SPECIFIC GRAVITY AND PER CENT SUMMERWOOD VARIATION IN A YOUNG DOUGLAS-FIR CLONE AND USE OF UNIFORMITY TRIAL IN PREDICTING SPECIFIC GRAVITY FROM INCREMENT CORES

by

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Dear Mac:

Please accept my sincerest apologies for not making the necessary corrections on my thesis any sooner. I am presently on vacation and have decided this matter cannot be put off any longer.

The three specific questions raised, and my answers, are as follows:

1. Page 26, conclusion 2. It was questioned whether the experimental techniques used could accurately measure specific gravity of segments of borings. I feel this conclusion was substantiated by my discussion of Mitchell's and Smith's work on these techniques at the U.S.F.P.L.
2. Page 37, Table 5. The column headed "Years" should be corrected to "trees".
3. Page 43, Table 1. There are definitely errors in this table. Fortunately for me, but still inexcusable on my part, the error is in the first column of saturated weight values. You will find the corrected values in my copy of the thesis. I am also enclosing my notebook to illustrate how the errors occurred. The saturated weights on page 8 of the notebook are the ones I used for Table No. 1, page 43 of the thesis. As can be seen in the notebook, these are in random specimen order. The transposition of these saturated weights to the table on page 12 of the notebook were in proper order, or by specimen number. Therefore, the specific gravity values in the notebook, pages 12 and 13, and in the thesis are correct.
4. I have also noted one other correction on page 46 of the thesis.

Again, I want to apologize for not taking care of this sooner. If anything else has to be done or corrected please let me know. Thank you for your patience.

Respectfully yours,

Dave Strauss

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SPECIFIC GRAVITY AND PER CENT SUMMERWOOD VARIATION IN A YOUNG DOUGLAS-FIR CLONE AND USE OF UNIFORMITY TRIAL IN PREDICTING SPECIFIC GRAVITY FROM INCREMENT CORES

INTRODUCTION

Forest genetics has received considerable impetus in tree improvement programs within the last decade. Improvement of wood quality may be achieved by silvicultural and genetic manipulations of forest resources. Silvicultural practices such as thinning and pruning may increase rate of growth and per cent clear lumber, but there might be limits to these methods of tree improvement. It appears possible to achieve further tree improvement through genetic manipulations and selection of superior trees as parent stock. One criterion for selection of elite or plus trees might be desirable growth characteristics such as disease and drought resistance, rate of growth, form, and seed production. Another criterion could be wood quality characteristics essential to the ultimate wood product. This thesis is concerned with the latter criterion of wood quality and its hereditary control.

Improvement of the forest resources by genetic manipulations must be preceded by well-defined objectives based on the needs of the forest products industry and a knowledge of hereditary control of wood quality. Lumber, plywood, and paper interests must know the qualities and properties of wood best suited for their needs, and forest geneticists must know how and to what extent wood properties may be controlled by heredity.

The objective of this study was to determine the variation of specific gravity and per cent summerwood in a young Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) clone. A clone is a group of trees vegetatively propagated from the same parent. Such material was selected for this study because, theoretically, any variation of specific gravity and per cent summerwood due to heredity should be eliminated. A secondary objective was to test the validity of the intended experimental technique and sample size by conducting a uniformity trial.

Research on wood quality, and the degree of its hereditary control, has been limited in the past due to the unavailability of experimental material. Many clones and progeny planted and destined to serve as experimental material for genetic-wood quality research have not attained suitable age for experimentation. Predictions of hereditary control on wood quality based on experiments conducted on very young trees may not be valid for the same trees at maturity. Physical properties of wood are affected by age and environment, and any evaluation of hereditary control on wood quality should consider these variables.

Tree improvement methods are analogous to methods used to improve farm crops. Farm crops are improved, to a limited degree, by crop rotation and the use of fertilizers. Further development is made through evolving hybrids and strains. Agriculturists are at an advantage in that the results of their work can be obtained annually or bi-annually since they are dealing with primary tissues in plants as opposed to secondary tissue or xylem with which the forest geneticist must deal.

A major contribution to wood-quality research has been the development of tools and techniques of analysis. These are presented under the next topic in this thesis.

WOOD QUALITY

There are many commercial species of wood potentially susceptible to improvement by genetic manipulations. The following discussion is presented with particular reference to Douglas-fir and other related coniferous species.

Wood quality can be defined as the presence or absence of those properties essential for the best use of a particular end product. Mitchell (10, p. 2) includes the economic concept in his definition of a high-quality tree when he states:

> A high-quality tree could be defined as one with a high proportion of its net volume in wood suitable for conversion into the higher grades of the more valuable end products and in sufficient quantity ordinarily to justify its economical harvest for such products.

Any approach to wood quality evaluation should consider the relationship of wood properties to desirable characteristics of the end product and the economics of procuring raw material for these products.

The relationship between properties and use characteristics originates with the minute anatomy of wood. The anatomical structure of wood, with particular reference to longitudinal cell elements which comprise 70 - 90 per cent of the total, has a direct bearing on properties and, consequently, on quality. Physical arrangement and chemical composition of molecules in fibers[1] influence per cent summerwood, cell wall thickness, fibril angle, fiber length and width,

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1. Fibers may be defined as a general term applied to fibrous-like, longitudinal cell elements in wood, i.e. tracheids in conifers, vessel and fiber elements in hardwoods.

and other anatomical features. These factors in turn affect or determine properties of wood such as density, strength, wood-moisture relationship, and thermal conductivity. A more thorough discussion is not intended here other than to state that properties can be traced to the minute anatomy of wood.

Each product of wood has certain desirable use characteristics which are dependent upon anatomical features and physical properties. An essential characteristic of kraft paper is high tear strength which improves with an increase in percentage of summerwood, or thick-walled fibers. Thin-walled fibers produce a dense pulp sheet low in opacity, with high burst and tensile strength. The quality of wood to be used for these two types of paper would depend upon quantity and quality of the fibers with respect to cell walls.

Orientation of fibrils affects wood quality. Fibrils are chain-like bundles of cellulose molecules in the secondary cell wall. The orientation of these bundles with respect to the axis of longitudinal fibers has an effect on strength and dimensional stability properties of wood. Wood in which the fibers have large fibril angles (nearly perpendicular to the longitudinal axis) is lower in bending strength and shrinks more in the longitudinal direction than wood characterized by fibers with small fibril angles.

Penetrability is believed to be affected by the size of the lumen or cell cavity and number and condition of cell wall pits. Pits are minute passageways or openings in the cell wall through which most liquids and dissolved matter move throughout the wood.

The quality of wood to be treated with preservatives or pulped with chemical liquors will, in part, be dependent upon these minute cell wall structures.

Genetic improvement of wood should be directed toward basic properties and anatomical features. In order to do this it is first necessary to investigate how and to what degree these properties and features may be genetically controlled.

Indexes and Measurement of Wood Quality

It is not practical to examine or evaluate all the basic properties of a particular species of wood in order to determine their transmissibility or heritability. This problem has been circumvented by general acceptance of specific gravity, per cent summerwood, and fibril angle as the major indexes of wood quality. Additional quality characteristics which aid in the evaluation of wood when used in conjunction with the above indexes are growth rate, age, fiber length and thickness, uniformity of growth, extractive content, and amount of reaction wood.

