998 g, 80.911% weight retention,

4.482 g oil/water loss). Gas chromatography analysis of the oil showed 1.073 g oil recovered.

Experiment 13, Typical Wood Drying (Tree #10) at 134 °C with the Abderhalden Drying Apparatus. Done as in experiment 11 except as follows: Ground Cedarwood (27.025 g) was weighed into the Abderhalden apparatus glass boat. The heat transfer medium used was 2-ethoxyethanol (bp. 135 °C), and a temperature of 134 °C was achieved within 0.5 hr. On the second day the final weight was achieved (21.611 g, 79.967% weight retention, 5.414 g oil/water loss).

Experiment 14, Wood Drying (Tree #10) at 100 °C with the Abderhalden Drying Apparatus in Dry Air. Done as in experiment 11 except as follows: Ground Cedarwood (23.772 g) was weighed out in the Abderhalden apparatus glass boat. The heat transfer medium used was water, and a temperature of 100 °C was achieved within 0.5 hr. Dry air at a flow rate of 13.4mL/min was used as the vapor carrier. On the second day the final weight was achieved (19.203 g, 80.780% weight retention, 4.569 g oil/water lose). Gas chromatography analysis of the oil showed 0.9961 g oil recovered.

Experiment 15, Wood Drying (Tree #10) at 134 °C with the Abderhalden Drying Apparatus in Dry Air. Done as in experiment 11 except as follows: Ground Cedarwood (28.801 g) was weighed into the Abderhalden apparatus glass boat. The heat transfer midium used was 2-ethoxyethanol bp. 135 °C, and a temperature of 134 °C was achieved within 1/2 hr. Dry air at a flow rate of 13.4mL/min was used as the vapor carrier. On the second day the final weight was achieved (22.975 g, 79.771% weight retention, 4.826 g oil/water loss).

Experiment 16, Supercritical Fluid Extraction of Heartwood of Tree #10. Ground samples of Cedarwood (199.4 mg and 399.3 mg) were mixed with Celite(306.3 mg and 600.4 mg respectively), covered with Kimwipes, inserted into extraction vials, and placed in the SFE extraction apparatus. The oven temperature was set at 40 °C, the restrictors at 150 °C, and the vials holding sample begun at -2 °C. Extraction was carried

out with CO_2 at 200 atmospheres with a flow rate of 280 mL/min for 2 min followed by CO_2 at 300 atmospheres with a flow rate of 380 mL/min for 10 min. The resulting oil was trapped in ether , the collection vials sealed, and placed in a refrigerator until analysis. The original samples suffered 4.1% and 4.8 % weight loss respectively.

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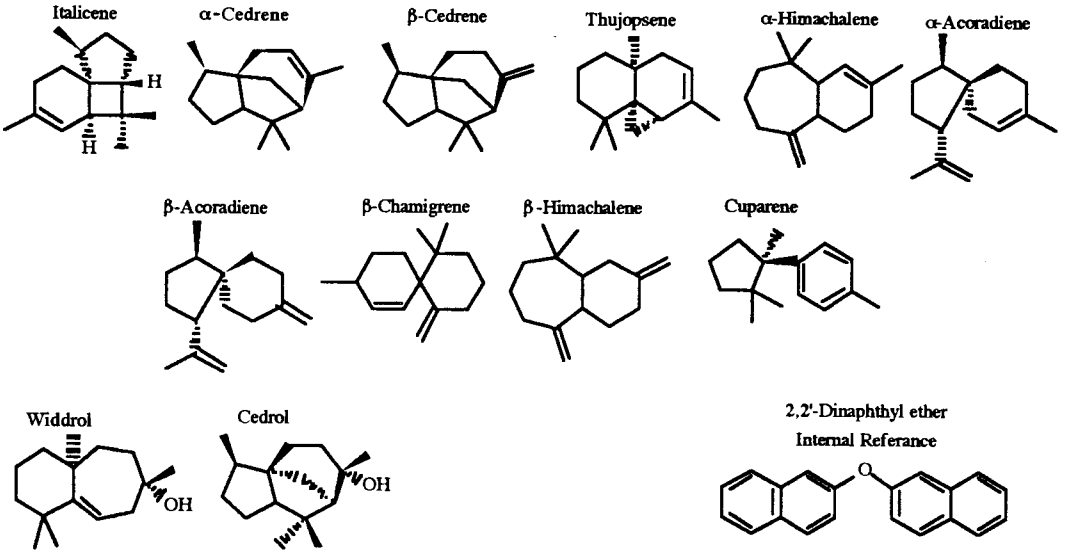
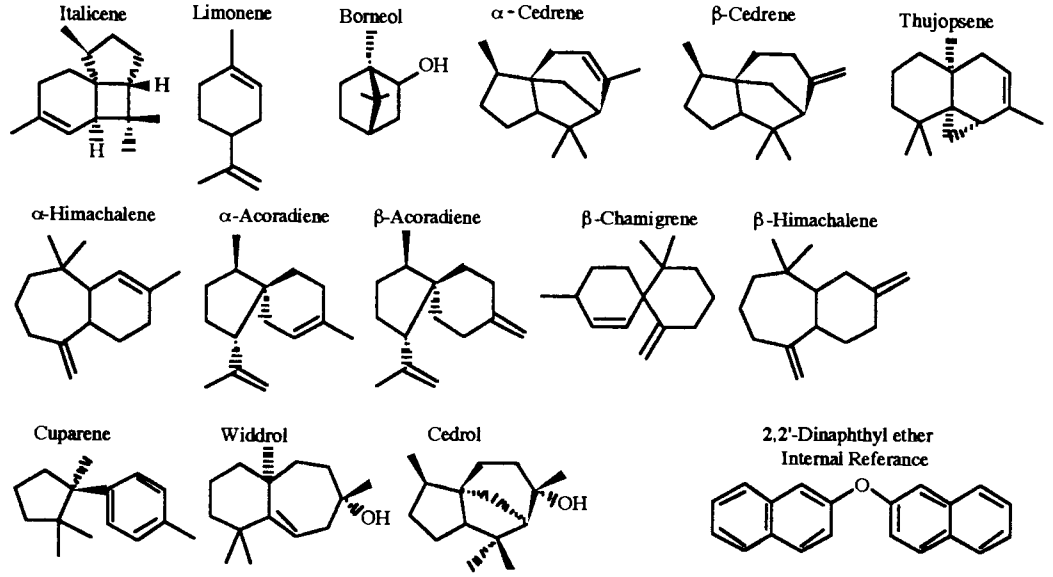
APPENDICES

APPENDIX A. Glossary of Structures

Heartwood Oil Constituents

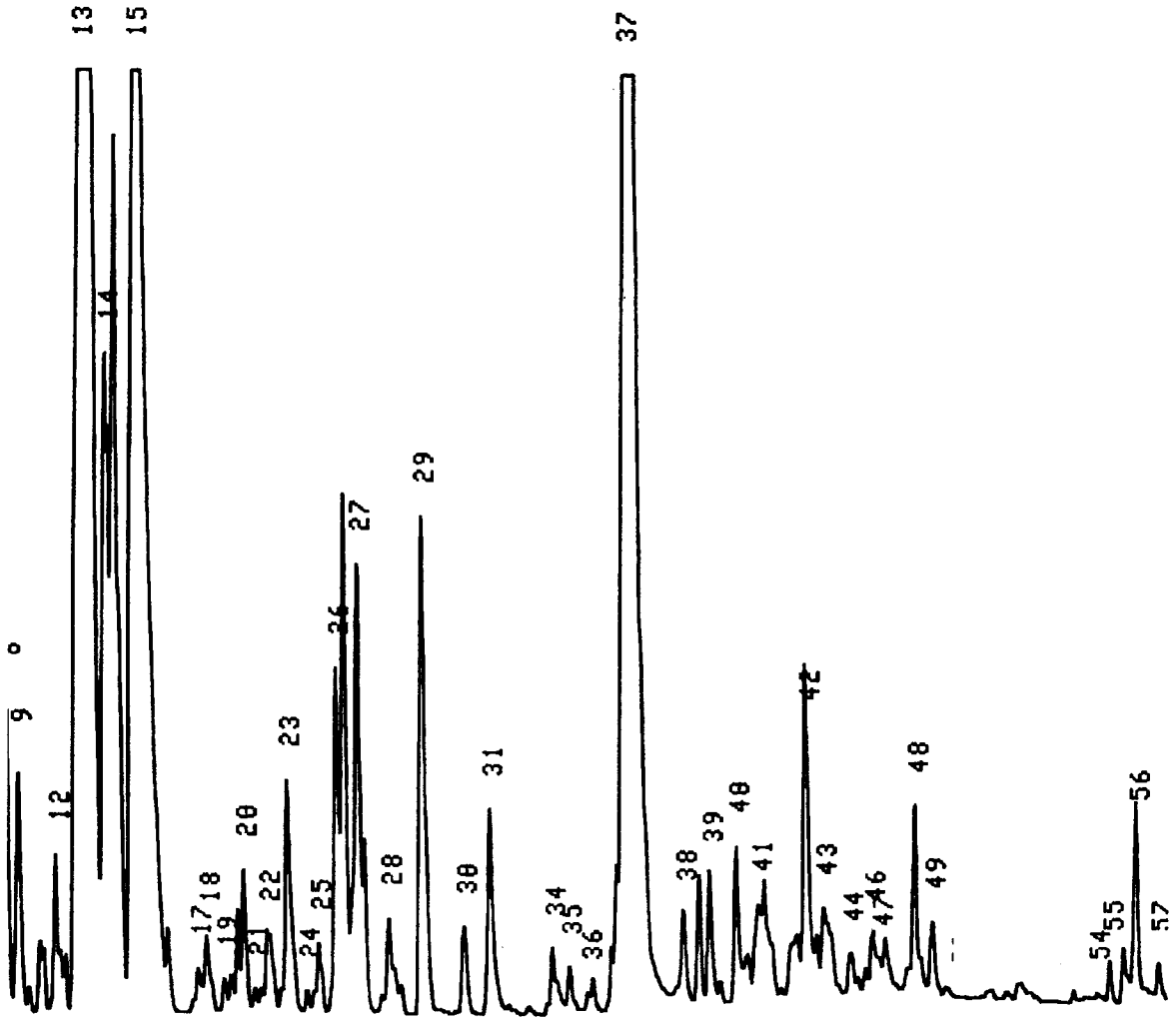


Sapwood Oil Constituents

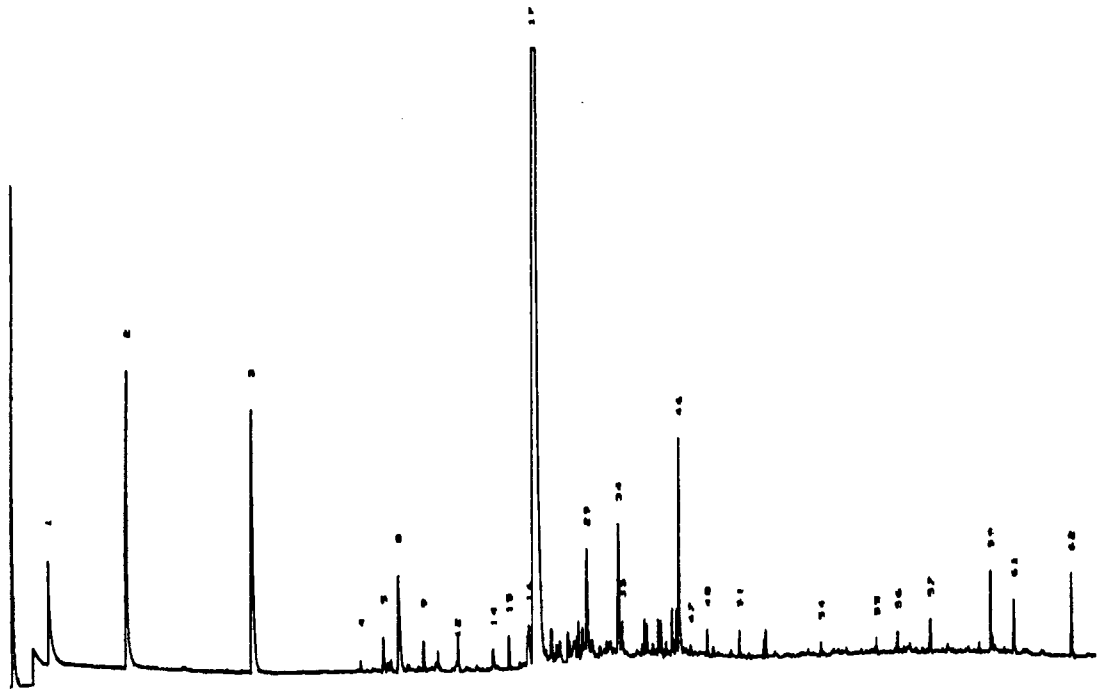


APPENDIX B. SELECTED GAS CHROMATOGRAMS

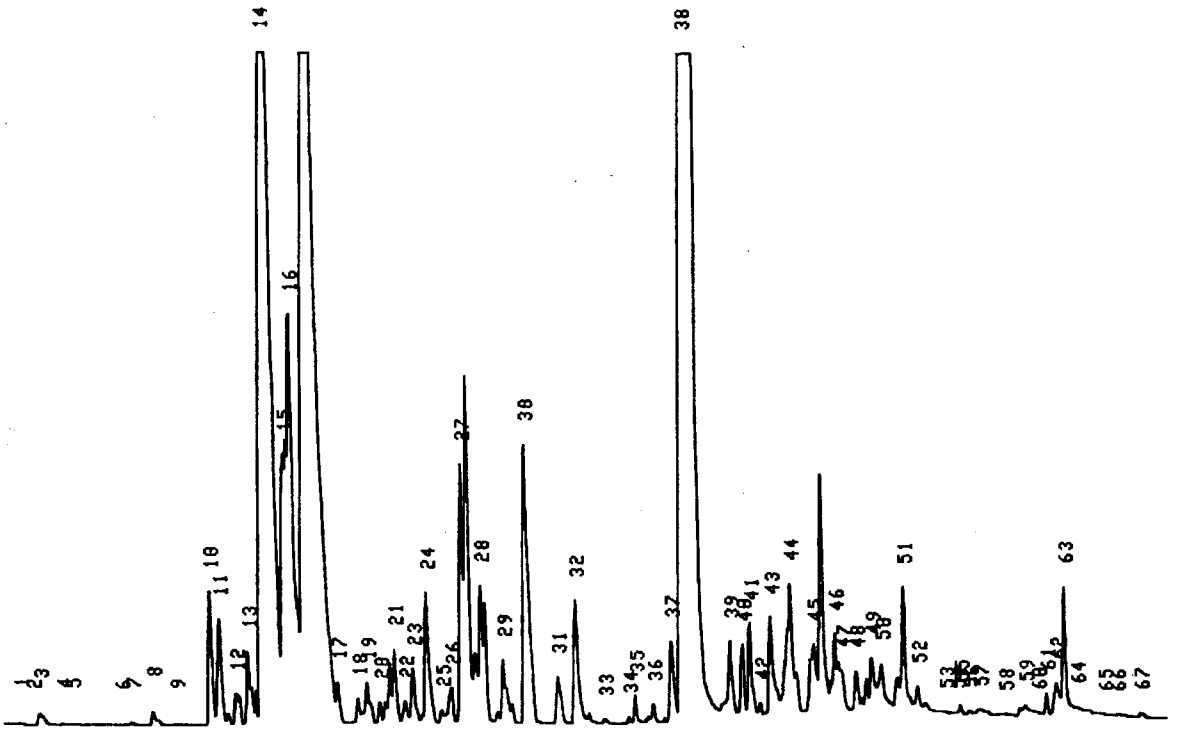
APPENDIX B1. *Juniperus Virginiana* L. heartwood oil gas chromatogram.



