# ...n and Related Properties ...glas Fir from Mill Samples

by
James D. Snodgrass
Arthur F. Noskowiak

A6


Bulletin 10
May 1968



Forest Research Laboratory
School of Forestry
OREGON STATE UNIVERSITY
Corvallis

## PROGRAM AND PURPOSE

The program of the Forest Research Laboratory is designed to provide information that will improve techniques of forest management and promote full utilization of forest products. Able specialists with well-equipped laboratories study Oregon's forest resources, supported by the forest industry and by state and federal funds.

Research in this field by wood scientists and technologists, chemists, and engineers includes studies of properties, processing, utilization, and marketing of wood and of timber by-products. Technical principles derived through this research can be applied to the operation of Oregon's forest industry.

The PROGRAM of research includes

- identifying and developing chemicals from wood,
- improving pulping of wood and wood residues,
- investigating and improving manufacturing techniques,
- extending life of wood by treating,
- developing better methods of seasoning wood for higher quality and reduced costs,
- cooperating with forest scientists to determine effects of growing conditions on wood properties, and
- evaluating engineering properties of wood and wood-based materials and structures.

The PURPOSE of research on forest products is to provide information that will enable the forest industry to expand markets, create new jobs, and bring more dollar returns by

>developing products from residues and timber now wasted, and

>improving treatment and design of present wood products.

## COVER PHOTOGRAPH

The testing crew at the Forest Research Laboratory arranged this display of specimens from Douglas fir dimension lumber, boards, and timbers to show their proportionate distribution among the various areas. Numbers on the stacks of specimens refer to areas shown on page 9. Keep in mind when comparing sizes of the stacks that their volumes vary more than would appear in the two-dimensional photograph, and also that the size of the stacks in the foreground is exaggerated because they are close to the camera.

# STRENGTH AND RELATED PROPERTIES OF DOUGLAS FIR FROM MILL SAMPLES

by
James D. Snodgrass
Professor of Forest Products, Forest Research Laboratory, Oregon State University until 1965, and now Senior Technologist, Central Wood Products Research and Development Department, Potlatch Forests, Inc., Lewiston, Idaho.

and
Arthur F. Noskowiak
Assistant Professor, Department of Forestry and Range Management, Washington State University, and affiliated there with the Wood Technology Section, College of Engineering Research Division,at the time this study was made.

This bulletin was based on research done jointly by Washington State University and Oregon State University in cooperation with the former Western Pine Association.

## FOREWORD

The former Western Pine Association, which merged into the Western Woods Products Association in 1964, was the chief sponsor of the survey of the strength of Douglas fir wood made in 1960 and described in this report. Personnel of Washington State and Oregon State Universities worked jointly on the survey. Plans were made early in 1960, and collecting of samples and testing them at the Laboratories were completed during the spring, summer, and early fall of the same year. A report was issued in limited quantity for review by the sponsor in September 1961, about 15 months after the actual start of the survey.

Keen, critical interest in results of the study prompted a lengthy, detailed review of the original report and consequent delay in issuing a final report. During the time of this review, the original sponsor and other industry groups provided partial financing in cooperation with the U.S. Forest Service for an extensive, accelerated survey of the density of certain western tree species, including Douglas fir. Results of our study helped in applying data on density to obtain improved estimates of strength of clear, unseasoned Douglas fir.

## TABLE OF CONTENTS

## ACKNOWLEDGMENTS

Statisticians Lyle D. Calvin at Oregon State University and Thomas S. Russell at Washington State University contributed much aid. Dr. George G. Marra, head of forest products research at Washington State, and Leif D. Espenas, his counterpart at Oregon State, helped and encouraged in all phases of the program.

Specialists at the U.S. Forest Products Laboratory reviewed the general work plan and made useful suggestions.

Personnel from forest products companies associated with the original sponsor provided valuable and pertinent suggestions; notable among them were Herbert B. McKean and Robert J. Hoyle, Jr., of Potlatch Forests, Inc., and Steele Barnett of Boise-Cascade Corporation.

Research Director Carl A. Rasmussen, Bernie E. Welch, and research technologist Ivan Orosz of the Western Pine Association were instrumental in developing the original program and assisting with orderly review of data.

Considerable financial support of the program came from the Western Pine Association and its many member companies.

Dr. Everett Ellis of the Forest Research Laboratory helpfully reviewed the final manuscript.