It is desirable to take samples without appreciable damage to standing trees when evaluating quality characteristics. This can be accomplished with increment cores which provide an expedient and simple method of obtaining the sample.

Specific Gravity The most useful index of quality is wood density, usually expressed as specific gravity since it is related to many of the physical and anatomical properties of wood. A high correlation has been found to exist between specific gravity and mechanical strength of wood. Therefore, specific gravity can be used as an indicator of high-valued structural lumber, and in the selection of high-grade poles and piling.

Specific gravity can be used as an estimate of fiber yield in the manufacture of pulp and paper. One pound more of kraft pulp is produced for every two-pound increase in wood density of southern yellow pine (11, p. 2). This same general relationship between wood density and pulp yield applies to other species.

Wood of high specific gravity is not desirable for all end products. A prediction of dimensional stability can be made from specific gravity information. Low density wood will shrink less across the grain than wood of higher density, resulting in a lower percentage of degrade and loss. Low specific gravity wood has good machining characteristics which are necessary for products such as moulding and cabinet stock.

<u>Measurement of Specific Gravity</u> Specific gravity of wood is commonly expressed as the ratio of ovendry weight in grams to the green volume in cubic centimeters. The green volume for large samples can be measured by displacement in water or mercury; however, this method is not as precise and rapid as the calibrated borer or maximum moisture content techniques when working with relatively small samples.

The calibrated borer technique, as described by Mitchell (12, p. 152), can be used to determine the green volume from the inside diameter of the borer and the length of the core. The U. S. Forest Products Laboratory has developed a special inside taper gauge for calibrating increment borers to a level of accuracy of about 0.002 inch. The length of the core is measured to the nearest 0.002 inch also. This method is applicable only to cores one inch or longer. The formula for calculating the volume is as follows:

$$(\text{Diameter in inches})^2 \times 0.7854 \times \frac{1.0}{0.061} = \text{volume (cc) per inch of core length.}$$

The cores are dried at 105° C to constant weight to obtain the oven-dry weight.

The determination of specific gravity of increment cores by the maximum moisture content method was first demonstrated by Keylworth and reported by Smith (15, p. 2-5) of the U. S. Forest Products Laboratory. The specific gravity of a small wood sample, based on green volume, is found from the maximum moisture content of completely saturated wood without first having to obtain the volume of the sample. Essentially, the procedure is as follows: a small wood sample is completely saturated under vacuum for seven to ten days, weighed, ovendried at 105° C, and weighed again. The maximum moisture content (M_{max}) in grams of water per gram of ovendry wood can be determined from measurements as follows:

$$M_{max} = \frac{m_m - m_o}{m_o}$$

where m_m is mass of water-saturated wood in grams, and m_o is ovendry weight in grams. Subsequently, specific gravity can be calculated with the formula:

$$\text{Specific gravity} = \frac{1}{M_{max} + \frac{1}{G_{so}}}$$

where G_{so} is the specific gravity of wood substance comprising the cell walls. The figure (G_{so}) has been shown by Stamm (16, p. 5) to have an average value of 1.53.

Simplicity of sampling with increment cores and the techniques described for measuring specific gravity are well adapted to large-scale, growth-quality studies.

Per Cent Summerwood Another index of wood quality is the proportion of summerwood in the annual rings of conifers and ring-porous hardwood species. Springwood is the first formed wood in each growing season, usually consisting of relatively thin-walled cells with large lumens or cell cavities. Conversely, summerwood is the last formed wood of the annual growth ring and is comprised of thick-walled cells with small lumens.

Per cent summerwood usually is correlated to specific gravity, although it will vary with position in the tree. Paul (13, p. 481) reported an investigation by Schrader on specific gravity variation of springwood and summerwood, separately, in southern pines. He found that springwood specific gravity varied 18 - 22 per cent around the median for four species, and summerwood specific gravity varied 24 - 35 per cent around the median for three species. He also hypothesized that if the relative proportion of springwood and summerwood remain the same, the heaviest wood will be found in the lower portion of the tree, and in cross section, on the outside of the tree.

The proportion of summerwood in annual growth rings can be correlated to mechanical strength and pulp yields. The increase in strength with an increase in per cent summerwood is attributed to the greater number of thickwalled, stronger cells in proportion to the weaker, thinwalled springwood cells. In pulping, paper sheets containing a high percentage of springwood felt or mat better and have a high bursting strength. The presence of summerwood fibers in a sheet tends to increase the tearing strength (2, p. 397-398).

Measurement of Summerwood Per cent summerwood measurements would be easy to obtain if an abrupt transition always existed between springwood and summerwood. The transition in young Douglas-fir wood usually is gradual, although it may appear abrupt to the naked eye. The reasons for gradual or abrupt transition are dependent upon age of the wood, inherent characteristics of the tree, and possibly supplemented by climatic and site conditions. Since it is necessary to distinguish this transition point and consistently do it on the same basis, it is common practice to make a microscopic identification of this junction on the basis of Elias Mork's (17, p. 3) definition of springwood and summerwood. This definition is:

> All tracheids in which the common wall between two cell wall cavities multiplied by two is equal to or greater than the width of the lumen are considered as summerwood; those in which the value is less than the width of a lumen are considered as springwood (all measurements being made in the radial direction).

Accurate per cent summerwood determinations can be made, after locating the transition point, by expressing the radial measurement of summerwood as a proportion of the total radial measurement of the annual ring.

Fibril Angle The secondary wall of wood fibers consists of chain-like bundles of cellulose, called fibrils. Strength and longitudinal shrinkage of wood and properties of pulp are greatly influenced by the angle at which fibrils lie with respect to the longitudinal axis of wood fibers. Therefore, the sizes of fibril angles are recognized as an important index of wood and paper properties. Small angles of less than 10° have been found to be associated with the favorable strength of kraft paper made from these woods (7, p. 243).

Measurement of Fibril Angle A simple technique to measure fibril angle, as described by Marts (7, p. 244-248), consists of the use of fluorescence microscopy aided by fluorochromes. Increment cores are split along their radial axes and treated with various fluorochromes to color contrast the different features of the wood. After drying the treated samples, the fibril angles can then be measured by observing with a microscope the spiral checks illuminated by ultraviolet light.

Only specific gravity and per cent summerwood were evaluated in this study of variations within the clone; however, it was deemed relevant to include fibril angle evaluation in this discussion, since it is one of the three major indexes of wood quality.

Through the determination of fibril angle, per cent summerwood, and specific gravity, it is possible to measure the transmissibility of wood properties from parent to offspring. These determinations could provide invaluable information as to the effect of silvicultural and genetic controls on timber. They also could serve to aid in the proper allocation of timber for specific or related uses.

Control of Wood Quality

This discussion has been concerned with wood quality and techniques employed for its evaluation. Other published work in the field of genetic control on wood quality has been limited. However, some consideration should be given to factors which appear related to the various properties of wood. These factors generally may be classified as silvicultural and genetic effects on quality. Although this study was concerned primarily with genetic effects, silvicultural aspects should not be omitted from a discussion of wood quality. Differences in environment and growth characteristics also will affect the quality of wood produced by trees within or between timber stands.

Evidence on silvicultural and genetic controls of wood quality for a particular species reported in the following discussion should not be applied to all species.