APPENDIX B2. *Juniperus Virginiana* L. sapwood oil gas chromatogram.



APPENDIX B3. *Juniperus Virginiana* L. Supercritical Fluid Extracted heartwood oil gas chromatogram.



APPENDIX C. SELECTED GC/MS SPECTRA

APPENDIX C1. Mass Spectra of Italicene from *Juniperus Virginiana* L. oil.

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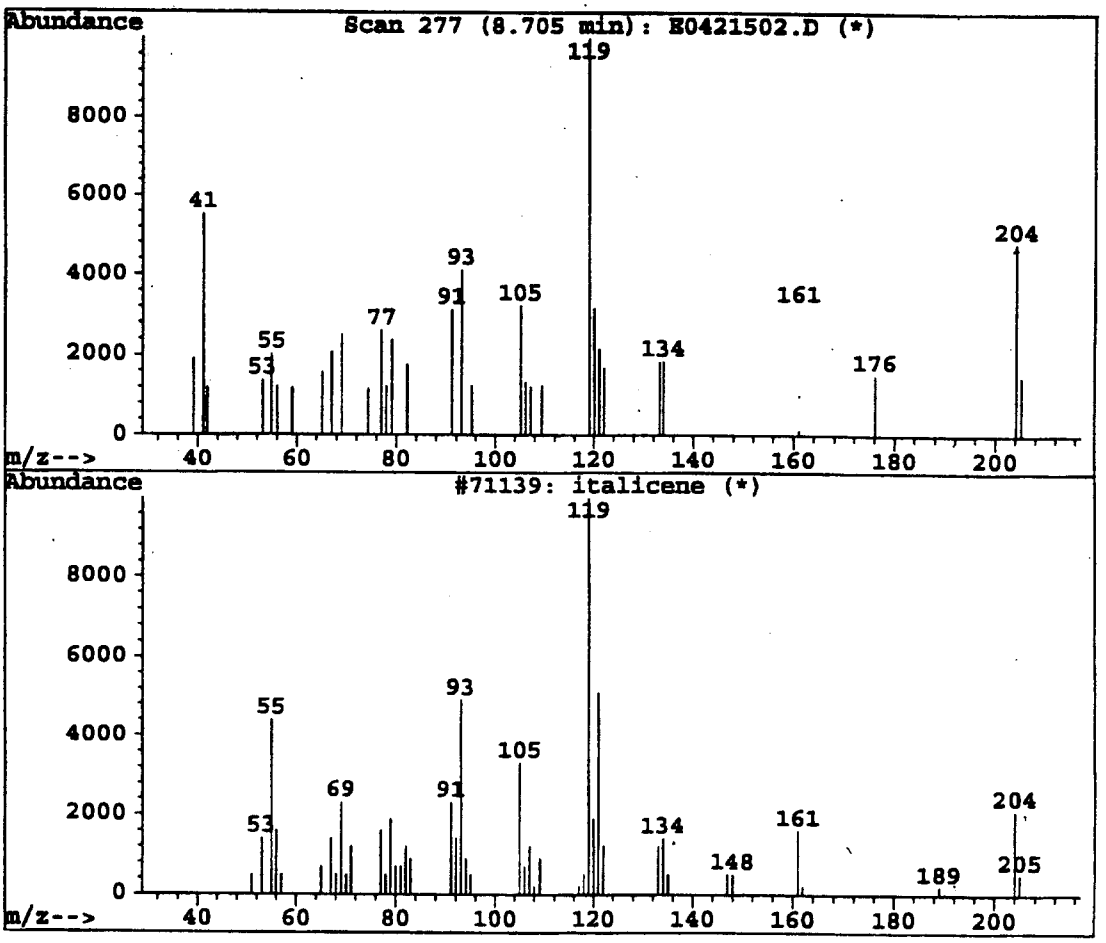
Quality : 90
ID : italicene



APPENDIX C2. Mass Spectra of alpha-longipinene from *Juniperus Virginiana* L. oil.

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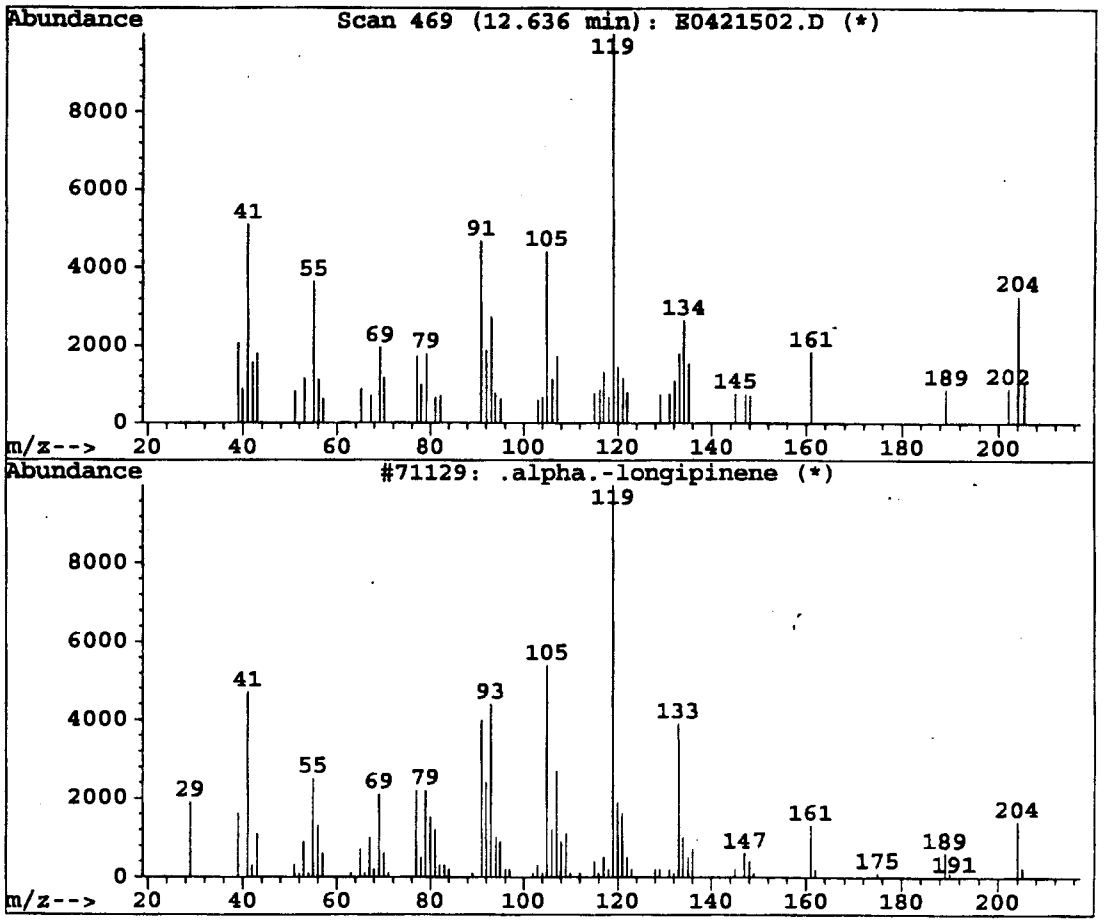
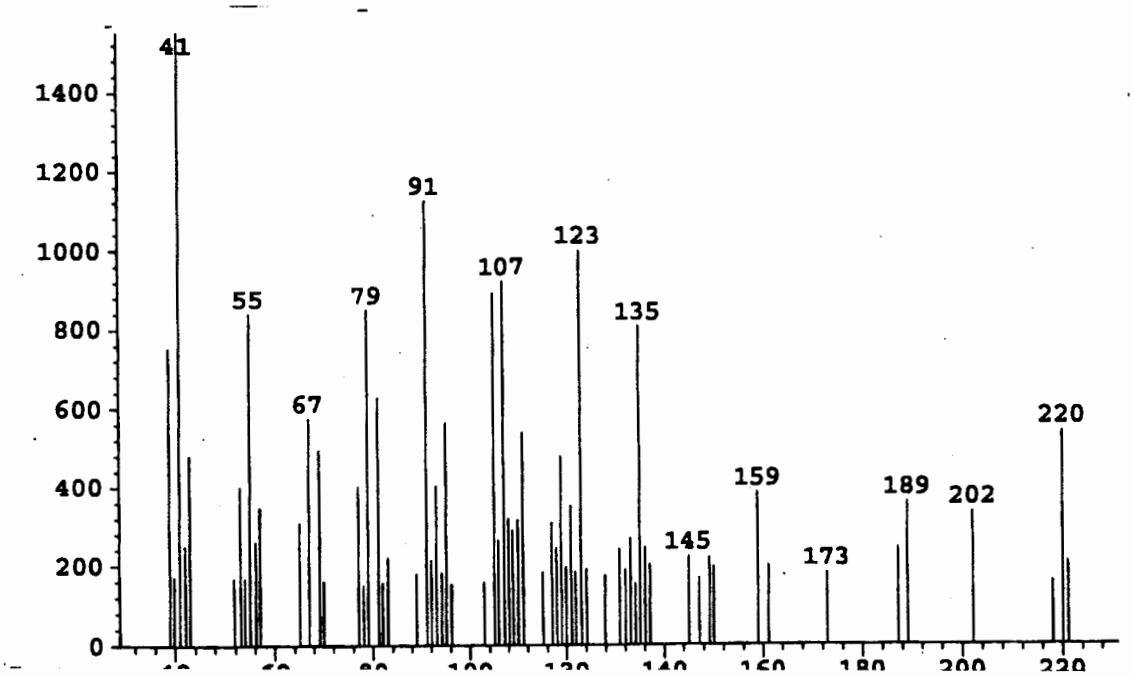
Quality : 92
ID : .alpha.-longipinene



APPENDIX C3. Mass Spectra of Unknown Sesquiterpene alcohol from *Juniperus Virginiana* L. oil.



APPENDIX D. INDIVIDUAL HEARTWOOD OIL YIELDS OF JUNIPERUS VIRGINIANA L. TREES. (All based on 20.00 g sample fresh weight, n=3)

Tree #1 oil yield

mg. of Oil	Yield & Average Deviation		
	Fresh weight	Dried@65 °c	Dried@100 °c
709.79 ± 15.67	3.55 % ± 0.08 %	4.35 % ± 0.10 %	4.40 % ± 0.10 %

Tree #2 oil yield

mg. of Oil	Yield & Average Deviation		
	Fresh weight	Dried@65 °c	Dried@100 °c
580.65 ± 7.37	2.90 % ± 0.04 %	3.45 % ± 0.04 %	3.56 % ± 0.05 %

Tree #3 oil yield

mg. of Oil	Yield & Average Deviation		
	Fresh weight	Dried@65 °c	Dried@100 °c
518.76 ± 4.56	2.59 % ± 0.02 %	3.21 % ± 0.03 %	3.23 % ± 0.03 %

Tree #4 oil yield

mg. of Oil	Yield & Average Deviation		
	Fresh weight	Dried@65 °c	Dried@100 °c
578.04 ± 13.70	2.89 % ± 0.07 %	3.65 % ± 0.08 %	3.57 % ± 0.08 %

Tree #5 oil yield

mg. of Oil	Yield & Average Deviation		
	Fresh weight	Dried@65 °c	Dried@100 °c
211.34 ± 2.91	1.06 % ± 0.01 %	1.28 % ± 0.02 %	1.28 % ± 0.02 %

Tree #5 oven-dried oil yield

mg. of Oil	Yield & Average Deviation
	Dried@100 °c
36.32 ± 1.54	0.182 % ± 0.008 %

Tree #7 first repetition oil yield

mg. of Oil	Yield & Average Deviation		
	Fresh weight	Dried@65 °c	Dried@100 °c
677.88 ± 18.66	3.39 % ± 0.09 %	4.13 % ± 0.11 %	4.26 % ± 0.12 %

Tree #7 second repetition oil yield

mg. of Oil	Yield & Average Deviation		
	Fresh weight	Dried@65 °c	Dried@100 °c
700.25 ± 14.47	3.50 % ± 0.07 %	4.26 % ± 0.09 %	4.40 % ± 0.09 %

Tree #8 oil yield

mg. of Oil	Yield & Average Deviation		
	Fresh weight	Dried@65 °c	Dried@100 °c
574.08 ± 7.34	2.87 % ± 0.04 %	3.40 % ± 0.04 %	3.48 % ± 0.04 %

Tree #9 oil yield

mg. of Oil	Yield & Average Deviation		
	Fresh weight	Dried@65 °c	Dried@100 °c
431.67 ± 23.64	2.16 % ± 0.12 %	2.57 % ± 0.14 %	2.68 % ± 0.15 %

Tree #10 oil yield

mg. of Oil	Yield & Average Deviation		
	Fresh weight	Dried@65 °c	Dried@100 °c
886.9 ± 66.07	4.43 % ± 0.33 %	5.43 % ± 0.40 %	5.48 % ± 0.41%

Tree #10 oven-dried oil yield, 100 °c, N_2, 23.480 g sample

mg. of Oil	Yield & Average Deviation	
	Fresh weight	Dried@100 °c
1074.18 ± 75.31	4.57 % ± 0.32 %	5.65 % ± 0.40 %

Tree #10 oven-dried oil yield, 100 °c, air, 23.772 g sample

mg. of Oil	Yield & Average Deviation	
	Fresh weight	Dried@100 °c
965.16 ± 45.25	4.06 % ± 0.19 %	5.03 % ± 0.24 %

Tree #10 oven-dried oil yield, 134 °c, N_2, 27.025 g sample

mg. of Oil	Yield & Average Deviation	
	Fresh weight	Dried@134 °c
967.63 ± 16.66	3.58 % ± 0.06 %	4.48 % ± 0.08 %

Tree #10 oven-dried oil yield, 134 °c, air, 28.801 g sample

mg. of Oil	Yield & Average Deviation	
	Fresh weight	Dried@134 °c
1357.90 ± 14.27	4.71 % ± 0.05 %	5.91 % ± 0.06 %

Industrial wood chips oven-dried oil yield, 100 °c, N_2, first repetition, 27.071 g sample

mg. of Oil	Yield	
	Fresh weight	Dried@100 °c
152.70 ±	0.564 % ±	0.662 % ±

Industrial wood chips oven-dried oil yield, 100 °c, N_2. second repetition, 24.930 g sample

mg. of Oil	Yield	
	Fresh weight	Dried@100 °c
131.10 ±	0.526 % ±	0.618 % ±

Industrial wood chips steam distilled, 20.000 g sample

mg. of Oil	Yield & Average Deviation		
	Fresh weight	Dried@100 °c	Dried@134 °c
66.5 ± 4.8	0.333 % ± 0.024%	0.391 % ± 0.028 %	0.386 % ± 0.028 %

APPENDIX E. HEARTWOOD OIL CONSTITUENTS AND RELATIVE PERCENTAGES OF INDIVIDUAL *JUNIPERUS VIRGINIANA* L. TREES

In the following appendix, n=3 for all samples. The symbol * indicates that mass spectroscopy was used to confirme the identity of a compound. The symbol ** indicates that the data are missing because of an unresolved or missing peak.