## SUMMARY

Modulus of elasticity, specific gravity, and major strength properties were determined and compared for clear, unseasoned wood of Douglas fir from coastal and interior sources that comprise the commercial range of this species in 10 western states of the United States.

Specimens were obtained from sawmills by proportionate-probability sampling. This differs from the standard procedure of gathering test material from standing trees at several locations within the range of a species. Samples were obtained from 405 mills, selected by probability techniques from 1,600 plants manufacturing Douglas fir lumber during 1959. The method of sampling resulted in random selection of only one specimen from a log and, probably, only one from a tree.

Efficiency and precision were achieved by dividing the range of Douglas fir into 19 areas for sampling. These were defined according to climate, topography, and political subdivisions, as well as by boundaries from previous studies. Strata were determined by segregating

mills into 6 classes within each area according to daily production capacity. The number of samples allocated to each stratum was based on the ratio of estimated volume of lumber produced in the stratum to estimated total production in the region.

Standard procedures for testing small, clear specimens of wood were followed as much as possible. Test data provided estimates of means and measures of dispersion for specific gravity, moduli of rupture and elasticity in static bending, and maximum crushing and shearing strengths parallel to grain. About 2,800 tests of each of these properties were made, all on unseasoned material cut from dimension lumber. About 2,100 supplementary tests of specific gravity also were made of unseasoned wood cut from boards and timbers gathered during the survey.

Estimated regional mean values of strength (except shearing strength), modulus of elasticity, and specific gravity were greater for Douglas fir from Coast than Interior sources. Differences between means for the two regions were significant at the 5 percent level of probability for all properties.

Percentage difference between average values ranged from 2 to 9 percent, depending on the property. The largest difference was for modulus of elasticity. Previous data indicated these differences vary from 5 to 26 percent, with the largest difference also for modulus of elasticity.

Average values for strength properties and specific gravity developed from mill samples agreed remarkably well with standard data for Douglas fir from the historic Coast region only. Strength properties and specific gravity of mill samples were strikingly lower in value than reported averages for material from the subregion called Interior West. The opposite was true for material from the Interior North subregion; substantial increases in values were detected by the present study. Information from a massive survey of timber density, made after our tests were conducted, confirmed our finding for specific gravity of Interior North material and modified a lower value developed from past standard samplings. Properties of material from the Interior South, although found in our study to be somewhat higher than reported from standard data, were lower than for other subregions.

# STRENGTH AND RELATED PROPERTIES OF DOUGLAS FIR FROM MILL SAMPLES

by

James D. Snodgrass and Arthur F. Noskowiak

## INTRODUCTION

The primary objective of our study was to develop precise, unbiased estimates of average values of salient strength and related properties of Douglas fir wood from specific regions so that differences could be analyzed statistically. A secondary objective was to demonstrate the feasibility of sampling the output of wood-processing plants by a special procedure that might be useful in the future, although perhaps with modifications.

Interpretation of basic data on strength, stiffness, and specific gravity of Douglas fir according to its geographic range resulted years ago in "regionalization" of the species. This situation is unique for an important domestic timber, because other species are not subdivided within their ranges of growth. The range of commercial Douglas fir includes 10 western states of the United States, however, and certain botanical evidence suggests that Douglas fir does have varietal forms (4, 7, 9, 13, 15).* Furthermore, differences between average values derived from usual tests of wood from coastal and inland sources had to be considered when regional classifications originally were established. Average values for coastal wood ranged from 5 percent higher for shearing strength to 26 percent higher for modulus of elasticity than those for material grown inland (7). Differences even larger than these were recorded from tests of standard samples of wood from coastal sources and similar samples from southwestern states. Until recently, available technical facts seemed to justify without question the argument for regionalization (2, 7, 8, 17, 24).

To re-examine this proposition, principal strength properties, modulus of elasticity, and specific gravity of unseasoned, clear specimens of Douglas fir were measured on material obtained from 405 sawmills within the range of the species. Proportionate-probability sampling was chosen for collecting test material instead of the usual procedure of getting specimens from selected standing trees at several locations. So-called green-chain or mill-sampling techniques were considered efficient ways of obtaining detailed information on basic

*Numbers in parentheses refer to references cited.

strength properties directly and at minimum cost, although these techniques have limitations that must be recognized.