Silvicultural Controls Apart from any inherent variation, wood may vary according to the age of the tree in which it develops, or with the height position it occupies in the tree (9, p. 21-30). Other causes of variation may be differences in moisture, soil, light, and temperature, including competition with other organisms which form part of the environment of the living tree. Zobel (20, p. 4-6) states that no one factor controls specific gravity, rather it is the resultant of reaction and interaction of several factors. He reported that growth rate, site index, tree age, soil characters, per cent clear bole, stand density, or moisture of site could not be found to have a strong influence on specific gravity of loblolly pine. When these factors were considered together, they accounted for only a small amount of the specific gravity variation.

Other workers who have examined the effects of these factors on specific gravity have not reached the same conclusions. A more complete review of similar work can be found in publications by Larson (5, p. 67-73), and Spurr and Hsiung (10, p. 199-200).

Likewise some different conclusions have been reported by various workers on per cent summerwood and specific gravity variation because of the close correlation of the two characteristics. Van Binjtenen (19, p. 176-177) conducted experiments to evaluate the effect of temperature, soil moisture, and photo-period on summerwood formation in seedlings and mature trees of loblolly pine. He concluded that the transition from springwood to summerwood was due to a change in the condition of the tree itself, and not to these environmental factors.

It is difficult to make any conclusive statements relative to growth and environmental factors which influence wood quality. However, it is important to recognize the possible effect of these factors, singly or in combinations, if a prediction of the transmissibility of wood properties from parent to offspring is to be made.

<u>Genetic Controls</u> Many investigators previously explained any unassignable causes of variation as due to experimental error. Present tendency is to assign these causes of variation to inherited characteristics. Evidence has been presented regarding the influence of genetic control on growth rate, bud bursting, disease resistance, and gum yield. It would seem logical to assume that there is genetic control on the anatomical and physical properties of wood as well.

Zobel (20, p. 9-11) has presented "circumstantial evidence" to support this assumption. As stated in the discussion of silvicultural controls, he reported that no one growth or environmental characteristic, such as growth rate, site index, tree age, soil characters, per cent clear bole, stand density, or moistness of site, could be found to have a strong influence on specific gravity of loblolly pine. When the various growth or environmental factors were considered together, they accounted for only a small amount of the specific gravity variation. He also found a correlation between specific gravity of mature wood and specific gravity of juvenile wood along the same radial section, which may indicate a hereditary factor of control. Therefore, he inferred from these results the possibility of genetic control on specific gravity.

Schreiner (14, p. 124-127) presented estimates of heritability of characteristics and properties related to use requirements and possible improvement procedures. These were based on personal experience, observation, and evaluation of the literature. He took the major physical, chemical, anatomical, and mechanical characteristics affecting wood quality and stated whether or not there was evidence for sufficient heritability to justify genetic improvement. He estimated that high or low density, small fibril angle, fiber length, abnormal grain, and chemical composition were heritable. Genetical improvement of pulp and paper qualities, penetravility, dimensional stability, durability, and machining qualities were predicted. There was insufficient evidence to make any estimates on the transmissibility of per cent summerwood, fiber wall thickness, per cent heartwood, and ease of gluing. Possible improvement procedures included genetic improvement, genetic improvement followed by some degree of silvicultural control, and silvicultural control plus research to determine possibilities for genetic improvement.

In a more recent study on the hereditary characteristics of wood of varying specific gravity in southern pine, Zobel and Rhodes (21, p. 281-285) found the following to be true:

1. The use of limbs to estimate the bole specific gravity of trees up to 11 years of age is feasible.

2. Four-year-old, open-pollinated progeny from two parent trees of high and low specific gravity were evaluated. The progeny of the high specific gravity parent had significantly higher wood specific gravity than that of the low specific gravity parent.

3. Progeny of three supposedly self-polinated parents were analyzed. The progeny of the higher specific gravity parent had significantly higher specific gravity than the progeny of the lower specific gravity parents.

4. No correlation could be found between specific gravity of limbs of four-year-old grafts and the specific gravity of the tree from which the grafts had been obtained.

Another example of genetic control on wood quality was reported by Echols (4, p. 20-22). He found the inheritance pattern indicates that tracheid length in slash pine is governed by a multiple gene series. Also, open-pollination resulted in an equalizing effect which tended to produce progeny with average tracheid length.

Erroneous inferences on magnitude of control of wood quality by environmental and genetic factors are easily made if these factors are not well defined or controlled in an evaluation. Since there is an interaction of these two factors on quality, one method to evaluate effectively the genetic control on wood quality would be to maintain an infallible control on all environmental factors. If a significant variation did occur in one of the measures of wood quality, it could be attributed to the hereditary makeup of the tree. An inference of genetic control could be made only under these conditions. Genetics would exercise no control if results of such a controlled experiment were significant, provided experimental error was negligible. An alternative method to evaluate genetic control on wood quality would involve sampling from genetically identical trees from an uncontrolled environment. Any variation in this case would be due to environmental factors. Negative variation would indicate experimental error since it is known that specific gravity does vary within a particular species. This latter technique would be the only valid way to evaluate the effect of environment and growth conditions on wood quality.

Summary Much work in wood quality has been on the development of techniques for evaluation. Sampling is done with large increment borers which permit fiber length and fibril angle analysis. Other significant indexes of wood quality which can be determined from increment core samples are specific gravity and per cent summerwood. Increment core samples are easily obtained and are nondestructive.

The conclusion has been reached that genetic manipulations to provide trees with superior growth characteristics is not all important. The wood of these superior trees may not be any better suited for a given end product than the wood of any other tree. The relationship among basic properties, wood quality, and end product characteristics must be fully understood before proper selection can be made of clonal or progeny stock destined for a particular end product.

UNIFORMITY TRIAL

Unassignable causes of variation, or extraneous variations, usually are classified as experimental error. This error may be attributed to inherent variability or lack of uniformity in the physical conduct of the experiment. Accuracy and precision of an experiment may be jeopardized by these extraneous variations (3, p. 15). A uniformity trial, or sample experiment, can be conducted to determine the most suitable grouping of experimental units and the degree of uniformity in the physical conduct of the experiment. Results of this uniformity trial would measure the accuracy and precision of the experiment (3, p. 36).

Objective

The twelve trees of the clone placed a limitation on the number of samples which could be used in the experiment. Therefore, it was decided to conduct the analysis of the clone on the basis of individual annual rings[1] dissected from increment cores. Two questions needed to be answered: (1) would this be a suitable grouping of units, and (2) could the experimenter attain precision in determining specific gravity of units of this dimension? The objective of this uniformity trial was to answer these two questions.

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1. Hereafter designated as experimental units.

Procedure

Material for this uniformity study consisted of four pieces of fast-growth, cant-trim, green Douglas-fir wood. A visual estimate of the proportion of summerwood to springwood was made when selecting this material to insure some variation in specific gravity among the four blocks. Increment borings were made parallel to the grain of the wood (Figure 1) to obtain relatively uniform specific gravity the entire length of the core. Each core when dissected into small segments representative of annual growth rings, or experimental units, provided samples essentially uniform in specific gravity. This was necessary in order that the statistical analysis would expose any variation in experimental techniques and not variation of specific gravity within the increment core. The increment cores were placed in test tubes containing distilled water and a few drops of 95 per cent ethyl alcohol as a preservative. They were stored under refrigeration until measurements were made for specific gravity.