APPENDIX E1. Major constituents, % in sample, and their weight % yield for Tree #1.

Compound	Amount in Oil and Ave. Deviation	Yield and Average Deviation		
		Fresh weight	Dried@65 °c	Dried@100 °c
1 Mass 204	0.428 % ± 0.019 %	0.0152 % ± 0.0010 %	0.0187 % ± 0.0012 %	0.0189 % ± 0.0012 %
Italicene*	0.382 % ± 0.009 %	0.0135 % ± 0.0006 %	0.0166 % ± 0.0007 %	0.0168 % ± 0.0007 %
a-Cedrene*	9.59 % ± 0.39 %	0.341 % ± 0.021 %	0.417 % ± 0.026 %	0.423 % ± 0.026 %
3 Mass 204	0.434 %	0.0158 %	0.0194 %	0.0197 %
b-Cedrene*	3.07 % ± 0.12 %	0.109 % ± 0.005 %	0.133 % ± 0.006 %	0.135 % ± 0.006 %
Thujopsene*	13.7 % ± 0.5 %	0.485 % ± 0.029 %	0.594 % ± 0.036 %	0.602 % ± 0.036 %
b-Chamigrene*	0.991 % ± 0.030 %	0.0352 % ± 0.0018 %	0.0431 % ± 0.0022 %	0.0437 % ± 0.0023 %
a-Selinene*	**			
a-Chamigrene*	1.59 % ± 0.07 %	0.0566 % ± 0.0028 %	0.693 % ± 0.0034 %	0.0702 % ± 0.0035 %
Cuparene*	3.11 % ± 0.11 %	0.111 % ± 0.0006 %	0.135 % ± 0.007 %	0.137 % ± 0.008 %
a-Longipinene	0.580 % ± 0.050 %	0.0206 % ± 0.0019 %	0.0252 % ± 0.0023 %	0.0255 % ± 0.0023 %
Unknown #1	0.112 % ± 0.005 %	0.0082 % ± 0.0057 %	0.0100 % ± 0.0070 %	0.0101 % ± 0.0071 %
Sesquiterpene Alcohol*	0.452 % ± 0.006 %	0.0160 % ± 0.0005 %	0.0196 % ± 0.0006 %	0.0199 % ± 0.0006 %
Unknown #2	0.481 % ± 0.007 %	0.0171 % ± 0.0003 %	0.0209 % ± 0.0004 %	0.0212 % ± 0.0004 %
Widdrol Cedrol*	49.8 % ± 0.9 %	1.76 % ± 0.01 %	2.16 % ± 0.02 %	2.19 % ± 0.02 %
6-Isocedrol	0.517 % ± 0.019 %	0.0183 % ± 0.0004 %	0.0225 % ± 0.0004 %	0.0227 % ± 0.0004 %
Unknown #3	0.354 % ± 0.114 %	0.0126 % ± 0.0043 %	0.0155 % ± 0.0053 %	0.0157 % ± 0.0054 %
Unknown #4	0.222 % ± 0.004 %	0.00775 % ± 0.00002 %	0.00950 % ± 0.00002 %	0.00962 % ± 0.00002 %
Unknown #5	0.637 % ± 0.051 %	0.0226 % ± 0.0014 %	0.0276 % ± 0.0017 %	0.0280 % ± 0.0017 %
Unknown #6	1.00 % ± 0.13 %	0.0355 % ± 0.0046 %	0.0435 % ± 0.0056 %	0.0441 % ± 0.0057 %
1 Mass 220	1.68 % ± 0.40 %	0.0601 % ± 0.016 %	0.0736 % ± 0.019 %	0.0746 % ± 0.019 %
Unknown #7	0.626 % ± 0.23 %	0.0220 % ± 0.0077 %	0.0270 % ± 0.0095 %	0.0273 % ± 0.0096 %
1 Mass 206	0.948 % ± 0.41 %	0.0339 % ± 0.016 %	0.0416 % ± 0.019 %	0.04 21% ± 0.019 %
Unknown # 8	0.797 % ± 0.017 %	0.0279 % ± 0.002 %	0.0341 % ± 0.002 %	0.0345 % ± 0.002 %
Unknown # 9	0.282 % ± 0.072 %	0.0099 % ± 0.0022 %	0.0121 % ± 0.0022 %	0.0122 % ± 0.0022 %
Unknown # 10	1.94 % ± 0.21 %	0.0688 % ± 0.0071 %	0.0844 % ± 0.0087 %	0.0854 % ± 0.0088 %

+ The components in the chart represent 93.04% ± 0.67% of the total oil sample.

APPENDIX E2. Major constituents, % in sample, and their weight % yield for Tree #2.

Compound	Amount in Oil and Ave. Deviation	Yield and Average Deviation		
		Fresh weight	Dried@65 °c	Dried@100 °c
1 Mass 204	0.280 % ± 0.062 %	0.0081 % ± 0.0018 %	0.0097 % ± 0.0022 %	0.0100 % ± 0.0022 %
Italicene*	0.305 % ± 0.003 %	0.0089 % ± 0.0001 %	0. 0105 % ± 0.0001 %	0.0109 % ± 0.0001 %
a-Cedrene*	6.11 % ± 0.64 %	0.178 % ± 0.021 %	0.211 % ± 0.024 %	0.218 % ± 0.025 %
3 Mass 204	0.245 %	0.0697 %	0.0828 %	0.0854 %
b-Cedrene*	0.912 % ± 0.003 %	0.0267 % ± 0.0002 %	0.0318 % ± 0.0003 %	0.327 % ± 0.0003 %
Thujopsene*	9.87 % ± 0.06 %	0.287 % ± 0.002 %	0.341 % ± 0.002 %	0.351 % ± 0.002 %
b-Chamigrene*	0.345 % ± 0.013 %	0.0100 % ± 0.0003 %	0.0119 % ± 0.0003 %	0.0123 % ± 0.0003 %
a-Selinene*	0.555 % ± 0.003 %	0.0161 % ± 0.0003 %	0.0192 % ± 0.0003 %	0.0198 % ± 0.0003 %
a-Chamigrene*	0.404 % ± 0.017 %	0.0117 % ± 0.0004 %	0.0139 % ± 0.0005 %	0.0144 % ± 0.0005 %
Cuparene*	0.805 % ± 0.013 %	0.0234 % ± 0.0005 %	0.0278 % ± 0.0006 %	0.286 % ± 0.0006 %
a-Longipinene	0.748 % ± 0.005 %	0.0217 % ± 0.0002 %	0.0258 % ± 0.0002 %	0.0266 % ± 0.0002 %
Unknown #1	0.133 % ± 0.002 %	0.00386 % ± 0.00001 %	0.0459 % ± 0.00002 %	0.0473 % ± 0.00002 %
Sesquiterpene Alcohol*	0.850 % ± 0.007 %	0.0247 % ± 0.0001 %	0.0293 % ± 0.0002 %	0.0302 % ± 0.0002 %
Unknown #2	1.04 % ± 0.02 %	0.0302 % ± 0.0003 %	0.0359 % ± 0.0004 %	0.0370 % ± 0.0004 %
Widdrol Cedrol*	64.2 % ± 0.2 %	1.87 % ± 0.02 %	2.22 % ± 0.03 %	2.28 % ± 0.03 %
6-Isocedrol	0.670 % ± 0.008 %	0.0194 % ± 0.0002 %	0.0231 % ± 0.0002 %	0.0238 % ± 0.0002 %
Unknown #3	0.220 % ± 0.002 %	0.00638 % ± 0.00005 %	0.00759 % ± 0.00006 %	0.00782 % ± 0.00007 %
Unknown #4	0.359 % ± 0.002 %	0.0104 % ± 0.0001 %	0.0124 % ± 0.0001 %	0.0128 % ± 0.0001 %
Unknown #5	0.387 % ± 0.005 %	0.0112 % ± 0.0001 %	0.0134 % ± 0.0001 %	0.0138 % ± 0.0001 %
Unknown #6	1.53 % ± 0.01 %	0.0445 % ± 0.0003 %	0.0529 % ± 0.0003 %	0.0545 % ± 0.0003 %
1 Mass 220	1.66 % ± 0.02 %	0.0478 % ± 0.0004 %	0.0568 % ± 0.0005 %	0.0586 % ± 0.0005 %
Unknown #7	0.474 % ± 0.004 %	0.0138 % ± 0.0001 %	0.0163 % ± 0.0002 %	0.0169 % ± 0.0002 %
1 Mass 206	0.682 % ± 0.011 %	0.0198 % ± 0.0006 %	0.0236 % ± 0.0007 %	0.0243 % ± 0.0007 %
Unknown #8	0.369 % ± 0.004 %	0.0107 % ± 0.0002 %	0.0127 % ± 0.0002 %	0.0131 % ± 0.0002 %
Unknown #9	**			
Unknown #10	1.25 % ± 0.04 %	0.0362 % ± 0.0016 %	0.0431 % ± 0.0019 %	0.0444 % ± 0.0019 %

+ The components in the chart represent 94.70% ± 0.20% of the total oil sample.

APPENDIX E3. Major constituents, % in sample, and their weight % yield for Tree #3.

Compound	Amount in Oil and Ave. Deviation	Yield and Average Deviation		
		Fresh weight	Dried@65 °c	Dried@100 °c
1 Mass 204	0.157 % ± 0.051 %	0.00407 % ± 0.0013 %	0.00505 % ± 0.0016 %	0.00508 % ± 0.0016 %
Italicene*	0.212 % ± 0.002 %	0.00551 % ± 0.00009 %	0.00684 % ± 0.00011 %	0.00687 % ± 0.00011 %
a-Cedrene*	4.15 % ± 0.02 %	0.108 % ± 0.002 %	0.133 % ± 0.002 %	0.134 % ± 0.002 %
3 Mass 204	0.568 % ± 0.004 %	0.0147 % ± 0.0002 %	0.0183 % ± 0.0003 %	0.0184 % ± 0.0003 %
b-Cedrene*	1.01 % ± 0.01 %	0.0263 % ± 0.0005 %	0.0326 % ± 0.0006 %	0.0328 % ± 0.0006 %
Thujopsene*	10.6 % ± 0.1 %	0.275 % ± 0.003 %	0.341 % ± 0.004 %	0.343 % ± 0.004 %
b-Chamigrene*	0.400 % ± 0.005 %	0.0104 % ± 0.0002 %	0.0129 % ± 0.0003 %	0.0129 % ± 0.0003 %
a-Selinene*	0.226 % ± 0.040 %	0.00587 % ± 0.0011 %	0.00728 % ± 0.0014 %	0.00732 % ± 0.0014 %
a-Chamigrene*	**			
Cuparene*	2.13 % ± 0.01 %	0.055 % ± 0.000 %	0.069 % ± 0.000 %	0.069 % ± 0.000 %
a-Longipinene	0.406 % ± 0.007 %	0.0105 % ± 0.0003 %	0.0130 % ± 0.0003 %	0.0131 % ± 0.0003 %
Unknown #1	0.104 % ± 0.003 %	0.00269 % ± 0.00008 %	0.00334 % ± 0.00010 %	0.00336 % ± 0.00010 %
Sesquiterpene Alcohol*	0.498 % ± 0.012 %	0.0129 % ± 0.0003 %	0.0160 % ± 0.0004 %	0.0161 % ± 0.0004 %
Unknown #2	0.840 % ± 0.008 %	0.0218 % ± 0.0002 %	0.0270 % ± 0.0003 %	0.0272 % ± 0.0003 %
Widdrol Cedrol*	63.2 % ± 0.9 %	1.64 % ± 0.02 %	2.03 % ± 0.02 %	2.05 % ± 0.02 %
6-Isocedrol	0.797 % ± 0.14 %	0.0207 % ± 0.0038 %	0.0257 % ± 0.0048 %	0.0258 % ± 0.0048 %
Unknown #3	0.336 % ± 0.056 %	0.0087 % ± 0.0015 %	0.0108 % ± 0.0019 %	0.0109 % ± 0.0019 %
Unknown #4	0.266 % ± 0.036 %	0.00692 % ± 0.00098 %	0.00858 % ± 0.0012 %	0.00863 % ± 0.00122 %
Unknown #5	0.531 % ± 0.042 %	0.0138 % ± 0.0012 %	0.0171 % ± 0.0015 %	0.0172 % ± 0.0015 %
Unknown #6	1.47 % ± 0.07 %	0.0380 % ± 0.0021 %	0.0472 % ± 0.0026 %	0.0474 % ± 0.0027 %
1 Mass 220	1.52 % ± 0.05 %	0.0395 % ± 0.0017 %	0.0490 % ± 0.0021 %	0.0492 % ± 0.0021 %
Unknown #7	0.489 % ± 0.039 %	0.0127 % ± 0.0011 %	0.0158 % ± 0.0014 %	0.0158 % ± 0.0014 %
1 Mass 206	1.77 % ± 0.02 %	0.0458 % ± 0.0009 %	0.0568 % ± 0.0011 %	0.0571 % ± 0.0011 %
Unknown #8	0.690 % ± 0.049 %	0.0179 % ± 0.0014 %	0.0222 % ± 0.0017 %	0.0223 % ± 0.0018 %
Unknown #9	**			
Unknown #10	2.17 % ± 0.021 %	0.0563 % ± 0.0006 %	0.0699 % ± 0.0008 %	0.0702 % ± 0.0008 %

+ The components in the chart represent 94.56% ± 0.71% of the total oil sample.

APPENDIX E4. Major constituents, % in sample, and their weight %yield for Tree #4.