Making a survey of strength and related properties of Douglas fir was justified because of three general objections raised before 1960 when our study began. First, some individuals believed that values for the inland region should be higher than shown by standard data. They argued that standard data are biased in a statistical as well as in a general sense because of the manner in which sampling was done in the past. In brief, were data reliable and representative? The question was difficult to answer, because rigorous proof through analysis of available data was not at hand and possibly could not be demonstrated.*

The second, and seemingly more valid, objection is related to conditions prevailing when some of the existing standard data on strength of Douglas fir were gathered. The fact that some data were gathered about 50 years ago (as of 1960) is not of itself especially important, if we assume that tests were made of material that is still representative. However, changes have taken place over the years in forests of Douglas fir. Old-growth trees have been removed and replaced by younger trees. Some of these and many stands of virgin timber formerly less accessible are currently important sources of logs. The mixture of types and qualities of timber being processed in any period--a year, for example--accordingly may have changed so much that available basic data no longer truly reflect the average characteristics of populations of trees being milled. Validity of this speculation could not be evaluated fully because of lack of appropriate studies. It seemed to justify, however, the gathering of new information on properties of Douglas fir currently available to the consumer.

A third issue concerned a scientific challenge to understand more fully the nature and sources of variability of wood, and the degree of homogeneity of properties within and among geographic localities of growth. One theory associated with this problem is that substantial volumes of Douglas fir may occur as pockets of weak material with low density located on limited, scattered areas, or as pockets of high-density material on other areas. Such areas certainly could not have been clearly defined within the general population of timber from results of previous samplings of Douglas fir, or any other species. Although not expressly designed to detect postulated pockets of low- and high-strength timber or to define their boundaries, our survey was planned to obtain new information on variability of strength and possibly develop limited insight into the heterogeneity of strength properties that exists.

*Technical discussion related to this problem will be found in references (12, 19, 22, 28).

Gathering bolts of Douglas fir throughout western forests would have been too costly and time-consuming because of the required scope and intensity of the survey. The plan for sampling, therefore, focused on sawmills as sampling units and sources of material for testing. Sampling at the mill, in contrast to taking samples in the forest, has been mentioned by Markwardt and Wilson (17), and was selected for specialized studies by McGowan (18), and Harris and Hellawell (10). The traditional standard procedure of forest sampling has been preferred, however, for scientific measurements of average strength properties of species. A recently reported example to the contrary concerning sampling of young-growth redwood is given in Research Paper FPL 53 of the Forest Products Laboratory, U.S. Forest Service, Madison, Wisconsin, "Strength and Related Properties of a Randomly Selected Sample of Second-Growth Redwood." February 1966.

Sampling at the mill was selected because this procedure would provide quick access, although admittedly indirect, to essentially the same populations of trees that supposedly are represented by standard sampling. A further recognized advantage was that many trees could be sampled at a production plant by taking only one piece from a log. This technique is consistent with the recommendations of several writers on the subject of efficient sampling of timber (12, 19, 21, 22, 28). Our study, however, was the first known attempt to sample wood on an intensive and wide-scale basis instead of sampling only a few standing trees. Mill sampling, then, was believed to have advantages of low cost, convenience, flexibility, and opportunity to eliminate known sources of bias, in comparison to the traditional procedure.

The boundary between regions is commonly assumed to be the one recommended by Drow (7); this is a line roughly coincident with $120^{\circ}$ west longitude in Washington and Oregon, and then extending southerly along the California-Nevada border (Figure 1). Recommendations for redefining the accepted boundary between regions, or further subdividing the full range of Douglas fir, were not specifically contemplated as a part of our study.

## FIELD AND LABORATORY PROCEDURES

The survey was limited to examining parts of the issues already outlined. Unbiased estimates of means and parameters of variability were needed for strength of wood from the two general regions, which in our study are designated "Coast" and "Interior." Furthermore, by "Coast West," we refer to the coastal areas of Oregon and Washington, a subregion of the coastal region heretofore called in other studies simply "Coast," or the "historic" or "traditional" Coast subregion. By the term "Coast East," we designate that subregion of the overall Coast region heretofore called "Interior West" (or "Intermediate"), which includes all Douglas fir areas in California, central Oregon, and central Washington. The subregions called "Interior North" and "Interior South" and the region known as "Interior" retain their designations as already recognized.