To ensure proper selection of wood blocks from which the increment cores were taken, the specific gravity of a small portion of the block immediately surrounding the increment core was determined by the water immersion method. The apparatus used for these measurements is illustrated in Figure 2. Specific gravities of the four blocks were found to be .435, .469, .475 and .492 respectively. It was necessary to have some difference in specific

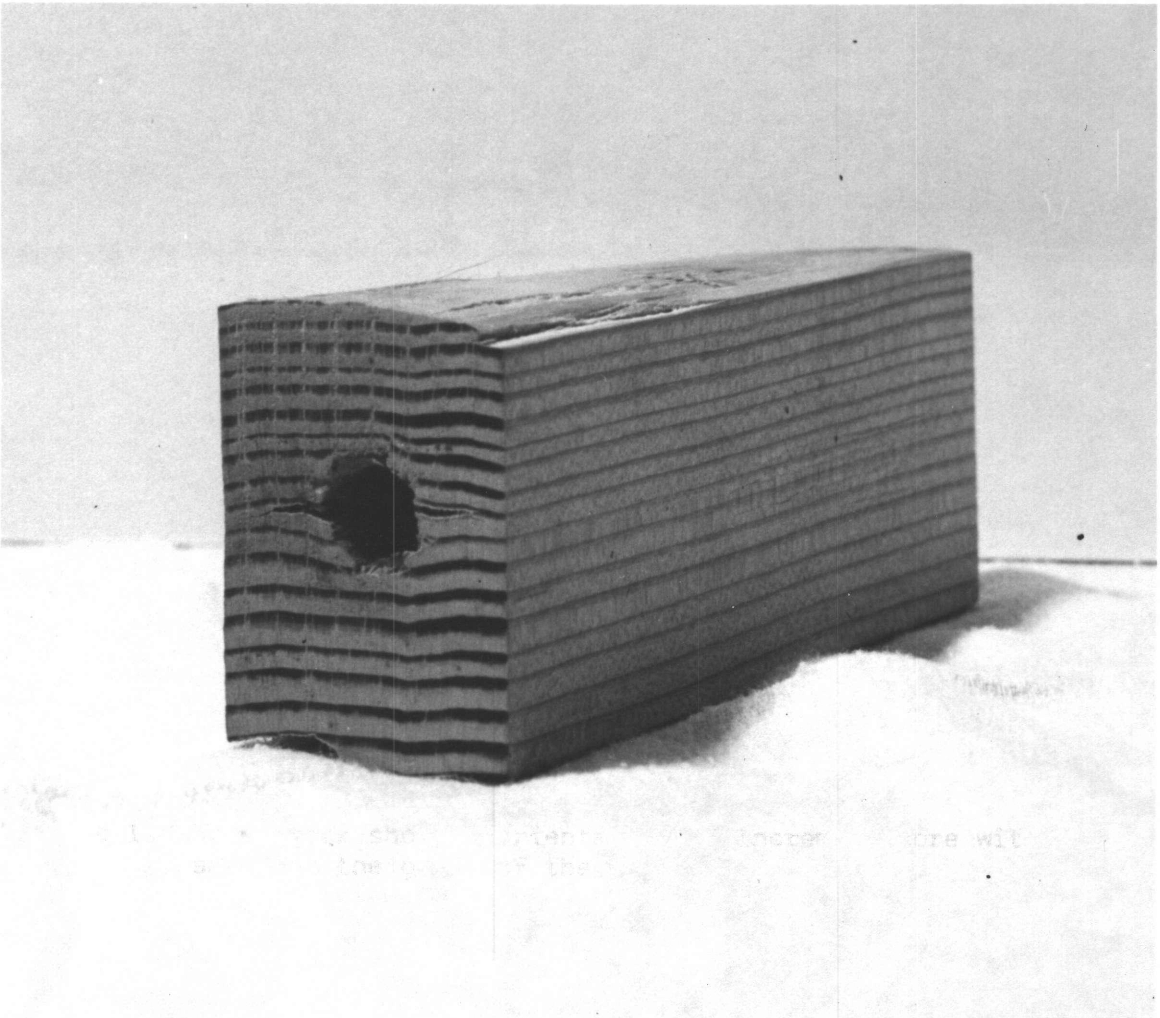

Figure 1. Wood block showing orientation of increment core with respect to the grain of the wood.

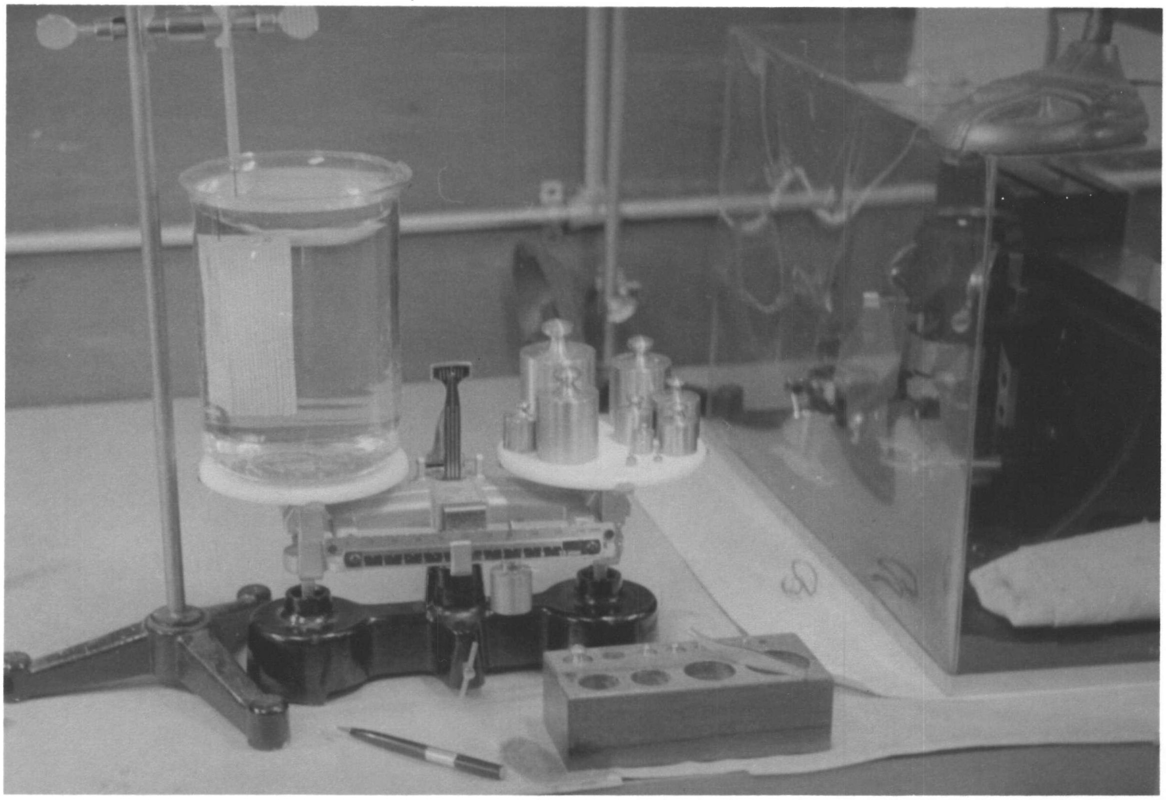

Figure 2. Apparatus used to determine specific gravity of wood blocks by water immersion method.

gravity among the four blocks in order that the statistical analysis might verify the ability of the experimental techniques, based on specific gravity measurements of experimental units, to differentiate one block from another. If there were too great a difference in specific gravity among the blocks, it would have been relatively simple for the experimental technique to differentiate the four blocks. The statistical analysis would not have provided a true evaluation of the experimental methods under these conditions.