Compound	Amount in Oil and Ave. Deviation	Yield and Average Deviation		
		Fresh weight	Dried@65 °c	Dried@100 °c
1 Mass 204	0.474 % ± 0.004 %	0.0137 % ± 0.0004 %	0.0167 % ± 0.0005 %	0.0169 % ± 0.0005 %
Italicene*	0.334 % ± 0.001 %	0.0097 % ± 0.0003 %	0.0118 % ± 0.0003 %	0.0119 % ± 0.0003 %
a-Cedrene*	7.21 % ± 0.48 %	0.208 % ± 0.009 %	0.253 % ± 0.012 %	0.257 % ± 0.012 %
3 Mass 204	0.924 %	0.0276 %	0.0336 %	0.0341 %
b-Cedrene*	1.74 % ± 0.22 %	0.0505 % ± 0.0074 %	0.0615 % ± 0.0090 %	0.0624 % ± 0.0092 %
Thujopsene*	6.94 % ± 0.03 %	0.200 % ± 0.005 %	0.244 % ± 0.007 %	0.248 % ± 0.007 %
b-Chamigrene*	0.432 % ± 0.004 %	0.0125 % ± 0.0003 %	0.0152 % ± 0.0003 %	0.0154 % ± 0.0003 %
a-Selinene*	0.688 % ± 0.007 %	0.0199 % ± 0.0005 %	0.0242 % ± 0.0007 %	0.0246 % ± 0.0007 %
a-Chamigrene*	0.649 % 0.020 %	0.0188 % ± 0.0008 %	0.0229 % ± 0.0010 %	0.0232 % ± 0.0010 %
Cuparene*	1.12 % ± 0.02 %	0.0324 % ± 0.0010 %	0.0394 % ± 0.0012 %	0.0400 % ± 0.0012 %
a-Longipinene	0.745 % ± 0.004 %	0.0215 % ± 0.0005 %	0.0262 % ± 0.0006 %	0.0266 % ± 0.0006 %
Unknown #1	0.128 % ± 0.006 %	0.00371 % ± 0.0003 %	0.00452 % ± 0.0003 %	0.00459 % ± 0. 0003 %
Sesquiterpene Alcohol*	0.817 % ± 0.012 %	0.0236 % ± 0.0005 %	0.0287 % ± 0.0007 %	0.0292 % ± 0.0007 %
Unknown #2	0.493 % ± 0.004 %	0.0142 % ± 0.0004 %	0.0173 % ± 0.0005 %	0.0176 % ± 0.0005 %
Widdrol Cedrol*	63.8 % ± 0.3 %	1.84 % ± 0.04 %	2.24 % ± 0.05 %	2.28 % ± 0.05 %
6-Isocedrol	0.566 % ± 0.004 %	0.0164 % ± 0.0004 %	0.0199 % ± 0.0004 %	0.0202 % ± 0.0004 %
Unknown #3	0.610 % ± 0.003 %	0.0176 % ± 0.0005 %	0.0215 % ± 0.0006 %	0.0218 % ± 0.0006 %
Unknown #4	0.476 % ± 0.007 %	0.0137 % ± 0.0002 %	0.0167 % ± 0.0003 %	0.0170 % ± 0.0003 %
Unknown #5	0.478 % ± 0.016 %	0.0138 % ± 0.0005 %	0.0168 % ± 0.0006 %	0.0171 % ± 0.0006 %
Unknown #6	1.24 % ± 0.017 %	0.0358 % ± 0.0010 %	0.0436 % ± 0.0012 %	0.0442 % ± 0.0012 %
1 Mass 220	1.17 % ± 0.017 %	0.0339 % ± 0.0011 %	0.0413 % ± 0.0013 %	0.0419 % ± 0.0013 %
Unknown #7	0.550 % ± 0.009 %	0.0159 % ± 0.0006 %	0.0194 % ± 0.0008 %	0.0197 % ± 0.0008 %
1 Mass 206	0.699 % ± 0.041 %	0.0202 % ± 0.0012 %	0.0246 % ± 0.0015 %	0.0250 % ± 0.0015 %
Unknown #8	0.550 % ± 0.005 %	0.0159 % ± 0.0005 %	0.0194 % ± 0.0006 %	0.0197 % ± 0.0006 %
Unknown #9	**			
Unknown #10	0.744 % ± 0.007 %	0.0215 % ± 0.0006 %	0.0262 % ± 0.0007 %	0.0266 % ± 0.0008 %

+ The components in the chart represent 92.92% ± 0.09% of the total oil sample.

APPENDIX E5.1. Major constituents, % in sample, and their weight % yield for Tree #5.1.

Compound	Amount in Oil and Ave. Deviation	Yield and Average Deviation		
		Fresh weight	Dried@65 °c	Dried@100 °c
1 Mass 204	0.449 % ± 0.002 %	0.0475 % ± 0.00006 %	0.0568 % ± 0.00007 %	0.0573 % ± 0.00007 %
Italicene*	0.338 % ± 0.00 %	0.00357 % ± 0.000 %	0.00427 % ± 0.000 %	0.00431 % ± 0.000 %
a-Cedrene*	9.75 % ± 0.08 %	0.103 % ± 0.0010 %	0.123 % ± 0.0012 %	0.124 % ± 0.0012 %
3 Mass 204	1.10 % ± 0.02 %	0.0116 % ± 0.0003 %	0.0139 % ± 0.0003 %	0.0140 % ± 0.0003 %
b-Cedrene*	2.45 % ± 0.05 %	0.0259 % ± 0.0005 %	0.0310 % ± 0.0006 %	0.0313 % ± 0.0006 %
Thujopsene*	12.4 % ± 0.1 %	0.131 % ± 0.0016 %	0.157 % ± 0.0019 %	0.158 % ± 0.0019 %
b-Chamigrene*	1.16 % ± 0.01 %	0.0122 % ± 0.0001 %	0.0147 % ± 0.0001 %	0.0148 % ± 0.0001 %
a-Selinene*	1.05 % ± 0.01 %	0.0110 % ± 0.0002 %	0.0131 % ± 0.0002 %	0.0132 % ± 0.0002 %
a-Chamigrene*	1.58 % 0.06 %	0.0165 % ± 0.0004 %	0.0197 % ± 0.0005 %	0.0199 % ± 0.0005 %
Cuparene*	1.82 % ± 0.05 %	0.0192 % ± 0.0008 %	0.0230 % ± 0.0010 %	0.0232 % ± 0.0010 %
a-Longipinene	1.14 % ± 0.00 %	0.0120 % ± 0.0002 %	0.0144 % ± 0.0002 %	0.0145 % ± 0.0002 %
Unknown #1	0.186 % ± 0.002 %	0.00196 % ± 0.0001 %	0.00235 % ± 0.0001 %	0.00237 % ± 0. 0001 %
Sesquiterpene Alcohol*	0.639 % ± 0.001 %	0.00675 % ± 0.0001 %	0.00807 % ± 0.0001 %	0.00814 % ± 0.0001 %
Unknown #2	0.426 % ± 0.003 %	0.00451 % ± 0.000 %	0.00539 % ± 0.000 %	0.00544 % ± 0.000 %
Widdrol Cedrol*	50.5 % ± 0.3 %	0.533 % ± 0.010 %	0.638 % ± 0.012 %	0.644 % ± 0.012 %
6-Isocedrol	0.855 % ± 0.005 %	0.0090 % ± 0.0001 %	0.0108 % ± 0.0002 %	0.0109 % ± 0.0002 %
Unknown #3	0.293 % ± 0.002 %	0.00310 % ± 0.0001 %	0.00371 % ± 0.0001 %	0.00374 % ± 0.0001 %
Unknown #4	0.350 % ± 0.002 %	0.00370 % ± 0.0001 %	0.00443 % ± 0.0001 %	0.00446 % ± 0.0001 %
Unknown #5	0.971 % ± 0.003 %	0.0103 % ± 0.0001 %	0.0123 % ± 0.0002 %	0.0124 % ± 0.0002 %
Unknown #6	1.37 % ± 0.00 %	0.0145 % ± 0.0002 %	0.0173 % ± 0.0002 %	0.0175 % ± 0.0002 %
1 Mass 220	1.38 % ± 0.01 %	0.0146 % ± 0.0002 %	0.0175 % ± 0.0002 %	0.0176 % ± 0.0002 %
Unknown #7	0.465 % ± 0.004 %	0.00491 % ± 0.0000 %	0.00588 % ± 0.0000 %	0.00593 % ± 0.0000 %
1 Mass 206	0.857 % ± 0.004 %	0.0090 % ± 0.0001 %	0.0108 % ± 0.0001 %	0.0109 % ± 0.0001 %
Unknown #8	0.938 % ± 0.010 %	0.0099 % ± 0.0000 %	0.0119 % ± 0.0000 %	0.0120 % ± 0.0000 %
Unknown #9	0.376 % ± 0.08 %	0.00397 % ± 0.0009 %	0.00475 % ± 0.0011 %	0.00479 % ± 0.0011 %
Unknown #10	0.949 % ± 0.19 %	0.0100 % ± 0.0020 %	0.0120 % ± 0.0024 %	0.0121 % ± 0.0024 %

+ The components in the chart represent 92.87% ± 1.63% of the total oil sample.

APPENDIX E5.2. Oven-dried major constituents, % in sample, and their weight % yield for Tree #5.

Compound	Amount in Oil and Ave. Deviation	Yield and Ave. Deviation Dried@100 °c
1 Mass 204	**	
Italicene*	**	
a-Cedrene*	6.58 % ± 0.11 %	0.120 % ± 0.0004 %
3 Mass 204	**	
b-Cedrene*	1.80 % ± 0.15 %	0.00328 % ± 0.00041 %
Thujopsene*	1.30 % ± 0.1 %	0.00233 % ± 0.00032 %
b-Chamigrene*	0.841 % ± 0.14 %	0.00154 % ± 0.00032 %
a-Selinene*	0.191 %	0.000326%
a-Chamigrene*	0.881 %	0.00150 %
Cuparene*	1.01 %	0.00171 %
a-Longipinene	0.166 %	0.000282%
Unknown #1	**	
Sesquiterpene Alcohol*	1.06 % ± 0.07 %	0.00193 % ± 0.0001 %
Unknown #2	0.185 % ± 0.014 %	0.000335% ± 0.00003 %
Widdrol Cedrol*	52.4 % ± 0.4 %	0.0953 % ± 0.0038 %
6-Isocedrol	0.497 % ± 0.27 %	0.000929% ± 0.00052 %
Unknown #3	0.674 % ± 0.070 %	0.00122 % ± 0.0001 %
Unknown #4	0.426 % ± 0.17 %	0.000547% ± 0.00041 %
Unknown #5	2.22 % ± 0.30 %	0.00404 % ± 0.00062 %
Unknown #6	2.80 % ± 0.16 %	0.00510 % ± 0.00007 %
1 Mass 220	1.96 % ± 0.31 %	0.0356 % ± 0.00050 %
Unknown #7	3.72 % ± 0.54 %	0.00678 % ± 0.0011 %
1 Mass 206	1.96 % ± 0.28 %	0.0359 % ± 0.00064 %
Unknown #8	4.11 % ± 0.03 %	0.00747 % ± 0.00031 %
Unknown #9	1.15 %	0.00196 %
Unknown #10	3.94 %	0.00670 %

+ The components in the chart represent 85.00% ± 3.92% of the total oil sample.

APPENDIX E7.1. Major constituents, % in sample, and their weight % yield for Tree #7.1.

Compound	Amount in Oil and Ave. Deviation	Yield and Average Deviation		
		Fresh weight	Dried@65 °c	Dried@100 °c
1 Mass 204	0.427 % ± 0.002 %	0.0145 % ± 0.0004 %	0.0176 % ± 0.0005 %	0.0182 % ± 0.0005 %
Italicene*	0.422 % ± 0.00 %	0.0143 % ± 0.0004 %	0.0174 % ± 0.0005 %	0.0180 % ± 0.0005 %
a-Cedrene*	6.99 % ± 1.1 %	0.236 % ± 0.035 %	0.288 % ± 0.043 %	0.298 % ± 0.045 %
3 Mass 204	1.38 %	0.0476 %	0.0579 %	0.0598 %
b-Cedrene*	1.04 %	0.0359 %	0.0437 %	0.0452 %
Thujopsene*	8.26 % ± 0.04 %	0.280 % ± 0.0068 %	0.341 % ± 0.0083 %	0.352 % ± 0.0086 %
b-Chamigrene*	0.347 % ± 0.002 %	0.0118 % ± 0.0004 %	0.0143 % ± 0.0005 %	0.0148 % ± 0.0005 %
a-Selinene*	0.608 % ± 0.002 %	0.0206 % ± 0.0006 %	0.0251 % ± 0.0007 %	0.0259 % ± 0.0008 %
a-Chamigrene*	0.437 % ± 0.014 %	0.0148 % ± 0.0005 %	0.0180 % ± 0.0007 %	0.0186 % ± 0.0007 %
Cuparene*	0.930 % ± 0.008 %	0.0315 % ± 0.0010 %	0.0384 % ± 0.0012 %	0.0397 % ± 0.0013 %
a-Longipinene	0.802 % ± 0.003 %	0.0272 % ± 0.0007 %	0.0331 % ± 0.0009 %	0.0342 % ± 0.0009 %
Unknown #1	0.141 % ± 0.001 %	0.00479 % ± 0.0001 %	0.00583 % ± 0.0002 %	0.00602 % ± 0. 0002 %
Sesquiterpene Alcohol*	0.685 % ± 0.002 %	0.0232 % ± 0.0006 %	0.0282 % ± 0.0007 %	0.0292 % ± 0.0008 %
Unknown #2	0.804 % ± 0.006 %	0.0272 % ± 0.0006 %	0.0332 % ± 0.0008 %	0.0343 % ± 0.0008 %
Widdrol Cedrol*	65.1 % ± 0.1 %	2.21 % ± 0.06 %	2.69 % ± 0.08 %	2.78 % ± 0.08 %
6-Isocedrol	0.779 % ± 0.008 %	0.0264 % ± 0.0007 %	0.0321 % ± 0.0008 %	0.0332 % ± 0.0008 %
Unknown #3	0.203 % ± 0.002 %	0.00688 % ± 0.0001 %	0.00838 % ± 0.0002 %	0.00865 % ± 0.0002 %
Unknown #4	0.307 % ± 0.003 %	0.0104 % ± 0.0002 %	0.0127 % ± 0.0002 %	0.0131 % ± 0.0002 %
Unknown #5	0.389 % ± 0.001 %	0.0132 % ± 0.0004 %	0.0161 % ± 0.0005 %	0.0166 % ± 0.0005 %
Unknown #6	1.52 % ± 0.01 %	0.0515 % ± 0.0012 %	0.0627 % ± 0.0015 %	0.0648 % ± 0.0016 %
1 Mass 220	1.68 % ± 0.01 %	0.0570 % ± 0.0016 %	0.0694 % ± 0.0019 %	0.0717 % ± 0.0020 %
Unknown #7	0.528 % ± 0.006 %	0.0179 % ± 0.0004 %	0.0218 % ± 0.0004 %	0.0225 % ± 0.0004 %
1 Mass 206	0.867 % ± 0.011 %	0.0294 % ± 0.0011 %	0.0358 % ± 0.0013 %	0.0370 % ± 0.0014 %
Unknown #8	0.427 % ± 0.006 %	0.0145 % ± 0.0005 %	0.0176 % ± 0.0006 %	0.0182 % ± 0.0006 %
Unknown #9	0.178 % ± 0.02 %	0.00601 % ± 0.0005 %	0.00732 % ± 0.0006 %	0.00756 % ± 0.0007 %
Unknown #10	1.97 % ± 0.10 %	0.0666 % ± 0.0040 %	0.0811 % ± 0.0049 %	0.0838 % ± 0.0051 %

+ The components in the chart represent 95.64% ± 0.13% of the total oil sample.

APPENDIX E7.2. Major constituents, % in sample, and their weight % yield for Tree #7.2.