To somewhat increase efficiency of sampling, the two populations to be sampled were divided into strata. Several sampling strata were delineated within particular geographic boundaries, called areas, existing within each region. Analysis therefore yielded information on variation of properties among areas within the major regions. Undoubtedly, these areas are much larger and contain more timber than would be thought of as pockets. Nonetheless, we believed that the actual existence within major regions of small areas yielding high- or low-strength material might be partially confirmed.

### Sampling plan

Details of the plan were based on sampling theory as described by Cochran (5). The commercial range of Douglas fir was divided into 19 areas for sampling. The Coast region included 10 areas and the Interior region had 9. Areas were defined primarily by climate, topography, and political subdivisions, as well as by boundaries recognized in previous studies. Strata were determined by segregating the mills within each area into six classes according to their capacity for producing lumber during an 8-hour shift. Because knowledge about variance within the populations was lacking, stratification was done according to the best judgment available, although we recognized that other plans for stratification might be equally effective.

The first assignment of samples was to regions. This was done by optimizing on both cost of sampling and expected variance between regions. Sixty percent of the total samples were assigned to Coast and 40 percent to Interior. Number of samples allocated to each stratum within each region was based on the ratio of the estimated volume of Douglas fir lumber produced in the stratum to the estimated total production in the region. The probability for selecting a site (mill) within a stratum was proportionate to estimated lumber production for the stratum, compared to production in the region.

Number of samples collected within strata differed for dimension lumber, boards, and timbers because estimated production of these items differed for most strata. Allocations by probability techniques were made separately for the three kinds of material. Samples of dimension lumber (Table 1) were considered the primary objects of the survey; they were tested for strength. Boards and timbers were secondary; they were measured only for specific gravity.

Multiple-strata areas are illustrated in Figure 1. Distribution of samples is shown in Table 1. Scope of the sampling for regions and their subdivisions (subregions) is shown in Table 2. The number of

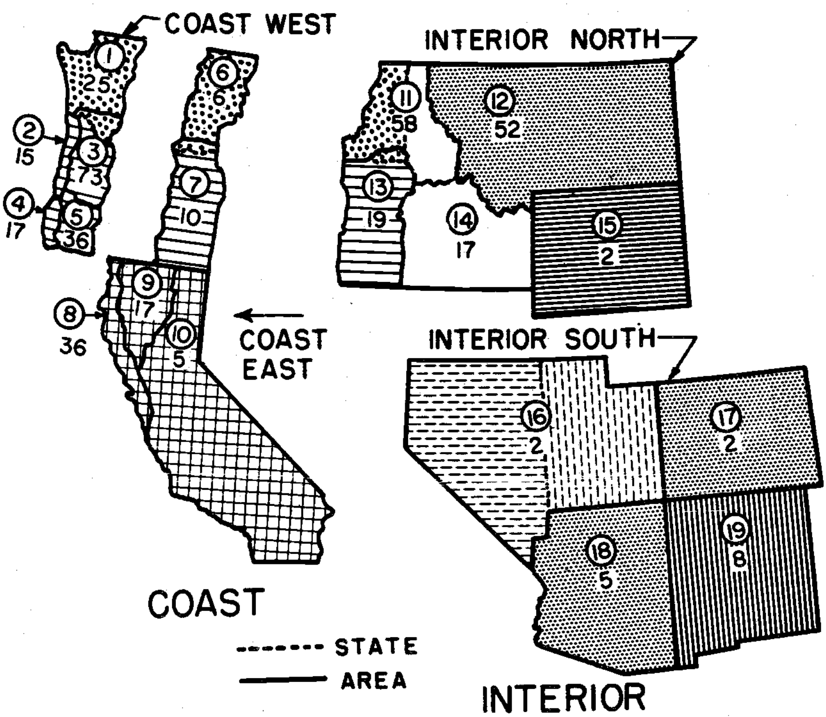


Figure 1. Coast and Interior regions were partitioned into multi-strata areas designated by numbers in circles. Number of samples gathered in an area is indicated under each circle. Oregon and Washington had areas in Coast West, Coast East, and Interior North subregions; the other states were entirely within a subregion.