Specific gravity measurements were made by the maximum moisture content method as described on page 7. The experimental units, representative in dimension of annual rings, were prepared by cutting segments approximately 3/16 inch parallel to the grain from each of the cores with a razor blade. Five units were cut from each core to give a total of twenty experimental units. The units were identified by placing them in small gauze bags with numbered tags stapled to the bags. This eliminated any unforeseen change in weight of the units by marking them directly with pen or pencil.

The evacuation system consisted of a 1500 milliliter evacuating flask equipped with a vacuum gauge calibrated to measure inches of mercury. The vacuum was drawn by an aspirator (Figure 3). The units were placed in the system and allowed to remain for fifteen days. The aspirator was operating eight hours a day with at least twenty-five inches of mercury vacuum on the system for the entire period. As was previously mentioned, four to five days was found to be sufficient time for somewhat larger units to attain their

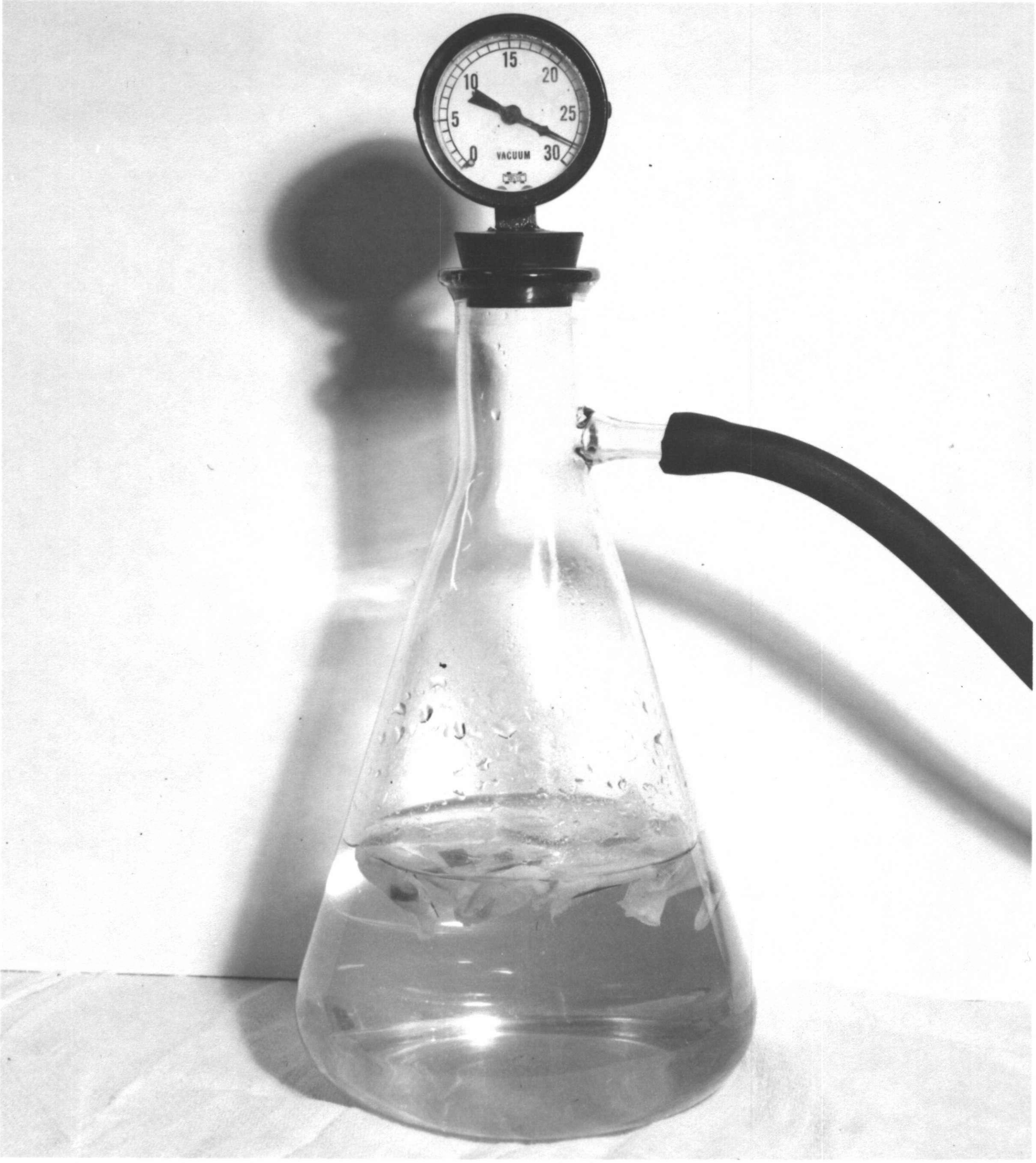

Figure 3. Apparatus used to saturate small wood specimens.

saturated condition.

Weighings of the saturated wood samples and the ovendry samples were made on a Mettler automatic balance which measured to the nearest milligram (Figure 4). To avoid change in weight by gain or loss of moisture, which could contribute considerable error, weighing bottles were used for all measurements. The experimental units were removed from the flask, wiped with a damp cloth to remove excess surface moisture, and immediately put into the weighing bottles. The difference in weight between the weighing bottle containing the unit and weighing bottle without the unit was recorded as the saturated weight. The units were placed in an oven at 105° C and allowed to dry until they maintained a constant minimum weight. At this time they were placed in weighing bottles with the lids removed and allowed to cool to room temperature in a dessicator. The weighing procedure was the same as described above. These recorded weights can be found in Table No. 1 of the Appendix.

Analysis and Conclusions

The saturated and ovendry weights were used to calculate the specific gravity of each experimental unit by substitution in the formula presented on page 8. These values are shown in Table No. 1 of the Appendix.

A completely randomized analysis of variance was conducted to test the precision of the experiment and the feasibility of using individual annual rings for the analysis. Since uniformity refers

Figure 4. Mettler automatic balance used to weigh small wood specimens.

to uniformity of treatment, all samples received the same treatment. The results of this analysis are shown in Table No. 1. The F-value, tested at the one per cent level, was found to be highly significant. The following conclusions were made from this analysis:

1. The precision of the experiment was adequate to differentiate the specific gravity of one piece of wood from another using dissected increment cores.
2. The experimental techniques used by the experimenter could accurately measure the specific gravity of an annual growth ring dissected from an increment core.
3. Five annual growth rings would be an adequate sample for determining specific gravity variations among and within young trees.