Compound	Amount in Oil and Ave. Deviation	Yield and Average Deviation		
		Fresh weight	Dried@65 °c	Dried@100 °c
1 Mass 204	0.216 % ± 0.006 %	0.00757 % ± 0.0004 %	0.00922 % ± 0.0004 %	0.00953 % ± 0.0005 %
Italicene*	0.389 % ± 0.01 %	0.0136 % ± 0.0005 %	0.0166 % ± 0.0006 %	0.0171 % ± 0.0007 %
a-Cedrene*	5.35 % ± 0.72 %	0.188 % ± 0.030 %	0.229 % ± 0.036 %	0.236 % ± 0.037 %
3 Mass 204	2.33 % ± 0.01 %	0.0802 % ± 0.0001 %	0.0976 % ± 0.0002 %	0.101 % ± 0.0002
b-Cedrene*	0.956 %	0.0345 %	0.0420 %	0.0434 %
Thujopsene*	9.11 % ± 0.14 %	0.319 % ± 0.012 %	0.388 % ± 0.014 %	0.401 % ± 0.015 %
b-Chamigrene*	0.313 % ± 0.007 %	0.0109 % ± 0.0004 %	0.0143 % ± 0.0005 %	0.0138 % ± 0.0005 %
a-Selinene*	0.686 % ± 0.010 %	0.0243 % ± 0.0008 %	0.0296 % ± 0.0010 %	0.0305 % ± 0.0010 %
a-Chamigrene*	0.436 % 0.019 %	0.0154 % ± 0.0010 %	±	0.0194 % ± 0.0013 %
Cuparene*	0.807 % ± 0.013 %	0.0283 % ± 0.0006 %	0.0344 % ± 0.0007 %	0.0356 % ± 0.0008 %
a-Longipinene	0.858 % ± 0.007 %	0.0300 % ± 0.0009 %	0.0366 % ± 0.0011 %	0.0378 % ± 0.0011 %
Unknown #1	0.143 % ± 0.002 %	0.00501 % ± 0.0000 %	0.00611 % ± 0.0001 %	0.00631 % ± 0. 0001 %
Sesquiterpene Alcohol*	0.699 % ± 0.005 %	0.0298 % ± 0.0006 %	0.0298 % ± 0.0006 %	0.0308 % ± 0.0006 %
Unknown #2	0.997 % ± 0.005 %	0.0349 % ± 0.0006 %	0.0425 % ± 0.0007 %	0.0439 % ± 0.0007 %
Widdrol Cedrol*	64.6 % ± 0.4 %	2.26 % ± 0.04 %	2.75 % ± 0.05 %	2.84 % ± 0.05 %
6-Isocedrol	0.747 % ± 0.001 %	0.0261 % ± 0.0006 %	0.0318 % ± 0.0007 %	0.0329 % ± 0.0007 %
Unknown #3	0.219 % ± 0.002 %	0.00767 % ± 0.0001 %	0.00934 % ± 0.0001 %	0.00965 % ± 0.0001 %
Unknown #4	0.332 % ± 0.001 %	0.0116 % ± 0.0003 %	0.0142 % ± 0.0003 %	0.0146 % ± 0.0003 %
Unknown #5	0.302 % ± 0.002 %	0.0106 % ± 0.0001 %	0.0129 % ± 0.0002 %	0.0133 % ± 0.0002 %
Unknown #6	1.50 % ± 0.00 %	0.0524 % ± 0.0012 %	0.0639 % ± 0.0015 %	0.0660 % ± 0.0015 %
1 Mass 220	1.76 % ± 0.02 %	0.0616 % ± 0.0009 %	0.0750 % ± 0.0011 %	0.0775 % ± 0.0012 %
Unknown #7	0.476 % ± 0.082 %	0.0167 % ± 0.0031 %	0.0203 % ± 0.0037 %	0.0210 % ± 0.0039 %
1 Mass 206	1.01 % ± 0.01 %	0.0354 % ± 0.0005 %	0.0431 % ± 0.0007 %	0.0445 % ± 0.0007 %
Unknown #8	0.475 % ± 0.008 %	0.0166 % ± 0.0003 %	0.0203 % ± 0.0004 %	0.0209 % ± 0.0004 %
Unknown #9	0.178 % ± 0.01 %	0.00625 % ± 0.0006 %	0.00761 % ± 0.0007 %	0.00786 % ± 0.0007 %
Unknown #10	2.11 % ± 0.11 %	0.0740 % ± 0.0047 %	0.0901 % ± 0.0057 %	0.0931 % ± 0.0059 %

+ The components in the chart represent 95.03% ± 0.90% of the total oil sample.

APPENDIX E8. Major constituents, % in sample, and their weight % yield for Tree #8.

Compound	Amount in Oil and Ave. Deviation	Yield and Average Deviation		
		Fresh weight	Dried@65 °c	Dried@100 °c
1 Mass 204	0.474 % ± 0.003 %	0.0136 % ± 0.0001 %	0.0161 % ± 0.0001 %	0.0165 % ± 0.0001 %
Italicene*	0.412 % ± 0.00 %	0.0118 % ± 0.0000 %	0.0140 % ± 0.0001 %	0.0144 % ± 0.0001 %
a-Cedrene*	6.52 % ± 0.48 %	0.187 % ± 0.012 %	0.222 % ± 0.015 %	0.227 % ± 0.015 %
3 Mass 204	1.40 % ± 0.32 %	0.0406 % ± 0.0096 %	0.0481 % ± 0.011 %	0.0492 % ± 0.012 %
b-Cedrene*	1.82 % ± 0.29 %	0.0521 % ± 0.0079 %	0.0617 % ± 0.0093 %	0.0632 % ± 0.0095 %
Thujopsene*	10.7 % ± 0.0 %	0.306 % ± 0.0028 %	0.363 % ± 0.0034 %	0.371 % ± 0.0034 %
b-Chamigrene*	0.627 % ± 0.004 %	0.0180 % ± 0.0002 %	0.0213 % ± 0.0002 %	0.0218 % ± 0.0002 %
a-Selinene*	1.22 % ± 0.42 %	0.0350 % ± 0.012 %	0.0414 % ± 0.014 %	0.0424 % ± 0.014 %
a-Chamigrene*	0.893 % 0.027 %	0.0257 % ± 0.0012 %	0.0305 % ± 0.0014 %	0.0312 % ± 0.0014 %
Cuparene*	1.45 % ± 0.02 %	0.0416 % ± 0.0004 %	0.0493 % ± 0.0005 %	0.0504 % ± 0.0005 %
a-Longipinene	1.01 % ± 0.01 %	0.0290 % ± 0.0001 %	0.0344 % ± 0.0002 %	0.0352 % ± 0.0002 %
Unknown #1	0.185 % ± 0.003 %	0.00531 % ± 0.0000 %	0.00630 % ± 0.0000 %	0.00644 % ± 0. 0000 %
Sesquiterpene Alcohol*	0.789 % ± 0.002 %	0.0226 % ± 0.0003 %	0.0268 % ± 0.0003 %	0.0275 % ± 0.0003 %
Unknown #2	0.636 % ± 0.001 %	0.0182 % ± 0.0003 %	0.0216 % ± 0.0003 %	0.0221 % ± 0.0003 %
Widdrol Cedrol*	58.0 % ± 0.8 %	1.66 % ± 0.04 %	1.97 % ± 0.04 %	2.02 % ± 0.04 %
6-Isocedrol	0.727 % ± 0.012 %	0.0208 % ± 0.0033 %	0.0247 % ± 0.039 %	0.0253 % ± 0.0040 %
Unknown #3	0.256 % ± 0.052 %	0.00732 % ± 0.0014 %	0.00868 % ± 0.0017 %	0.00888 % ± 0.0017 %
Unknown #4	0.320 % ± 0.037 %	0.0092 % ± 0.0010 %	0.0109 % ± 0.0011 %	0.0111 % ± 0.0012 %
Unknown #5	0.570 % ± 0.043 %	0.0164 % ± 0.0011 %	0.0194 % ± 0.0013 %	0.0198 % ± 0.0013 %
Unknown #6	1.33 % ± 0.08 %	0.0383 % ± 0.0019 %	0.0454 % ± 0.0023 %	0.0464 % ± 0.0023 %
1 Mass 220	1.33 % ± 0.08 %	0.0383 % ± 0.0020 %	0.0454 % ± 0.0023 %	0.0464 % ± 0.0024 %
Unknown #7	0.583 % ± 0.039 %	0.0167 % ± 0.0010 %	0.0198 % ± 0.0012 %	0.0203 % ± 0.0012 %
1 Mass 206	1.06 % ± 0.03 %	0.0303 % ± 0.0007 %	0.0359 % ± 0.0008 %	0.0368 % ± 0.0008 %
Unknown #8	0.875 % ± 0.017 %	0.0251 % ± 0.0005 %	0.0298 % ± 0.0006 %	0.0305 % ± 0.0006 %
Unknown #9	0.327 % ± 0.01 %	0.00939 % ± 0.0002 %	0.0111 % ± 0.0002 %	0.0114 % ± 0.0003 %
Unknown #10	2.04 % ± 0.04 %	0.0586 % ± 0.0008 %	0.0695 % ± 0.0010 %	0.0711 % ± 0.0010 %

+ The components in the chart represent 94.73% ± 0.40% of the total oil sample.

APPENDIX E9. Major constituents, % in sample, and their weight % yield for Tree #9.

Compound	Amount in Oil and Ave. Deviation	Yield and Average Deviation		
		Fresh weight	Dried@65 °c	Dried@100 °c
1 Mass 204	0.308 % ± 0.0015 %	0.00665 % ± 0.0004 %	0.00792 % ± 0.0005 %	0.00827 % ± 0.0005 %
Italicene*	0.430 % ± 0.0015 %	0.00928 % ± 0.0005 %	0.0111 % ± 0.0006 %	0.0115 % ± 0.0007 %
a-Cedrene*	8.63 % ± 0.054 %	0.186 % ± 0.0111 %	0.222 % ± 0.013 %	0.232 % ± 0.014 %
3 Mass 204	**			
b-Cedrene*	2.15 % ± 0.024 %	0.0464 % ± 0.0025 %	0.0553 % ± 0.0029 %	0.0577 % ± 0.0031 %
Thujopsene*	11.4 % ± 0.022 %	0.246 % ± 0.014 %	0.294 % ± 0.017 %	0.306 % ± 0.0017 %
b-Chamigrene*	0.677 % ± 0.0016 %	0.0146 % ± 0.0008 %	0.0174 % ± 0.0009 %	0.0182 % ± 0.0010 %
a-Selinene*	1.02 % ± 0.057 %	0.0227 % ± 0.0025 %	0.0270 % ± 0.0030 %	0.0282 % ± 0.0031 %
a-Chamigrene*	1.26 % 0.15 %	0.0280 % ± 0.0049 %	0.0334 % ± 0.0058 %	0.0349 % ± 0.0060 %
Cuparene*	0.815 % ± 0.13 %	0.0175 % ± 0.0024 %	0.0208 % ± 0.0029 %	0.0217 % ± 0.0030 %
a-Longipinene	1.21 % ± 0.0057 %	0.0260 % ± 0.0015 %	0.0310 % ± 0.0017 %	0.0324 % ± 0.0018 %
Unknown #1	0.169 % ± 0.0050 %	0.00368 % ± 0.0003 %	0.00438 % ± 0.0003 %	0.00457 % ± 0.0004 %
Sesquiterpene Alcohol*	0.579 % ± 0.0071 %	0.0125 % ± 0.0006 %	0.0149 % ± 0.0007 %	0.0155 % ± 0.0008 %
Unknown #2	0.569 % ± 0.026 %	0.0123 % ± 0.0005 %	0.0146 % ± 0.0006 %	0.0152 % ± 0.0006 %
Widdrol Cedrol*	54.4 % ± 0.064 %	1.17 % ± 0.07 %	1.40 % ± 0.08 %	1.46 % ± 0.08 %
6-Isocedrol	0.645 % ± 0.002 %	0.0139 % ± 0.0009 %	0.0166 % ± 0.0009 %	0.0173 % ± 0.0009 %
Unknown #3	0.158 % ± 0.0016 %	0.00340 % ± 0.0002 %	0.00405 % ± 0.0002 %	0.00423 % ± 0.0002 %
Unknown #4	0.223 % ± 0.027 %	0.0048 % ± 0.0004 %	0.0057 % ± 0.0005 %	0.0060 % ± 0.0005 %
Unknown #5	0.922 % ± 0.015 %	0.0199 % ± 0.00094 %	0.0237 % ± 0.0011 %	0.0247 % ± 0.0012 %
Unknown #6	1.58 % ± 0.00 %	0.0340 % ± 0.0019 %	0.0405 % ± 0.0023 %	0.0423 % ± 0.0024 %
1 Mass 220	1.99 % ± 0.18 %	0.0430 % ± 0.0041 %	0.0512 % ± 0.0049 %	0.0534 % ± 0.0051 %
Unknown #7	0.463 % ± 0.0041 %	0.0100 % ± 0.0005 %	0.0119 % ± 0.0006 %	0.0124 % ± 0.0006 %
1 Mass 206	0.481 % ± 0.012 %	0.0104 % ± 0.0006 %	0.0124 % ± 0.0007 %	0.0129 % ± 0.0008 %
Unknown #8	0.375 % ± 0.0033 %	0.0081 % ± 0.0005 %	0.0096 % ± 0.0006 %	0.0101 % ± 0.0006 %
Unknown #9	0.200 % ± 0.038 %	0.00426 % ± 0.0007 %	0.0507 % ± 0.0008 %	0.0529 % ± 0.0008 %
Unknown #10	3.26 % ± 0.10 %	0.0704 % ± 0.0047 %	0.0839 % ± 0.0055 %	0.0876 % ± 0.0058 %

+ The components in the chart represent 93.16% ± 1.65% of the total oil sample.

APPENDIX E10.1. Major constituents, % in sample, and their weight % yield for Tree #10.

Compound	Amount in Oil and Ave. Deviation	Yield and Average Deviation		
		Fresh weight	Dried@65 °c	Dried@100 °c
1 Mass 204	0.247 % ± 0.013 %	0.0110 % ± 0.0014 %	0.0135 % ± 0.0018 %	0.0136 % ± 0.0018 %
Italicene*	0.421 % ± 0.0050 %	0.0187 % ± 0.0012 %	0.0229 % ± 0.0015 %	0.0231 % ± 0.0015 %
a-Cedrene*	7.87 % ± 0.11 %	0.349 % ± 0.026 %	0.427 % ± 0.032 %	0.432 % ± 0.033 %
3 Mass 204	**			
b-Cedrene*	2.51 % ± 0.035 %	0.111 % ± 0.0086 %	0.136 % ± 0.010 %	0.138 % ± 0.011 %
Thujopsene*	9.27 % ± 0.14 %	0.411 % ± 0.032 %	0.503 % ± 0.039 %	0.508 % ± 0.0040 %
b-Chamigrene*	0.608 % ± 0.010 %	0.0270 % ± 0.0018 %	0.0330 % ± 0.0023 %	0.0333 % ± 0.0023 %
a-Selinene*	**			
a-Chamigrene*	**			
Cuparene*	2.61 % ± 0.080 %	0.116 % ± 0.012 %	0.142 % ± 0.015 %	0.143 % ± 0.015 %
a-Longipinene	0.155 % ± 0.084 %	0.00672 % ± 0.0033 %	0.00822 % ± 0.0040 %	0.00830 % ± 0.0041 %
Unknown #1	0.142 % ± 0.043 %	0.00615 % ± 0.0016 %	0.00753 % ± 0.0019 %	0.00761 % ± 0.0019 %
Sesquiterpene Alcohol*	0.746 % ± 0.015 %	0.0331 % ± 0.0022 %	0.0405 % ± 0.0027 %	0.0408 % ± 0.0028 %
Unknown #2	0.294 % ± 0.0024 %	0.0130 % ± 0.0011 %	0.0159 % ± 0.0013 %	0.0161 % ± 0.0013 %
Widdrol Cedrol*	61.3 % ± 0.15 %	2.72 % ± 0.21 %	3.33 % ± 0.25 %	3.36 % ± 0.25 %
6-Isocedrol	0.574 % ± 0.011 %	0.0255 % ± 0.0017 %	0.0312 % ± 0.0021 %	0.0315 % ± 0.0021 %
Unknown #3	**			
Unknown #4	0.656 % ± 0.010 %	0.0291 % ± 0.0019 %	0.0356 % ± 0.0024 %	0.0359 % ± 0.0024 %
Unknown #5	0.922 % ± 0.015 %	0.0199 % ± 0.00094 %	0.0237 % ± 0.0011 %	0.0247 % ± 0.0012 %
Unknown #6	0.825 % ± 0.017 %	0.0365 % ± 0.0024 %	0.0447 % ± 0.0029 %	0.0452 % ± 0.0030 %
1 Mass 220	1.57 % ± 0.021 %	0.0693 % ± 0.0042 %	0.0849 % ± 0.0051 %	0.0857 % ± 0.0052 %
Unknown #7	0.227 % ± 0.0041 %	0.0100 % ± 0.00071 %	0.0123 % ± 0.00087 %	0.0124 % ± 0.00088 %
1 Mass 206	1.40 % ± 0.21 %	0.0627 % ± 0.015 %	0.0767 % ± 0.018 %	0.0775 % ± 0.018 %
Unknown #8	0.410 % ± 0.16 %	0.0176 % ± 0.0060 %	0.0216 % ± 0.0073 %	0.0218 % ± 0.0074 %
Unknown #9	**			
Unknown #10	1.92 % ± 0.016 %	0.0854 % ± 0.0070 %	0.105 % ± 0.0086 %	0.106 % ± 0.0087 %

+ The components in the chart represent 94.43% ± 0.31% of the total oil sample.