Table 1. Number of Samples from Dimension Lumber within Strata.[1,2]

| Area (See Fig. 1) | Strata and capacity, M fbm per 8-hour shift | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1<br>0-9 | 2<br>10-19 | 3<br>20-39 | 4<br>40-79 | 5<br>80-119 | 6<br>120+ | All |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Coast West | | | | | | | |
| 1 | 2 | 4 | 6 | 5 | 3 | 5 | 25 |
| 2 | [ 0 | 1 | 2] [3] | 5 | 2 | 5 | 15 |
| 3 | 2 | 3 | 10 | 21 | 15 | 22 | 73 |
| 4 | [ 0 | 0 | 3] | 4 | 2 | 8 | 17 |
| 5 | [ 0 | 2] | 3 | 13 | 10 | 8 | 36 |
| All | 4 | 10 | 24 | 48 | 32 | 48 | 166 |
| Coast East | | | | | | | |
| 6 | [ 1 | 1] | 2 | [ 2 | 0 | 0] | 6 |
| 7 | [ 1 | 1] | 2 | 4 | [ 1 | 1] | 10 |
| 8 | [ 1 | 2] | 4 | 13 | 7 | 9 | 36 |
| 9 | [ 0 | 1 | 5] | 6 | [ 4 | 1] | 17 |
| 10 | [ 1 | 2] | [ 2 | 0 | 0 | 0] | 5 |
| All | 4 | 7 | 15 | 25 | 12 | 11 | 74 |
| All Coast | 8 | 17 | 39 | 73 | 44 | 59 | 240 |
| Interior North | | | | | | | |
| 11 | 9 | 19 | 19 | [ 11 | 0 | 0] | 58 |
| 12 | 8 | 16 | 15 | 10 | [ 3 | 0] | 52 |
| 13 | 2 | 5 | 9 | [ 3 | 0 | 0] | 19 |
| 14 | 3 | 4 | 7 | [ 3 | 0 | 0] | 17 |
| 15 | [ 2 | 0 | 0 | 0 | 0 | 0] | 2 |
| All | 24 | 44 | 50 | 27 | 3 | 0 | 148 |
| Interior South | | | | | | | |
| 16 | [ 2 | 0 | 0 | 0 | 0 | 0] | 2 |
| 17 | [ 2 | 0 | 0 | 0 | 0 | 0] | 2 |
| 18 | [ 2 | 0] | [ 3 | 0 | 0 | 0] | 5 |
| 19 | [ 3 | 1] | [ 3 | 1 | 0 | 0] | 8 |
| All | 9 | 1 | 6 | 1 | 0 | 0 | 17 |
| All Int | 33 | 45 | 56 | 28 | 3 | 0 | 165 |
| All areas | 41 | 62 | 95 | 101 | 47 | 59 | 405 |

[1]Samples were allocated and collected within each region proportionately to Douglas fir lumber manufactured within the region except for areas 16-19.

[2]Most samples of dimension lumber had seven specimens, but most samples of boards and timbers had five.

[3]Samples bracketed within areas were combined for analysis.

Table 2. Sampling of Dimension Lumber and Distribution of Lumber Production and Standing Timber.

| Area | Samples[1] | Speci-mens[2] | Proportion | | | |
|---|---|---|---|---|---|---|
| | | | Within region | | Within range | |
| | | | Lumber[3] | Timber[4] | Lumber[3] | Timber[4] |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| | | | % | % | % | % |
| Coast West | | | | | | |
| 1 | 25 | 170 | 10.7 | 12.2 | 9.3 | 9.6 |
| 2 | 15 | 105 | 6.4 | 34.5[5] | 5.5 | 27.1[5] |
| 3 | 73 | 508 | 30.2 | | 26.2 | |
| 4 | 17 | 119 | 6.7 | 7.2 | 5.8 | 5.6 |
| 5 | 36 | 251 | 14.7 | 15.6 | 12.8 | 12.2 |
| All | 166 | 1,153 | 68.7 | 69.5 | 59.6 | 54.5 |
| Coast East | | | | | | |
| 6 | 6 | 40 | 2.1 | 4.3 | 1.9 | 3.4 |
| 7 | 10 | 70 | 3.7 | 2.7 | 3.2 | 2.1 |
| 8 | 36 | 252 | 15.7 | 15.0 | 13.6 | 11.8 |
| 9 | 17 | 119 | 7.4 | 8.5[5] | 6.4 | 6.7[5] |
| 10 | 5 | 35 | 2.4 | | 2.0 | |
| All | 74 | 516 | 31.3 | 30.5 | 27.1 | 24.0 |
| All Coast | 240 | 1,669 | 100.0 | 100.0 | 86.7 | 78.5 |
| Interior North | | | | | | |
| 11 | 58 | 402 | 36.5 | 17.5 | 4.8 | 3.8 |
| 12 | 52 | 363 | 31.8 | 33.4 | 4.2 | 7.2 |
| 13 | 19 | 131 | 12.7 | 9.0 | 1.7 | 2.0 |
| 14 | 17 | 119 | 10.2 | 21.5 | 1.4 | 4.6 |
| 15 | 2 | 14 | 0.7 | 1.9 | 0.1 | 0.4 |
| All | 148 | 1,029 | 91.9 | 83.3 | 12.2 | 18.0 |
| Interior South | | | | | | |
| 16 | 2 | 14 | 1.1 | 2.5 | 0.1 | 0.5 |
| 17 | 2 | 14 | 1.8 | 6.6 | 0.3 | 1.4 |
| 18 | 5 | 35 | 1.2 | 3.0 | 0.2 | 0.6 |
| 19 | 8 | 56 | 4.0 | 4.6 | 0.5 | 1.0 |
| All | 17 | 119 | 8.1 | 16.7 | 1.1 | 3.5 |
| All Int | 165 | 1,148 | 100.0 | 100.0 | 13.3 | 21.5 |
| All areas | 405 | 2,817 | --- | --- | 100.0 | 100.0 |