Table No. 1. Analysis of Variance: Effectiveness - - -

Source of Variation	D.F.	Sum of Squares	Mean Square	F
Between Samples	3	.00916725	.00257188	28.35
Within Sample	16	.00145160	.00009072	
Total	19	.00916725		

EXPERIMENTAL PROCEDURE

Per cent summerwood and specific gravity were the two indexes of wood quality evaluated from samples obtained by taking increment cores from a young Douglas-fir clone. Use of the clonal material provided a definite control on the genetic factor of variation. The hypothesis that variation in per cent summerwood and specific gravity did not exist within each tree and among trees of the clone was tested for this experiment. The alternative hypothesis was that per cent summerwood and specific gravity did vary within the clone. Data were analyzed statistically to determine cause and extent of variation of these two qualities. The possibility of an external indicator of specific gravity in the clone also was investigated.

Description of the Clone

The clone on which this study was conducted is located on a one-fifth acre, Site III area in MacDonald Forest, property of the Oregon State College School of Forestry. It is comprised of twelve Douglas-fir trees ranging in diameter from three to six inches at breast height (Figure 5).

Dr. Walter F. McCulloch (8, p. 211-212) made the cuttings in January, 1939 of branch tips from a tree fifty years old. Twenty trees out of the 360 cuttings treated with four different concentrations of indolebutyric acid to stimulate rooting survived by May, 1942, after being transplanted from flats to the Oregon Forest

Figure 5. Young Douglas-fir clone on which the study was conducted.

Nursery, and subsequently to their present location. The trees had failed to develop a well-defined leader in 1942. This condition persisted for several years longer because the cores taken at breast height in March, 1958, exhibited only 7 to 12 annual growth rings.

Samples

A young Douglas-fir, adjacent to the clone and of approximately the same age, was felled and examined. The objective was to provide an indicator, prior to sampling the clone, for the presence of compression wood, if any, and specifically, at what height increment cores could be taken from the clone. Five, four-inch bolts were removed from the tree at heights of 6 inches, 4 feet, 8 feet, 12 feet, and 16 feet, respectively, and examined for compression wood. Visual examination of the five bolts did not reveal the presence of compression wood in the tree. Since this tree was adjacent to and growing under the same conditions of the clone, it was theorized that the probability of compression wood being present in the clone was low. Therefore, trees of the clone could be sampled at a position convenient to boring and not dictated by the possible presence of compression wood.

An eight millimeter increment borer was used to obtain one core from each of eleven of the twelve trees in the clone. Tree number 10 of the clone was too small to bore safely. All cores were taken from the north side of the trees at breast height to eliminate any possible variation in specific gravity due to position in the tree. The cores were placed in labeled test tubes containing distilled water and a few drops of 95 per cent ethyl alcohol to act as a preservative. Test tubes were stored under refrigeration until measurements were made for per cent summerwood and specific gravity.

Per Cent Summerwood

Mork's definition of summerwood was used to determine the transition point between springwood and summerwood as described on page 11.

A thin section was removed from each core with a microtome knife to expose a well-defined transverse surface. Measurements were made with a Bausch and Lomb microscope equipped with a calibrated traveling stage, 10 x objective, and 5 x eyepiece with crosshair to give a 50 x magnification (Figure 6). Direct illumination was provided with a blue incadescent lamp. A channeled wooden block, glued to a glass slide, was fabricated to support the cores. A piece of water-saturated tissue was placed under the core to prevent excess evaporation since it was desired to keep the sample in a green condition prior to specific gravity determinations. The annual rings measured consisted of only the last five years, 1957 to 1953. This number of experimental units, or annual rings, was the minimum number in some cores, and had been previously validated by the uniformity trial. The experimental units were numbered consecutively from the bark toward the pith as indicated in Appendix

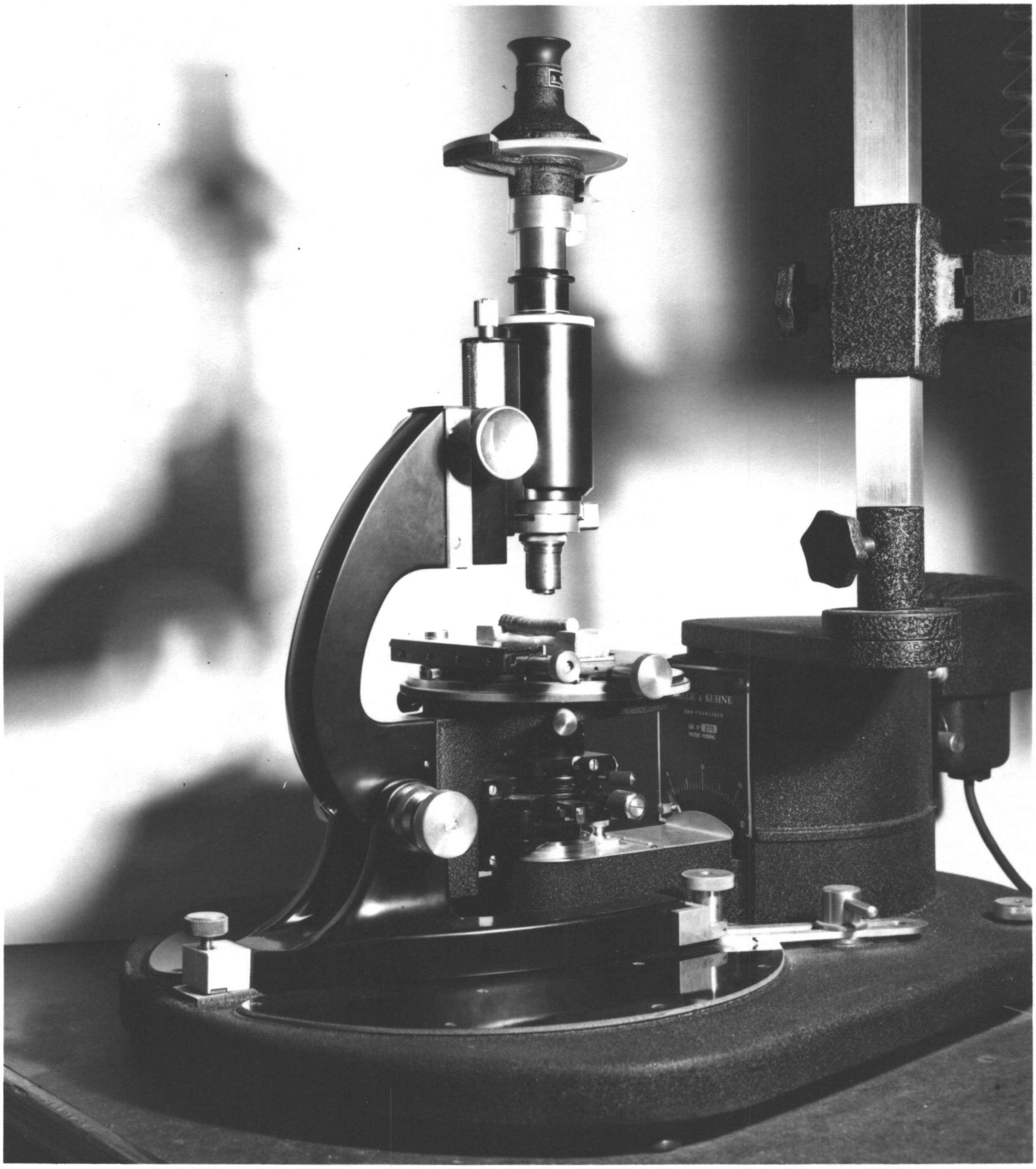

Figure 6. Microscope equipped with traveling stage used to make per cent summerwood measurements.