APPENDIX E10.2. Major constituents, in sample, and weight % yield; Tree #10 dried in air at 100 °c.

Compound	Amount in Oil and Average Deviation	Yield and Average Deviation	
		Fresh weight	Dried@100 °c
1 Mass 204	0.552 % ± 0.012 %	0.0224 % ± 0.0013 %	0.0278 % ± 0.0016 %
Italicene*	0.522 % ± 0.03 %	0.0212 % ± 0.0018 %	0.0263 % ± 0.0023 %
a-Cedrene*	12.9 % ± 0.2 %	0.524 % ± 0.029 %	0.649 % ± 0.0364 %
3 Mass 204	1.54 % ± 0.39 %	0.0632 % ± 0.018 %	0.0783 % ± 0.023 %
b-Cedrene*	3.01 % ± 0.36 %	0.121 % ± 0.008 %	0.150 % ± 0.010 %
Thujopsene*	16.2 % ± 0.3 %	0.659 % ± 0.038 %	0.816 % ± 0.047 %
b-Chamigrene*	0.625 % ± 0.004 %	0.0254 % ± 0.0013 %	0.0314 % ± 0.0016 %
a-Selinene*	0.716 % ± 0.037 %	0.0291 % ± 0.0025 %	0.0360 % ± 0.031 %
a-Chamigrene*	1.12 % ± 0.01 %	0.0453 % ± 0.0020 %	0.0561 % ± 0.0024 %
Cuparene*	1.44 % ± 0.02 %	0.0585 % ± 0.0034 %	0.0724 % ± 0.0042 %
a-Longipinene	1.37 % ± 0.02 %	0.0557 % ± 0.0025 %	0.0689 % ± 0.0031 %
Unknown #1	0.232 % ± 0.008 %	0.00943 % ± 0.0005 %	0.0117 % ± 0.0006 %
Sesquiterpene Alcohol*	0.554 % ± 0.014 %	0.0225 % ± 0.0014 %	0.0278 % ± 0.0017 %
Unknown #2	**		
Widdrol & Cedrol*	49.2 % ± 0.0 %	2.00 % ± 0.09 %	2.47 % ± 0.012 %
6-Isocedrol	0.215 % ± 0.004 %	0.0871 % ± 0.0005 %	0.0108 % ± 0.0006 %
Unknown #3	0.534 %	0.0227 %	0.0281 %
Unknown #4	0.543 % ± 0.000 %	0.0215 % ± 0.0010 %	0.0266 % ± 0.0013 %
Unknown #5	0.357 % ± 0.010 %	0.0145 % ± 0.0004 %	0.0179 % ± 0.0006 %
Unknown #6	0.817 % ± 0.006 %	0.0332 % ± 0.0014 %	0.0410 % ± 0.0018 %
1 Mass 220	1.08 % ± 0.09 %	0.0433 % ± 0.0011 %	0.0536 % ± 0.0013 %
Unknown #7	0.582 % ± 0.027 %	0.0236 % ± 0.0001 %	0.0292 % ± 0.0001 %
1 Mass 206	0.598 %	0.0248 %	0.0307 %
Unknown #8	0.326 %	0.0135 %	0.0167 %
Unknown #9	**		
Unknown #10	0.688 % ± 0.103 %	0.0279 % ± 0.0047 %	0.0346 % ± 0.0058 %

+ The components in the chart represent 94.16% ± 0.57% of the total oil sample.

APPENDIX E10.3. Major constituents, % in sample, and their weight % yield; Tree #10 dried in nitrogen at 100 °c.

Compound	Amount in Oil and Average Deviation	Yield and Average Deviation	
		Fresh weight	Dried@100 °c
1 Mass 204	0.546 % ± 0.003 %	0.0250 % ± 0.0016 %	0.0309 % ± 0.0020 %
Italicene*	0.504 % ± 0.01 %	0.0230 % ± 0.0014 %	0.0285 % ± 0.0017 %
a-Cedrene*	12.9 % ± 0.0 %	0.590 % ± 0.040 %	0.729 % ± 0.050 %
3 Mass 204	1.49 % ± 0.48 %	0.0671 % ± 0.020 %	0.0830 % ± 0.024 %
b-Cedrene*	3.12 % ± 0.46 %	0.144 % ± 0.028 %	0.177 % ± 0.034 %
Thujopsene*	16.2 % ± 0.1 %	0.740 % ± 0.049 %	0.914 % ± 0.060 %
b-Chamigrene*	0.644 % ± 0.016 %	0.0294 % ± 0.0014 %	0.0363 % ± 0.0017 %
a-Selinene*	1.23 % ± 0.48 %	0.0571 % ± 0.025 %	0.0706 % ± 0.031 %
a-Chamigrene*	1.06 % ± 0.04 %	0.0471 % ± 0.0054 %	0.0583 % ± 0.0067 %
Cuparene*	1.54 % ± 0.02 %	0.0704 % ± 0.0048 %	0.0870 % ± 0.0059 %
a-Longipinene	1.32 % ± 0.00 %	0.0604 % ± 0.0042 %	0.0747 % ± 0.0052 %
Unknown #1	0.231 % ± 0.005 %	0.0106 % ± 0.0008 %	0.0131 % ± 0.0009 %
Sesquiterpene Alcohol*	0.573 % ± 0.006 %	0.0262 % ± 0.0019 %	0.0324 % ± 0.0024 %
Unknown #2	**		
Widdrol & Cedrol*	49.0 % ± 0.2 %	2.24 % ± 0.15 %	2.77 % ± 0.18 %
6-Isocedrol	0.213 % ± 0.008 %	0.00976 % ± 0.0010 %	0.0121 % ± 0.0013 %
Unknown #3	**		
Unknown #4	0.487 % ± 0.004 %	0.0223 % ± 0.0015 %	0.0275 % ± 0.0018 %
Unknown #5	0.340 % ± 0.010 %	0.0156 % ± 0.0015 %	0.0193 % ± 0.0019 %
Unknown #6	0.810 % ± 0.012 %	0.0370 % ± 0.0021 %	0.0457 % ± 0.0026 %
1 Mass 220	1.16 % ± 0.05 %	0.0513 % ± 0.0016 %	0.0634 % ± 0.0019 %
Unknown #7	0.567 % ± 0.023 %	0.0260 % ± 0.0028 %	0.0322 % ± 0.0034 %
1 Mass 206	0.716 % ± 0.17 %	0.0331 % ± 0.0096 %	0.0410 % ± 0.012 %
Unknown #8	0.319 % ± 0.017 %	0.0142 % ± 0.0018 %	0.0175 % ± 0.0023 %
Unknown #9	0.192 %	0.00932 %	0.0115 %
Unknown #10	0.754 % ± 0.074 %	0.0346 % ± 0.0045 %	0.0427 % ± 0.0055 %

+ The components in the chart represent 94.91% ± 0.83% of the total oil sample.

APPENDIX E10.4. Major constituents, % in sample, and their weight % yield; Tree #10 dried in air at 134 °c.

Compound	Amount in Oil and Average Deviation	Yield and Average Deviation	
		Fresh weight	Dried@100 °c
1 Mass 204	0.502 % ± 0.091 %	0.0236 % ± 0.0042 %	0.0296 % ± 0.0052 %
Italicene*	0.638 % ± 0.12 %	0.0301 % ± 0.0060 %	0.0377 % ± 0.0075 %
a-Cedrene*	13.5 % ± 0.2 %	0.638 % ± 0.012 %	0.799 % ± 0.015 %
3 Mass 204	**		
b-Cedrene*	4.86 % ± 0.05 %	0.229 % ± 0.05 %	0.287 % ± 0.005 %
Thujopsene*	16.8 % ± 0.2 %	0.793 % ± 0.014 %	0.994 % ± 0.018 %
b-Chamigrene*	0.795 % ± 0.008 %	0.0375 % ± 0.0006 %	0.0470 % ± 0.0008 %
a-Selinene*	**		
a-Chamigrene*	1.85 % ± 0.03 %	0.0874 % ± 0.0024 %	0.110 % ± 0.0030 %
Cuparene*	1.78 % ± 0.04 %	0.0841 % ± 0.0016 %	0.105 % ± 0.0020 %
a-Longipinene	1.29 % ± 0.01 %	0.0607 % ± 0.0010 %	0.0761 % ± 0.0013 %
Unknown #1	0.269 % ± 0.048 %	0.0127 % ± 0.0023 %	0.0159 % ± 0.0029 %
Sesquiterpene Alcohol*	0.593 % ± 0.007 %	0.0280 % ± 0.0005 %	0.0351 % ± 0.0006 %
Unknown #2	**		
Widdrol & Cedrol*	46.2 % ± 0.1 %	2.18 % ± 0.02 %	2.73 % ± 0.02 %
6-Isocedrol	0.206 % ± 0.003 %	0.00971 % ± 0.00020 %	0.0122 % ± 0.0002 %
Unknown #3	**		
Unknown #4	0.489 % ± 0.005 %	0.0230 % ± 0.0004 %	0.0289 % ± 0.0005 %
Unknown #5	0.408 % ± 0.000 %	0.0192 % ± 0.0002 %	0.0241 % ± 0.0003 %
Unknown #6	0.515 % ± 0.015 %	0.0243 % ± 0.0006 %	0.0304 % ± 0.0007 %
1 Mass 220	0.90 % ± 0.02 %	0.0422 % ± 0.0006 %	0.0530 % ± 0.0008 %
Unknown #7	**		
1 Mass 206	0.869 % ± 0.19 %	0.0409 % ± 0.0087 %	0.0513 % ± 0.011 %
Unknown #8	0.202 % ± 0.10 %	0.00955 % ± 0.0049 %	0.0120 % ± 0.0062 %
Unknown #9	0.183 % ± 0.05 %	0.00861 % ± 0.0025 %	0.0108 % ± 0.0032 %
Unknown #10	0.948 % ± 0.073 %	0.0447 % ± 0.0032 %	0.0560 % ± 0.0040 %

+ The components in the chart represent 94.91% ± 0.83% of the total oil sample.

APPENDIX E10.5. Major constituents, % in sample, and their weight % yield; Tree #10 dried in nitrogen at 134 °c.

Compound	Amount in Oil and Average Deviation	Yield and Average Deviation	
		Fresh weight	Dried@100 °c
1 Mass 204	0.592 % ± 0.038 %	0.0212 % ± 0.0011 %	0.0265 % ± 0.0014 %
Italicene*	0.599 % ± 0.01 %	0.0215 % ± 0.0005 %	0.0268 % ± 0.0006 %
a-Cedrene*	13.4 % ± 0.3 %	0.480 % ± 0.0016 %	0.600 % ± 0.0020 %
3 Mass 204	**		
b-Cedrene*	4.88 % ± 0.10 %	0.174 % ± 0.001 %	0.218 % ± 0.001 %
Thujopsene*	17.2 % ± 0.3 %	0.614 % ± 0.0008 %	0.768 % ± 0.0010 %
b-Chamigrene*	0.775 % ± 0.017 %	0.0278 % ± 0.0010 %	0.0347 % ± 0.0012 %
a-Selinene*	**		
a-Chamigrene*	1.62 % ± 0.03 %	0.0581 % ± 0.0006 %	0.0726 % ± 0.0007 %
Cuparene*	1.86 % ± 0.04 %	0.0666 % ± 0.0022 %	0.0833 % ± 0.0027 %
a-Longipinene	1.23 % ± 0.01 %	0.0439 % ± 0.0008 %	0.0549 % ± 0.0010 %
Unknown #1	0.292 % ± 0.01 %	0.0105 % ± 0.0010 %	0.0131 % ± 0.0013 %
Sesquiterpene Alcohol*	0.582 % ± 0.006 %	0.0208 % ± 0.0006 %	0.0261 % ± 0.0007 %
Unknown #2	**		
Widdrol & Cedrol*	42.2 % ± 0.4 %	1.66 % ± 0.04 %	2.07 % ± 0.05 %
6-Isocedrol	0.208 % ± 0.004 %	0.00744 % ± 0.00027 %	0.00930 % ± 0.00034 %
Unknown #3	**		
Unknown #4	0.485 % ± 0.022 %	0.0174 % ± 0.0010 %	0.0217 % ± 0.0012 %
Unknown #5	0.376 % ± 0.014 %	0.0134 % ± 0.0005 %	0.0168 % ± 0.0006 %
Unknown #6	0.584 % ± 0.12 %	0.0208 % ± 0.0040 %	0.0261 % ± 0.0050 %
1 Mass 220	0.873 % ± 0.019 %	0.0313 % ± 0.0012 %	0.0391 % ± 0.0015 %
Unknown #7	0.449 % ± 0.006 %	0.0161 % ± 0.0003 %	0.0201 % ± 0.0004 %
1 Mass 206	0.835 % ± 0.16 %	0.0299 % ± 0.0059 %	0.0374 % ± 0.0073 %
Unknown #8	0.267 % ± 0.082 %	0.0070 % ± 0.0029 %	0.0087 % ± 0.0037 %
Unknown #9	0.160 % ± 0.03 %	0.00596 % ± 0.0015 %	0.0746 % ± 0.0018 %
Unknown #10	0.647 % ± 0.12 %	0.0232 % ± 0.0044 %	0.0291 % ± 0.0055 %

+ The components in the chart represent 94.91% ± 0.83% of the total oil sample.

APPENDIX E11.1. Major constituents, % in sample, and their weight % yield for steam distilled industrial wood chips.