[1]From column 8 of Table 1.

[2]From column 2 of Table 3.

[3]Based on estimated total volume of Douglas fir lumber produced during 8-hour period in 1959.

[4]Based on estimated cubic-foot volume of all standing Douglas fir timber to a 5-inch top diameter in 1963 (U.S. Forest Service surveys).

[5]Data for individual areas could not be developed.

specimens listed in column 3 applies only to tests for modulus of elasticity, modulus of rupture, and specific gravity of dimension lumber. Numbers differed slightly for tests in compression and shear (See columns 15 and 21 of Table 3). For specific gravity tests of boards and timbers, numbers differed appreciably. Factors in column 4, Table 2 were used for weighting in the computation of subregional means for specific gravity and all strength properties of dimension lumber, and also for specific gravity of boards. Regional weights in column 6, Table 2 were used to compute general means for the species. Because the basis for the plan was the estimated production of Douglas fir in 1959 from all western sawmills, we were curious about possible agreement between our distribution and the distribution of forest volume. Comparisons are given by columns 4 and 5, and also columns 6 and 7, of Table 2. With a few exceptions, the first two columns (within-region weight) compare closely. When the hazards involved in such estimates are considered, the agreement was surprising.

Sampling units (mills) were chosen at random from lists of companies (6,23,26,27) by location and production capacity. Mills were assigned to one of six production classes based upon volume of Douglas fir lumber manufactured during an 8-hour shift. Original target was to get samples from 400 mills, out of a total of about 1,600 mills cutting Douglas fir in 10 western states; 405 mill samples actually were collected.

Collecting samples

Field crews working independently from Pullman, Washington, and Corvallis, Oregon, collected samples. Collections were planned so that most localities were covered by two series of spaced visits. Different mills, selected at random, were contacted during each series. Spacing of the random visits was designed to offset unknown seasonal effects on the supply of logs that mills happened to be processing. Because all samples were collected within about 5 months starting in June 1960, these effects, if present, obviously were not fully included.

Samples were obtained from rough, unseasoned dimension lumber. A time-and-count system controlled selection of individual pieces of lumber of random length, width, and grade appearing on the sorting chain during the sampling period. Time between selection of pieces of lumber was long enough to insure that two pieces did not come from the same log. Probability was high that only one piece was obtained from any one tree.

Pieces 4 feet long were cut from lumber selected, and seven such pieces constituted a sample. As pieces were selected, a crayon-mark cutting index was put on the right corner of the upper face nearest the collector. This index was the starting point for orientation of specimens to be prepared for testing at the laboratory. Three additional 4-foot pieces were collected as spare material for use if anv of the first seven did not yield suitable, clear, surfaced specimens for tests.