Table No. 2.

The proportion of summerwood to springwood was measured for each experimental unit, by moving the microscope stage parallel with the core. The ratio of summerwood width to total annual ring width was calculated to give per cent summerwood. These data are shown in Table No. 2 of the Appendix.

An analysis of variance was conducted to determine variation of per cent summerwood within each tree and among trees of the clone. Results of this analysis are discussed on page 34.

Specific Gravity

The procedure for determining specific gravity of small wood samples as described in the uniformity trial was used to determine specific gravity of units dissected from increment cores.

The experimental units were prepared by dissecting each increment core into its respective annual rings with a razor blade. Therefore, the five last-formed annual rings from the eleven cores gave a total of 55 experimental units. Each unit was placed in a gauze bag and labeled saturated, weighed, ovendried, and weighed again. The specific gravity was calculated by substituting the saturated weight, ovendry weight, and specific gravity of wood substance comprising the cell wall into the formula given on page 9. Calculated specific gravity values are shown in Table No. 3 of the

Appendix.

These data were statistically analyzed by analysis of variance. Results of this analysis are shown in Table No. 3 on page 35.

ANALYSIS OF RESULTS

One of the most significant results of this study was illustrated by the uniformity trial. It established the validity and accuracy of the experimental procedure to determine specific gravity of annual ring sgements dissected from increment cores. Results of the uniformity trial also established the number of experimental units per core, or sample size, required to differentiate trees by specific gravity within the clone. The nature of these uniformity trial results diminished the possibility of accepting the hypothesis that specific gravity did not vary within the clone in the event it was actually false.

Variation of Per Cent Summerwood

A randomized block analysis of variance was performed to test the effect of environment on per cent summerwood. It can be seen from Table No. 2 that per cent summerwood did not vary significantly at the one per cent level within or among trees of the clone. Therefore, environmental factors had no influence on the proportion of summerwood to springwood formed by the trees in the clone. These results were as one might expect since all trees were growing in the same location and environment presumably would affect all trees to the same degree.

Table No. 2 Analysis of Variance: Effect of Environment on Per Cent Summerwood

Source of Variation	D.F.	Sum of Squares	Mean Square	F
Annual Rings	4	252.4935	63.123374	1.1645
Trees	10	580.7659	58.07659	1.0714
Error	40	2,168.1705	54.2042625	
Total	54	3,001.4299		

Variation of Specific Gravity

The effect of environment on specific gravity was analyzed by a randomized block analysis of variance.

Table No. 3 Analysis of Variance: Effect of Environment on Specific Gravity

Source of Variation	D.F.	Sum of Squares	Mean Square	F
Annual Rings	4	.03759510	.00939878	14.09
Trees	10	.01871438	.00187144	2.80
Error	40	.02668824	.00066721	
Total	54	.08299772		

F-values were significant for both trees and annual rings at the one per cent level, which indicated that environment caused specific gravity to vary from year to year within trees and among trees in the clone as shown in Table No. 3.

Multiple Range Tests

Since there is a correlation between per cent summerwood and specific gravity, it would be expected that the two indexes of wood quality in the clone would vary to the same degree. However, per cent summerwood was found not to vary significantly within and among trees of the clone while specific gravity did vary significantly. Multiple range tests (6, p. 238), used to determine which population means are equal and which are different, were conducted to determine which groups of trees and growth years had significantly different specific gravities.

Table No. 4. Multiple Range Test: Degree of Variation in Mean Specific Gravity by Growth Year

Year	Mean Specific Gravity
1955	.3524
1953	.3727
1954	.3928
1957	.4142
1956	.4235

Table No. 4 shows that specific gravity of wood formed in 1957 and 1956 was significantly higher at the one per cent level than specific gravity of wood formed in the three preceding years.

Table No. 5. Multiple Range Test: Degree of Variation in Mean Specific Gravity by Trees.

Trees ~~Year~~	Mean Specific Gravity
12	.3567
2	.3733
4	.3833
11	.3856
9	.3895
6	.3897
8	.3924
1	.3947
5	.3971
7	.4057
3	.4345

It can be seen from Table No. 5 that tree No. 3 had a significantly higher specific gravity at the one per cent level than trees No. 2 and 12.

The low specific gravity of wood formed in years 1953 and 1955 could have been influenced by weather or other growing conditions those years. Position of the wood in the tree with respect to the transverse axis, or age, might have influenced these results. The annual rings compared were formed in the same respective years; however, their age from the pith varied. Since specific gravity of wood appears to vary with age from the pith, this might have been a contributing factor to the specific gravity variation found.

The significantly higher specific gravity of tree No. 3 as compared to trees No. 2 and 12 might have been caused by differences in rate of growth associated with environmental factors as indicated under Silvicultural Controls on page 13.

It appears that environment and age of wood influence specific gravity significantly when genetic variation is controlled. The possibility exists that this variation in specific gravity might be inherent to the clone. This is highly improbable since all trees of the clone are genetically identical. Only continuous and more exhaustive research on the genetic influence of wood quality will provide an indisputable answer to the causes of quality variation.

External Indicator of Specific Gravity

As a supplement to this study, it was decided to determine whether some external growth characteristic could serve as an indicator of specific gravity. A visual analysis of the clone indicated tree height to be the only growth characteristic which might be correlated to specific gravity. Therefore, a regression analysis of mean specific gravity on total tree height measured in 1955 was conducted to test the validity of this hypothesis. The resulting correlation coefficient of -.415 rejected tree height as an indicator of wood specific gravity in the clone.

SUMMARY

Variation of specific gravity and per cent summerwood in a young Douglas-fir clone was determined from annual rings dissected from increment cores. Per cent summerwood was found not to vary within trees and among annual rings of the same year. Specific gravity was found to vary within and among trees of the clone. The significance of wood quality and the influence of genetic, environmental and age factors on the clone were discussed. Common indexes of wood quality and the tools and techniques used to measure these indexes were discussed. A uniformity trial, or sample experiment, was conducted to determine the accuracy of the experimental technique and the proper sample size for a valid statistical analysis. Data which were statistically analyzed to determine extent of specific gravity and per cent summerwood variation in the clone are presented in the Appendix.

CONCLUSIONS

The conclusions reached in this study of per cent summerwood and specific gravity variation in a young Douglas-fir clone can be summarized as follows:

1. The precision of the uniformity trial was adequate to differentiate the specific gravity of one piece of wood from another using dissected increment cores.
2. The experimental techniques employed could accurately measure the specific gravity of an annual growth ring dissected from an increment core.
3. Five annual growth rings would be an adequate sample for determining specific gravity variation among and within young trees.
4. Environment had no effect on per cent summerwood formation in the clone.
5. Variation of specific gravity within and among trees of the clone due to environment and age was significant. Since all trees of the clone had the same genetic identity, it is not possible to attribute differences in specific gravity to inherent variation.
6. Total tree height was not a satisfactory external indicator of specific gravity.