Compound	Amount in Oil and Ave. Deviation	Yield and Average Deviation		
		Fresh weight	Dried@65 °c	Dried@100 °c
1 Mass 204	0.125 % ± 0.039 %	0.000410 % ± 0.00013 %	0.000482 % ± 0.00015 %	0.000476 % ± 0.00015 %
Italicene*	0.108 % ± 0.0016 %	0.000360 % ± 0.00003 %	0.000423 % ± 0.00004 %	0.000418 % ± 0.00004 %
a-Cedrene*	0.99 % ± 0.027 %	0.00330 % ± 0.00029 %	0.00387 % ± 0.00034 %	0.000383 % ± 0.00033 %
3 Mass 204	**			
b-Cedrene*	0.408 % ± 0.017 %	0.00135 % ± 0.00009 %	0.00159 % ± 0.00011 %	0.00157 % ± 0.00011 %
Thujopsene*	1.13 % ± 0.027 %	0.00375 % ± 0.00026 %	0.00440 % ± 0.00030 %	0.00435 % ± 0.00030 %
b-Chamigrene*	0.163 % ± 0.0057 %	0.000541 % ± 0.00003 %	0.000635 % ± 0.00003 %	0.000627 % ± 0.00003 %
a-Selinene*	**			
a-Chamigrene*	**			
Cuparene*	0.856 % ± 0.019 %	0.00285 % ± 0.00027 %	0.00335 % ± 0.00032 %	0.00331 % ± 0.00031 %
a-Longipinene	0.214 % ± 0.053 %	0.000710 % ± 0.00018 %	0.000834 % ± 0.00021 %	0.000824 % ± 0.00021 %
Unknown #1	0.0962 % ± 0.014 %	0.000319 % ± 0.00005 %	0.000375 % ± 0.00005 %	0.000370 % ± 0.00005 %
Sesquiterpene Alcohol*	0.974 % ± 0.023 %	0.00324 % ± 0.00028 %	0.00381 % ± 0.00032 %	0.00376 % ± 0.00032 %
Unknown #2	0.233 % ± 0.0039 %	0.000776 % ± 0.00006 %	0.000911 % ± 0.00007 %	0.000900 % ± 0.00007 %
Widdrol Cedrol*	68.2 % ± 1.0 %	0.227 % ± 0.020 %	0.267 % ± 0.023 %	0.263 % ± 0.023 %
6-Isocedrol	0.656 % ± 0.016 %	0.00218 % ± 0.00013 %	0.00256 % ± 0.00016 %	0.00253 % ± 0.00015 %
Unknown #3	0.437 %	0.00161 %	0.00189 %	0.00187 %
Unknown #4	0.984 % ± 0.021 %	0.00327 % ± 0.00027 %	0.00384 % ± 0.00032 %	0.00380 % ± 0.00031 %
Unknown #5	0.596 % ± 0.030 %	0.00188 % ± 0.0017 %	0.00221 % ± 0.00020 %	0.00218 % ± 0.00020 %
Unknown #6	0.966 % ± 0.090 %	0.00318 % ± 0.00009 %	0.00374 % ± 0.00011 %	0.00369 % ± 0.00010 %
1 Mass 220	3.32 % ± 0.79 %	0.0112 % ± 0.0032 %	0.0132 % ± 0.0038 %	0.0130 % ± 0.0037 %
Unknown #7	1.04 %	0.00312 %	0.00367 %	0.00362 %
1 Mass 206	4.11 %	0.0124 %	0.0145 %	0.0144 %
Unknown #8	4.18 % ± 0.21 %	0.0145 % ± 0.00013 %	0.0170 % ± 0.00016 %	0.0168 % ± 0.00016 %
Unknown #9	0.932 % ± 0.17 %	0.00318 % ± 0.00089 %	0.00373 % ± 0.0010 %	0.00369 % ± 0.0010 %
Unknown #10	2.67 % ± 0.32 %	0.00884 % ± 0.0010 %	0.0104 % ± 0.0012 %	0.0103 % ± 0.0011 %

+ The components in the chart represent 87.73% ± 1.07% of the total oil sample.

APPENDIX E11.2. Major constituents , their %, and average deviation in sample for Advanced Phytonics® extract of industrial wood chips.

Compound	Amount in Oil	Compound	Amount in Oil
1 Mass 204	0.200 % ± 0.032 %	Widdrol/Cedrol*	54.5 % ± 2.1 %
Italicene*	0.406 % ± 0.018 %	Unknown #2	**
a-Cedrene*	5.70 % ± 0.31 %	6-Isocedrol	1.31 % ± 0.59 %
3 Mass 204	**	Unknown #3	0.954 %
b-Cedrene*	1.94 % ± 0.10 %	Unknown #4	0.607 %
Thujopsene*	6.24 % ± 0.35 %	Unknown #5	0.682 % ± 0.036 %
b-Chamigrene*	0.404 % ± 0.008 %	Unknown #6	1.26 % ± 0.09 %
a-Selinene*	0.441 % ± 0.003 %	1 Mass 220	1.82 % ± 0.06 %
a-Chamigrene*	1.04 %	Unknown #7	0.393 % ± 0.59 %
Cuparene*	2.26 % ± 0.20 %	1 Mass 206	1.83 % ± 0.76 %
a-Longipinene	0.567 % ± 0.043 %	Unknown #8	1.52 % ± 0.02 %
Unknown #1	0.264 % ± 0.071 %	Unknown #9	0.66 % ± 0.11 %
Sesquiterpene Alcohol*	0.936 % ± 0.032 %	Unknown #10	1.76 % ± 0.30 %

+ The components in the chart represent 85.21% ± 3.23% of the total oil sample.

APPENDIX E11.3. Major constituents , their %, and average deviation in sample for plant processed industrial wood chips.

Compound	Amount in Oil	Compound	Amount in Oil
1 Mass 204	0.436 % ± 0.014 %	Unknown #2	**
Italicene*	0.277 % ± 0.003 %	Widdrol/Cedrol*	39.4 % ± 0.3 %
a-Cedrene*	13.3 % ± 0.9 %	6-Isocedrol	0.437 % ± 0.002 %
3 Mass 204	1.77 %	Unknown #3	0.526 % ± 0.004 %
b-Cedrene*	3.32 % ± 0.01 %	Unknown #4	**
Thujopsene*	22.7 % ± 0.2 %	Unknown #5	0.277 % ± 0.002 %
b-Chamigrene*	1.33 % ± 0.01 %	Unknown #6	0.504 % ± 0.003 %
a-Selinene*	**	1 Mass 220	1.08 % ± 0.05 %
a-Chamigrene*	3.03 % ± 0.02 %	Unknown #7	0.181 % ± 0.004 %
Cuparene*	2.63 % ± 0.03 %	1 Mass 206	0.340 % ± 0.080 %
a-Longipinene	1.94 % ± 0.00 %	Unknown #8	0.117 % ± 0.035 %
Unknown #1	0.330 % ± 0.045 %	Unknown #9	**
Sesquiterpene Alcohol*	0.605 % ± 0.009 %	Unknown #10	0.184 % ± 0.022 %

+ The components in the chart represent 91.88% ± 2.76% of the total oil sample.

APPENDIX E11.4. Major constituents, % in sample, and their weight % yield for 100 °c, nitrogen atmosphere ovendried industrial wood chips; repetition one.

Compound	Amount in Oil and Av. Deviation	Yield and Average Deviation Fresh weight	Dried@100 °c
1 Mass 204	0.173 % ± 0.027 %	0.00097 % ± 0.00015 %	0.00114 % ± 0.00018 %
Italicene*	0.273 % ± 0.045 %	0.00154 % ± 0.00025 %	0.00181 % ± 0.00030 %
a-Cedrene*	3.81 % ± 0.05 %	0.0215 % ± 0.0003 %	0.0253 % ± 0.0003 %
3 Mass 204	**		
b-Cedrene*	1.83 % ± 0.03 %	0.0103 % ± 0.0002 %	0.0121 % ± 0.0002 %
Thujopsene*	5.43 % ± 0.12 %	0.0306 % ± 0.0007 %	0.0359 % ± 0.0008 %
b-Chamigren*	0.471 % ± 0.097 %	0.00266 % ± 0.00055 %	0.00312 % ± 0.00064 %
a-Selinene*	0.251 % ± 0.007 %	0.00141 % ± 0.00004 %	0.00166 % ± 0.00005 %
a-Chamigren*	**		
Cuparene*	2.49 % ± 0.04 %	0.0140 % ± 0.0002 %	0.0165 % ± 0.0002 %
a-Longipinene	0.409 % ± 0.037 %	0.00231 % ± 0.00021 %	0.00271 % ± 0.00024 %
Unknown #1	0.256 % ± 0.027 %	0.00144 % ± 0.00015 %	0.00169 % ± 0.00018 %
Sesquiterpene Alcohol*	0.756 % ± 0.016 %	0.00426 % ± 0.00009 %	0.00500 % ± 0.00011 %
Unknown #2	**		
Widdrol Cedrol*	67.2 % ± 0.3 %	0.379 % ± 0.002 %	0.445 % ± 0.002 %
6-Isocedrol	0.341 % ± 0.009 %	0.00192 % ± 0.00005 %	0.00226 % ± 0.00006 %
Unknown #3	0.427 % ± 0.18 %	0.00241 % ± 0.00010 %	0.00282 % ± 0.00012 %
Unknown #4	0.491 % ± 0.12 %	0.00277 % ± 0.00069 %	0.00325 % ± 0.00080 %
Unknown #5	0.387 % ± 0.002 %	0.00218 % ± 0.00001 %	0.00256 % ± 0.00001 %
Unknown #6	0.711 % ± 0.004 %	0.00401 % ± 0.00002 %	0.00471 % ± 0.00002 %
1 Mass 220	1.14 % ± 0.41 %	0.00645 % ± 0.0023 %	0.00757 % ± 0.0027 %
Unknown #7	1.23 % ± 0.57 %	0.0070 % ± 0.0032 %	0.0082 % ± 0.0038 %
1 Mass 206	2.66 % ± 0.05 %	0.0150 % ± 0.0003 %	0.0176 % ± 0.0003 %
Unknown #8	**		
Unknown #9	**		
Unknown #10	1.78 % ± 0.12 %	0.0100 % ± 0.0007 %	0.0118 % ± 0.0008 %

+ The components in the chart represent 90.29% ± 2.41% of the total oil sample.

APPENDIX E11.5. Major constituents, % in sample, and their weight % yield for 100 °c, nitrogen atmosphere ovendried industrial wood chips; repetition two.

Compound	Amount in Oil and Av. Deviation	Yield and Average Deviation Fresh weight	Dried@100 °c
1 Mass 204	0.143 % ± 0.021 %	0.000754 % ± 0.00011 %	0.000886 % ± 0.00013 %
Italicene*	0.293 % ± 0.010 %	0.00154 % ± 0.00005 %	0.00181 % ± 0.00006 %
a-Cedrene*	4.05 % ± 0.05 %	0.0213 % ± 0.0003 %	0.0250 % ± 0.0003 %
3 Mass 204	**		
b-Cedrene*	1.83 % ± 0.03 %	0.0096 % ± 0.0001 %	0.0113 % ± 0.0002 %
Thujopsene*	4.96 % ± 0.08 %	0.0261 % ± 0.0004 %	0.0306 % ± 0.0005 %
b-Chamigren*	0.507 % ± 0.095 %	0.00267 % ± 0.00050 %	0.00313 % ± 0.00058 %
a-Selinene*	0.342 % ± 0.004 %	0.00180 % ± 0.00002 %	0.00211 % ± 0.00002 %
a-Chamigren*	**		
Cuparene*	2.31 % ± 0.04 %	0.0122 % ± 0.0002 %	0.0143 % ± 0.0002 %
a-Longipinene	0.604 % ± 0.13 %	0.00318 % ± 0.00069 %	0.00373 % ± 0.00081 %
Unknown #1	0.247 % ± 0.040 %	0.00130 % ± 0.00021 %	0.00153 % ± 0.00025 %
Sesquiterpene Alcohol*	0.737 % ± 0.022 %	0.00388 % ± 0.00012 %	0.00456 % ± 0.00014 %
Unknown #2	**		
Widdrol Cedrol*	66.8 % ± 0.5 %	0.352 % ± 0.003 %	0.413 % ± 0.003 %
6-Isocedrol	0.359 % ± 0.007 %	0.00182 % ± 0.00004 %	0.00222 % ± 0.00004 %
Unknown #3	0.500 % ± 0.16 %	0.00263 % ± 0.00086 %	0.00309 % ± 0.00010 %
Unknown #4	0.373 %	0.00196 %	0.00231 %
Unknown #5	0.398 % ± 0.006 %	0.00209 % ± 0.00003 %	0.00246 % ± 0.00004 %
Unknown #6	0.790 % ± 0.13 %	0.00415 % ± 0.00070 %	0.00488 % ± 0.00082 %
1 Mass 220	1.33 % ± 0.61 %	0.0070 % ± 0.0032 %	0.0082 % ± 0.0038 %
Unknown #7	0.397 %	0.00209 %	0.00245 %
1 Mass 206	2.10 % ± 0.54 %	0.0110 % ± 0.0028 %	0.0130 % ± 0.0033 %
Unknown #8	1.25 %	0.00657 %	0.00772 %
Unknown #9	0.474 %	0.00249 %	0.00293 %
Unknown #10	1.62 % ± 0.11 %	0.00854 % ± 0.00060 %	0.0100 % ± 0.00070 %

+ The components in the chart represent 91.00% ± 1.97% of the total oil sample.

APPENDIX F. SAPWOOD OIL YIELD OF INDIVIDUAL *JUNIPERUS VIRGINIANA* L. TREES. For all samples n=3.

Sapwood of tree #1 Milligrams of oil obtained from a 20.00g sample and overall yield

mg. of Oil	Yield and Average Deviation		
	Fresh weight	Dried@65 °c	Dried@100 °c
33.7 ± 0.0030	0.169 % ± 0.000015 %	0.362 % ± 0.000032 %	0.380 % ± 0.000034 %

APPENDIX G. SAPWOOD OIL CONSTITUENTS AND THEIR RELATIVE PERCENTAGES OF INDIVIDUAL *JUNIPERUS VIRGINIANA* L. TREES.

APPENDIX G1. Major constituents+, % in sample, and their weight % yield for Tree #1.