At sawmills producing boards or timbers (or both) in addition to dimension lumber, a sample of five pieces of each of these products was gathered. Only specific gravity of such specimens was measured. We expected by this "opportunity" sampling to obtain estimates of specific gravity for all zones in logs, because dimension lumber is cut often from the inner portions of a log, and boards usually are cut from the

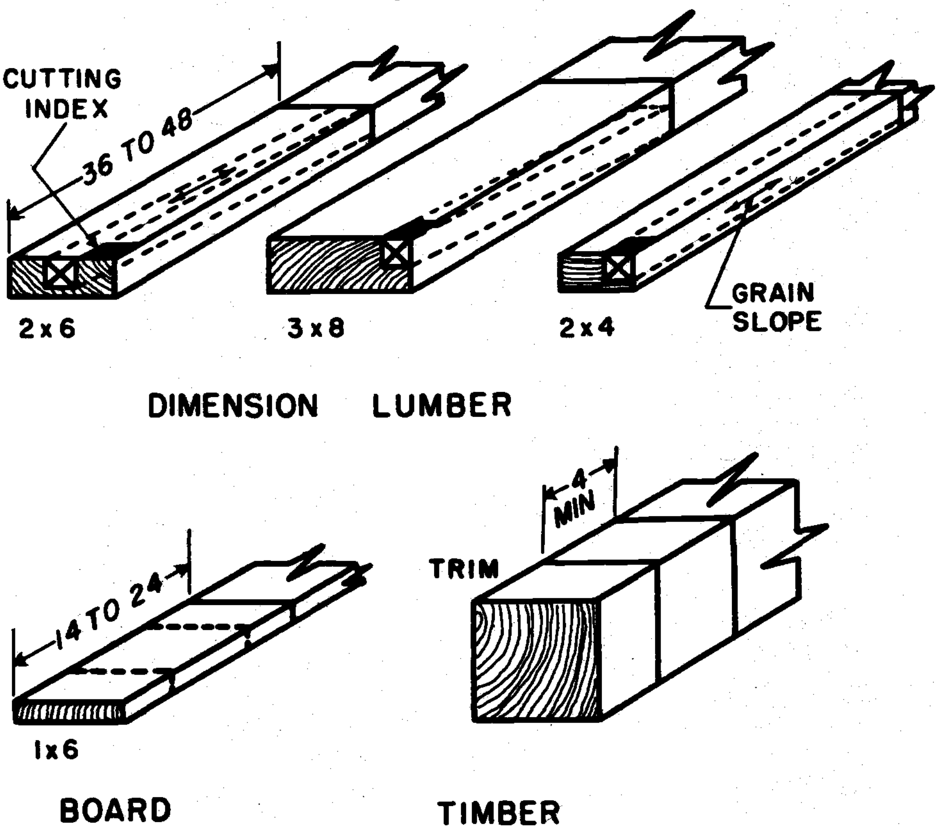


Figure 2. Pieces of unseasoned dimension lumber about 4 feet long were sawed from long lengths at sawmills, and a "cutting index" was put on the near right corner. Sticks about 1.75 inches square were prepared by ripping generally parallel to the grain of the piece, and as near as possible to the cutting index. Pieces of unseasoned boards and timbers also were collected for auxiliary tests of specific gravity. Dimensions shown are inches.

outside. Timbers frequently contain pith and wide-ringed wood surrounding the pith at the log's center and, because they are special products, are cut to order at few sawmills.

Preparing and testing specimens

The same objectivity was practiced in preparing specimens as in selecting samples. The cutting index previously mentioned was in the same position on all pieces, and cutting of blanks, from which final test specimens came, was started from this location, as shown in Figure 2. All collected material was kept wet; consequently, specimens were unseasoned when tested.

Three major tests for strength were made on specimens obtained from dimension lumber: static bending, compression parallel to grain, and shear parallel to grain. Specific gravity was measured on sections 6 inches long that were cut from specimens broken in static bending (Figure 3). Pieces of the boards and cross sections from timbers were measured for specific gravity only.