RECOMMENDATIONS

The following recommendations are presented to those who might be contemplating research in wood quality:

1. A uniformity trial, or sample experiment, should be conducted to validate experimental techniques and proper sample size.
2. Rigid controls should be placed on environmental and/or genetic factors when an evaluation of wood quality is made. Also, it should be known to what degree these factors are present in clones or progeny being evaluated.

Other recommendations relative to future wood quality evaluation of this clone are as follows:

1. Determine extent and causes of variation of fibril angle and other wood fiber characteristics.
2. Determine the transmissibility of wood quality between the parent tree and the clone.

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A P P E N D I X

Table No. 1

Calculated Specific Gravities for Uniformity Trial

Saturated Weight	Oven Dry Weight	Specific Gravity
~~0.278~~ 0.284	0.101	.4056
~~0.323~~ 0.263	0.095	.4129
~~0.321~~ 0.351	0.129	.4211
0.351	0.124	.4025
~~0.243~~ 0.290	0.103	.4050
~~0.263~~ 0.348	0.130	.4291
~~0.280~~ 0.300	0.112	.4288
~~0.262~~ 0.279	0.102	.4186
~~0.290~~ 0.318	0.117	.4217
~~0.336~~ 0.262	0.098	.4297
~~0.351~~ 0.280	0.112	.4643
~~0.284~~ 0.336	0.141	.4910
~~0.253~~ 0.342	0.136	.4612
~~0.318~~ 0.323	0.126	.4510
~~0.279~~ 0.321	0.125	.4501
~~0.242~~ 0.278	0.104	.4298
~~0.348~~ 0.222	0.084	.4354
~~0.300~~ 0.253	0.095	.4316
~~0.342~~ 0.242	0.091	.4324
~~0.222~~ 0.243	0.091	.4303

Table No. 2
Per Cent Summerwood Measurements of Experimental Units from Cores Removed from All Trees

Sample (Core Number)	Annual Rings*					
	1	2	3	4	5	6
1	28.8	26.5	34.8	27.6	20.4	21.6
2	12.9	21.7	26.5	21.7	21.2	15.7
3	42.5	43.2	17.0	27.5	26.5	22.4
4	29.3	19.6	20.0	20.0	24.1	25.5
5	19.6	30.8	29.5	30.2	38.3	63.8
6	25.0	32.7	23.0	26.4	26.7	22.0
7	29.9	30.4	18.5	16.9	19.3	34.3
8	25.8	29.8	18.8	29.6	27.1	20.6
9	23.0	41.7	15.3	21.5	18.5	28.6
11	43.8	30.6	20.3	25.6	23.1	
12	13.2	17.6	38.7	23.5	19.1	20.0

*Bark to pith in ascending order.

Table No. 3
Calculated Specific Gravities of Experimental Units from Cores Removed from All Trees

Sample*	Saturated Weight (gms)	Ovendry Weight (gms)	M_{max}	$M_{max} + \frac{1}{1.53}$	Specific Gravity
1-1	0.382	0.125	2.0560	2.7096	.3691
1-2	0.207	0.081	1.5556	2.2092	.4527
1-3	0.259	0.087	1.9770	2.6306	.3801
1-4	0.360	0.129	1.7907	2.4443	.4091
1-5	0.267	0.086	2.1047	2.7583	.3625
1-6	0.298	0.106	1.8113	2.4649	.4057
2-1	0.351	0.117	2.0000	2.6536	.3768
2-2	0.255	0.085	2.0000	2.6536	.3768
2-3	0.284	0.088	2.2273	2.8809	.3471
2-4	0.349	0.120	1.9083	2.5619	.3903
2-5	0.316	0.105	2.0095	2.6631	.3755
2-6	0.304	0.103	1.9515	2.6051	.3839
3-1	0.248	0.105	1.3619	2.0155	.4962
3-2	0.210	0.082	1.5610	2.2146	.4515
3-3	0.268	0.091	1.9451	2.5987	.3848
3-4	0.418	0.159	1.6289	2.2825	.4381
3-5	0.275	0.097	1.8351	2.4887	.4018
3-6	0.284	0.103	1.7573	2.4109	.4148
4-1	0.335	0.123	1.7236	2.3772	.4207
4-2	0.285	0.100	1.8500	2.5036	.3994
4-3	0.370	0.113	2.2743	2.9279	.3415
4-4	0.428	0.144	1.9722	2.6258	.3808
4-5	0.335	0.111	2.0180	2.6716	.3743
4-6	0.300	0.105	1.8571	2.5107	.3983
5-1	0.294	0.113	1.6018	2.2554	.4434
5-2	0.223	0.081	1.7531	2.4067	.4155
5-3	0.244	0.076	2.2105	2.8641	.3491
5-4	0.370	0.123	2.0081	2.6617	.3757
5-5	0.258	0.091	1.8352	2.4888	.4018
6-1	0.444	0.161	1.7578	2.4114	.4147
6-2	0.292	0.114	1.5614	2.2150	.4515
6-3	0.339	0.102	2.3235	2.9771	.3359
6-4	0.419	0.140	1.9929	2.6465	.3779
6-5	0.349	0.114	2.0614	2.7150	.3683
6-6	0.310	0.099	2.1313	2.7849	.3591

*Bark to pith in ascending order.

Table No. 3 (Continued)
Calculated Specific Gravities of Experimental Units from Cores Removed from All Trees

Sample*	Saturated Weight (gms)	Ovendry Weight (gms)	M_{max}	$M_{max} + \frac{1}{1.53}$	Specific Gravity
7-1	0.424	0.164	1.5854	2.2390	.4466
7-2	0.279	0.104	1.6827	2.3363	~~.4380~~, 4280
7-3	0.317	0.104	2.0481	2.7017	.3701
7-4	0.345	0.122	1.8279	2.4815	.4030
7-5	0.333	0.112	1.9732	2.6268	.3807
8-1	0.358	0.135	1.6519	2.3055	.4337
8-2	0.286	0.112	1.5536	2.2072	.4531
8-3	0.385	0.120	2.2083	2.8619	.3494
8-4	0.398	0.132	2.0152	2.6688	.3747
8-5	0.345	0.108	2.1944	2.8480	.3511
8-6	0.358	0.120	1.9833	2.6369	.3792
9-1	0.355	0.130	1.7308	2.3844	.4194
9-2	0.222	0.089	1.4944	2.1480	.4655
9-3	0.325	0.091	2.5714	3.2250	.3101
9-4	0.383	0.131	1.9237	2.5773	.3880
9-5	0.309	0.100	2.0900	2.7436	.3645
9-6	0.290	0.103	1.8155	2.4691	.4050
11-1	0.375	0.135	1.7778	2.4314	.4113
11-2	0.285	0.104	1.7404	2.3940	.4177
11-3	0.391	0.121	2.2314	2.8850	.3466
11-4	0.475	0.167	1.8443	2.4979	.4003
11-5	0.446	0.140	2.1857	2.8393	.3522
12-1	0.432	0.126	2.4286	3.0822	.3244
12-2	0.375	0.116	2.2328	2.8864	.3465
12-3	0.348	0.112	2.1071	2.7607	.3622
12-4	0.402	0.136	1.9559	2.6095	.3832
12-5	0.390	0.127	2.0709	2.7245	.3670
12-6	0.378	0.126	2.0000	2.6536	.3768

*Bark to pith in ascending order.