Compound	Amount in Oil and Ave Deviation	Yield and Average Deviation		
		Fresh weight	Dried@65 °c	Dried@100 °c
Limonene	1.69 % ± 0.043 %	0.00284 % ± 0.00007 %	0.00610 % ± 0.00016 %	0.00640 % ± 0.00016 %
Unknown #1s	4.53 % ± 0.17 %	0.00764 % ± 0.00029 %	0.0164 % ± 0.00062 %	0.0172 % ± 0.00065 %
l-Borneol	4.60 % ± 0.11 %	0.00776 % ± 0.00018 %	0.0167 % ± 0.00040 %	0.0175 % ± 0.00042 %
a-Cedrene*	0.357 % ± 0.0031 %	0.000603 % ± 0.00000 %	0.00129 % ± 0.00001 %	0.00136 % ± 0.00001 %
3 Mass 204	0.0957 % ± 0.012 %	0.000161 % ± 0.00002 %	0.000346 % ± 0.00005 %	0.000363 % ± 0.00005 %
b-Cedrene*	0.100 % ± 0.013 %	0.000169 % ± 0.00002 %	0.000362 % ± 0.00005 %	0.000380 % ± 0.00005 %
Thujopsene*	1.59 % ± 0.013 %	0.00267 % ± 0.00002 %	0.00574 % ± 0.00004 %	0.00602 % ± 0.00004 %
b-Chamigrene*	0.112 % ± 0.010 %	0.000188 % ± 0.00002 %	0.000404 % ± 0.00004 %	0.000424 % ± 0.00004 %
a-Chamigrene*	0.0823 % ± 0.00082 %	0.000139 % ± 0.00000 %	0.000298 % ± 0.00000 %	0.000312 % ± 0.00000 %
Cuparene*	0.342 % ± 0.0083 %	0.000576 % ± 0.00001 %	0.00124 % ± 0.00003 %	0.00130 % ± 0.00003 %
Sesquiterpene	**			
Unknown #1	**			
Sesquiterpene Alcohol*	0.200 % ± 0.0023 %	0.000336 % ± 0.00000 %	0.000722 % ± 0.00001 %	0.000758 % ± 0.00001 %
Unknown #2	0.741 % ± 0.20 %	0.00125 % ± 0.00034 %	0.00268 % ± 0.00073 %	0.00281 % ± 0.00076 %
Widdrol Cedrol*	71.1 % ± 0.32 %	0.120 % ± 0.00052 %	0.257 % ± 0.0011 %	0.270 % ± 0.0012 %
6-Isocedrol	0.399 % ± 0.014 %	0.000673 % ± 0.00002 %	0.00144 % ± 0.00005 %	0.00151 % ± 0.00005 %
Unknown #3	0.155 % ± 0.015 %	0.000261 % ± 0.00003 %	0.000559 % ± 0.00005 %	0.000587 % ± 0.00006 %
Unknown #4	0.323 % ± 0.018 %	0.000545 % ± 0.00003 %	0.00117 % ± 0.00007 %	0.00123 % ± 0.00007 %
Unknown #5	**			
Unknown #6	0.415 % ± 0.077 %	0.000699 % ± 0.00013 %	0.00150 % ± 0.00028 %	0.00157 % ± 0.00029 %
1 Mass 220	1.22 % ± 0.017 %	0.00206 % ± 0.00003 %	0.00442 % ± 0.00006 %	0.00463 % ± 0.00006 %
Unknown #7	0.269 % ± 0.0078 %	0.000454 % ± 0.00001 %	0.000974 % ± 0.00003 %	0.00102 % ± 0.00003 %
1 Mass 206	1.43 % ± 0.011 %	0.00241 % ± 0.00002 %	0.00518 % ± 0.00004 %	0.00543 % ± 0.00004 %
Unknown #8	0.335 % ± 0.0091 %	0.000565 % ± 0.00001 %	0.00121 % ± 0.00003 %	0.00127 % ± 0.00003 %
Unknown #9	0.389 % ± 0.010 %	0.000657 % ± 0.00002 %	0.00141 % ± 0.00004 %	0.00148 % ± 0.00004 %
Unknown #10	1.87 % ± 0.018 %	0.00315 % ± 0.00003 %	0.00677 % ± 0.00005 %	0.00710 % ± 0.00005 %

+ The components in the chart represent 92.30% ± 0.38% of the total oil sample.
* Mass spectroscopy confirmed the identity of these compounds.
** Unresolved or missing peak.

APPENDIX H. INDIVIDUAL *JUNIPERUS VIRGINIANA* L. TREE DATA

Appendix H1. Individual Tree Data[1]

Tree number	Age in years	Stand density	DBH (cm)	Crown dia. (m)	Crown length (m)
1	70	Closed	23.62	4.36	6.25

Date of Harvest	Tree height (m)	Ht at 3" top (m)	Basal area(M^2)	Tree green wt (kg)	Tree dry wt (kg)
12/7/93	11.00	8.66	0.044	357.84	205.01

Live br& Fo green wt (kg)	Live br& Fo dry wt (kg)	Foliage green wt (kg)	Foliage dry wt (kg)	br1/4" to 1" green wt (kg)	br1/4" to 1" dry wt (kg)
122.4	60.97	68.54	28.86	20.81	11.49

br> 1" green wt (kg)	br> 1" dry wt (kg)	Dead br green wt (kg)	Dead br green wt (kg)	Bolewood green wt (kg)	Bolewood dry wt (kg)
33.05	20.62	51.95	43.22	183.49	100.82

Heartwood green wt (kg)	Heartwood dry wt (kg)	Sapwood green wt (kg)	Sapwood dry wt (kg)	Bark green wt (kg)	Bark dry wt (kg)
80.74	54.90	85.69	40.96	8.26	4.96

Soil type	Collection area co				
Stephenville -Darnell	Payne				

[1]Information provided by Russel Wayne Lykins, MS thesis Estimation of Aboveground Eastern Redcedar Biomass, OSU 1995

Appendix H2. Individual Tree Data[1]

Tree number	Age in years	Stand density	DBH (cm)	Crown dia. (m)	Crown length (m)
2	32	Open	23.37	7.50	9.24

Date of Harvest	Tree height (m)	Ht at 3" top (m)	Basal area(M^2)	Tree green wt (kg)	Tree dry wt (kg)
4/7/94	9.24	7.41	0.043	678.00	362.42

Live br& Fo green wt (kg)	Live br& Fo dry wt (kg)	Foliage green wt (kg)	Foliage dry wt (kg)	br1/4" to 1" green wt (kg)	br1/4" to 1" dry wt (kg)
48.13	29.83	21.95	12.73	17.33	11.20

br> 1" green wt (kg)	br> 1" dry wt (kg)	Dead br green wt (kg)	Dead br green wt (kg)	Bolewood green wt (kg)	Bolewood dry wt (kg)
8.85	5.90	6.42	5.33	69.02	39.42

Heartwood green wt (kg)	Heartwood dry wt (kg)	Sapwood green wt (kg)	Sapwood dry wt (kg)	Bark green wt (kg)	Bark dry wt (kg)
24.43	18.18	40.86	18.55	3.73	2.69

Soil type	Collection area co				
Nobscot-Pratt	Woodward				

[1]Information provided by Russel Wayne Lykins, MS thesis Estimation of Aboveground Eastern Redcedar Biomass, OSU 1995

Appendix H3. Individual Tree Data[1]

Tree number	Age in years	Stand density	DBH (cm)	Crown dia. (m)	Crown length (m)
3	31	Open	19.33	6.80	6.84

Date of Harvest	Tree height (m)	Ht at 3" top (m)	Basal area(M^2)	Tree green wt (kg)	Tree dry wt (kg)
5/17/94	6.84	4.10	0.029	482.05	274.62

Live br& Fo green wt (kg)	Live br& Fo dry wt (kg)	Foliage green wt (kg)	Foliage dry wt (kg)	br1/4" to 1" green wt (kg)	br1/4" to 1" dry wt (kg)
401.72	227.12	180.37	103.17	88.78	49.45

br> 1" green wt (kg)	br> 1" dry wt (kg)	Dead br green wt (kg)	Dead br green wt (kg)	Bolewood green wt (kg)	Bolewood dry wt (kg)
132.57	74.50	1.00	0.78	79.33	46.72

Heartwood green wt (kg)	Heartwood dry wt (kg)	Sapwood green wt (kg)	Sapwood dry wt (kg)	Bark green wt (kg)	Bark dry wt (kg)
31.42	24.00	42.84	19.49	5.08	3.23

Soil type	Collection area co				
Nobscot-Pratt	Woodward				

[1]Information provided by Russel Wayne Lykins, MS thesis Estimation of Aboveground Eastern Redcedar Biomass, OSU 1995

Appendix H4. Individual Tree Data[1]

Tree number	Age in years	Stand density	DBH (cm)	Crown dia. (m)	Crown length (m)
4	61	Open	45.47	10.67	10.59

Date of Harvest	Tree height (m)	Ht at 3" top (m)	Basal area(M^2)	Tree green wt (kg)	Tree dry wt (kg)
6/1/94	10.59	7.76	0.162	1740.21	1006.33

Live br& Fo green wt (kg)	Live br& Fo dry wt (kg)	Foliage green wt (kg)	Foliage dry wt (kg)	br1/4" to 1" green wt (kg)	br1/4" to 1" dry wt (kg)
1189.18	690.33	388.86	217.76	129.62	76.86

br> 1" green wt (kg)	br> 1" dry wt (kg)	Dead br green wt (kg)	Dead br green wt (kg)	Bolewood green wt (kg)	Bolewood dry wt (kg)
670.70	395.71	27.62	24.53	523.41	291.47

Heartwood green wt (kg)	Heartwood dry wt (kg)	Sapwood green wt (kg)	Sapwood dry wt (kg)	Bark green wt (kg)	Bark dry wt (kg)
195.23	120.62	297.82	120.62	30.36	19.16

Soil type	Collection area co				
Nobscot-Pratt	Woodward				

[1]Information provided by Russel Wayne Lykins, MS thesis Estimation of Aboveground Eastern Redcedar Biomass, OSU 1995

Appendix H5. Individual Tree Data[1]

Tree number	Age in years	Stand density	DBH (cm)	Crown dia. (m)	Crown length (m)
5	45	Closed	16.64	4.34	6.55

Date of Harvest	Tree height (m)	Ht at 3" top (m)	Basal area(M^2)	Tree green wt (kg)	Tree dry wt (kg)
6/2/94	8.32	5.62	0.022	123.57	74.58

Live br& Fo green wt (kg)	Live br& Fo dry wt (kg)	Foliage green wt (kg)	Foliage dry wt (kg)	br1/4" to 1" green wt (kg)	br1/4" to 1" dry wt (kg)
48.13	29.83	21.95	12.73	17.33	11.20

br> 1" green wt (kg)	br> 1" dry wt (kg)	Dead br green wt (kg)	Dead br green wt (kg)	Bolewood green wt (kg)	Bolewood dry wt (kg)
8.85	5.90	6.42	5.33	69.02	39.42

Heartwood green wt (kg)	Heartwood dry wt (kg)	Sapwood green wt (kg)	Sapwood dry wt (kg)	Bark green wt (kg)	Bark dry wt (kg)
24.43	18.18	40.86	18.55	3.73	2.69

Soil type	Collection area co				
Nobscot-Pratt	Woodward				

[1]Information provided by Russel Wayne Lykins, MS thesis Estimation of Aboveground Eastern Redcedar Biomass, OSU 1995

Appendix H7. Individual Tree Data[1]

Tree number	Age in years	Stand density	DBH (cm)	Crown dia. (m)	Crown length (m)
7	63	Closed	33.48	5.43	8.90

Date of Harvest	Tree height (m)	Ht at 3" top (m)	Basal area(M^2)	Tree green wt (kg)	Tree dry wt (kg)
6/23/94	14.51	11.80	0.088	651.43	390.68

Live br& Fo green wt (kg)	Live br& Fo dry wt (kg)	Foliage green wt (kg)	Foliage dry wt (kg)	br1/4" to 1" green wt (kg)	br1/4" to 1" dry wt (kg)
196.53	111.02	74.88	42.76	36.55	21.71

br> 1" green wt (kg)	br> 1" dry wt (kg)	Dead br green wt (kg)	Dead br green wt (kg)	Bolewood green wt (kg)	Bolewood dry wt (kg)
85.10	46.55	37.08	34.34	417.82	245.32

Heartwood green wt (kg)	Heartwood dry wt (kg)	Sapwood green wt (kg)	Sapwood dry wt (kg)	Bark green wt (kg)	Bark dry wt (kg)
189.69	143.22	211.42	92.39	16.71	9.71

Soil type	Collection area co				
Dougherty-Eufaula	Kingfisher				

[1]Information provided by Russel Wayne Lykins, MS thesis Estimation of Aboveground Eastern Redcedar Biomass, OSU 1995

Appendix H8. Individual Tree Data[1]

Tree number	Age in years	Stand density	DBH (cm)	Crown dia. (m)	Crown length (m)
8	47	Open	28.07	7.28	8.60

Date of Harvest	Tree height (m)	Ht at 3" top (m)	Basal area(M^2)	Tree green wt (kg)	Tree dry wt (kg)
7/14/94	8.60	6.19	0.062	938.86	510.61

Live br& Fo green wt (kg)	Live br& Fo dry wt (kg)	Foliage green wt (kg)	Foliage dry wt (kg)	br1/4" to 1" green wt (kg)	br1/4" to 1" dry wt (kg)
720.32	395.64	384.65	213.48	112.37	61.80

br> 1" green wt (kg)	br> 1" dry wt (kg)	Dead br green wt (kg)	Dead br green wt (kg)	Bolewood green wt (kg)	Bolewood dry wt (kg)
223.30	120.36	1.67	1.48	216.87	113.49

Heartwood green wt (kg)	Heartwood dry wt (kg)	Sapwood green wt (kg)	Sapwood dry wt (kg)	Bark green wt (kg)	Bark dry wt (kg)
59.64	44.13	146.39	61.92	10.84	7.44

Soil type	Collection area co				
Dougherty-Eufaula	Kingfisher				

[1]Information provided by Russel Wayne Lykins, MS thesis Estimation of Aboveground Eastern Redcedar Biomass, OSU 1995

Appendix H9. Individual Tree Data[1]

Tree number	Age in years	Stand density	DBH (cm)	Crown dia. (m)	Crown length (m)
9	52	Closed	13.34	2.51	2.99

Date of Harvest	Tree height (m)	Ht at 3" top (m)	Basal area(M^2)	Tree green wt (kg)	Tree dry wt (kg)
7/19/94	8.56	5.61	0.014	71.86	42.78

Live br& Fo green wt (kg)	Live br& Fo dry wt (kg)	Foliage green wt (kg)	Foliage dry wt (kg)	br1/4" to 1" green wt (kg)	br1/4" to 1" dry wt (kg)
17.03	9.78	9.13	5.25	6.74	3.85

br> 1" green wt (kg)	br> 1" dry wt (kg)	Dead br green wt (kg)	Dead br green wt (kg)	Bolewood green wt (kg)	Bolewood dry wt (kg)
1.16	0.68	6.38	5.74	48.45	27.26

Heartwood green wt (kg)	Heartwood dry wt (kg)	Sapwood green wt (kg)	Sapwood dry wt (kg)	Bark green wt (kg)	Bark dry wt (kg)
21.95	15.89	23.84	10.23	2.66	1.14

Soil type	Collection area co				
Dougherty-Eufaula	Kingfisher				

[1]Information provided by Russel Wayne Lykins, MS thesis Estimation of Aboveground Eastern Redcedar Biomass, OSU 1995

Appendix H10. Individual Tree Data[1]

Tree number	Age in years	Stand density	DBH (cm)	Crown dia. (m)	Crown length (m)
10	82	Closed	37.34	6.64	9.02

Date of Harvest	Tree height (m)	Ht at 3" top (m)	Basal area(M^2)	Tree green wt (kg)	Tree dry wt (kg)
8/3/94	18.04	14.78	0.110	923.69	603.61

Live br& Fo green wt (kg)	Live br& Fo dry wt (kg)	Foliage green wt (kg)	Foliage dry wt (kg)	br1/4" to 1" green wt (kg)	br1/4" to 1" dry wt (kg)
249.79	153.03	104.41	59.72	55.95	36.26

br> 1" green wt (kg)	br> 1" dry wt (kg)	Dead br green wt (kg)	Dead br green wt (kg)	Bolewood green wt (kg)	Bolewood dry wt (kg)
89.42	57.05	76.14	67.38	597.76	383.2

Heartwood green wt (kg)	Heartwood dry wt (kg)	Sapwood green wt (kg)	Sapwood dry wt (kg)	Bark green wt (kg)	Bark dry wt (kg)
346.70	255.87	209.22	96.66	41.81	30.67

Soil type	Collection area co				
Quinlan-Woodward	Dewey				

[1]Information provided by Russel Wayne Lykins, MS thesis Estimation of Aboveground Eastern Redcedar Biomass, OSU 1995

VITA

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