Some departure from standard procedures as given by the American Society for Testing and Materials (1) was necessary for testing

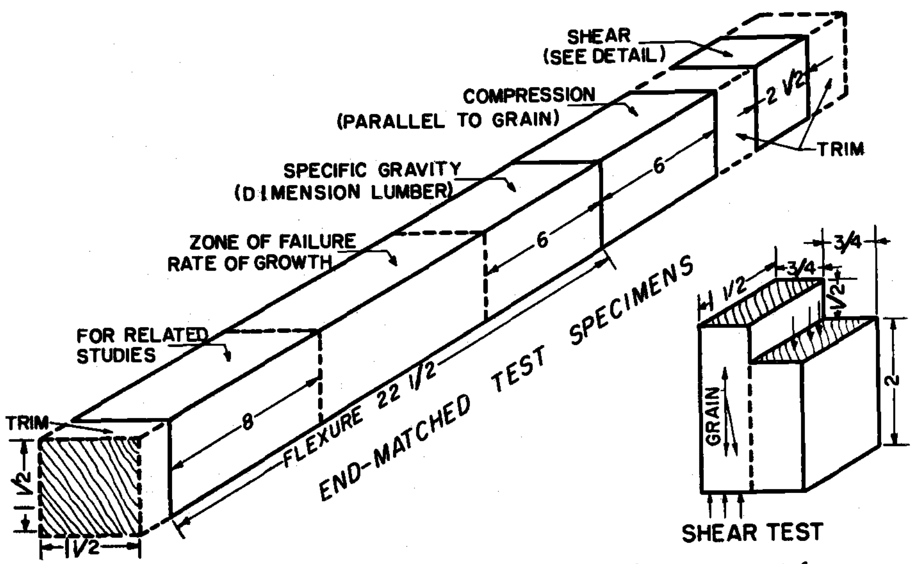


Figure 3. End-matched specimens for a test series were cut from a clear stick with straight grain (surfaced uniformly to a cross section 1 1/2 inches square) that was prepared without regard to orientation of annual rings. Flexure specimen was subdivided for other uses after it was tested. Shear-test specimen was machined to achieve failure parallel to the longitudinal axis of the specimen. Dimensions are inches.

clear specimens of wood. Size of specimens (1 1/2 inches square in cross section, instead of 2 inches) and orientation of annual rings with respect to surfaces of the specimen had to be nonstandard, because most test pieces were made from lumber nominally 2 inches thick. Specimen geometry, rates of loading, and precision of measuring loads and deformations followed standard practice, however.

There was no difficulty in preparing specimens with acceptably straight grain that were free from defects and blemishes that might have biased test results. A few specimens with obvious extensive compression wood were replaced by specimens from spare material.

Responsibility for testing was shared on the following basis:

Personnel at Washington State University, testing dimension lumber, obtained moduli of elasticity and rupture from tests in static bending, measured specific gravity (based on unseasoned volume and oven-dry weight) of the 6-inch section from the specimen broken in the bending tests, and measured rate of growth for all specimens having fewer than 20 annual rings to the inch.

Personnel at Oregon State University did tests of axial compression and shear parallel to grain on dimension lumber (end-matched to the bending specimen) to obtain maximum crushing and maximum shearing strengths, and measured specific gravity of specimens from boards and sections cross-cut from timbers.

A total of 2,835 (7 x 405) tests of each major property were planned on specimens cut from dimension lumber. For a few mill samples, however, there were insufficient suitable pieces to prepare a full series of specimens for testing even with inclusion of the three spare pieces, chiefly because of unseen defects. Consequently, number of tests of each property was not seven for all samples, although the final program came close to that objective.

Theoretically, 2,025 (5 x 405) measurements of specific gravity for boards and for timbers were possible. Because boards were not produced at all sawmills, however, only 1,688 pieces could be collected. Scarce, sporadic production of timbers permitted collection of only 417 specimens of this type of material, mostly from mills in the Coast region.

## COMPUTATIONS AND ANALYSES

Basic computations were made at Washington State University, where a computer was programmed to calculate values of strength, modulus of elasticity, and specific gravity of individual specimens from laboratory test data. For each property, the sample average (mean) for each mill was the datum needed for most of the analysis. In addition, the simple (unweighted) means of sample means for strata within regions, together with appropriate variances, were computed. An analysis of variance was made so that homogeneity of variance within and among strata in a region could be examined. Further analyses such as correlation, regression, and study of distributions were made at Oregon State University.

### Consolidation of strata

Some potential strata were combined across mill-production classes within areas so that there were at least two mill samples in each composite stratum, and so that means and variances were about the same magnitude for the combined potential strata (Table 1). Thirty-eight of the 114 possible sampling strata in both regions had no lumber production (hence no samples allocated), and 13 had only one sample allocated. Potential strata with lumber production therefore totaled 76 (114 minus 38). This number was further reduced to 66 because of combining. The Coast sample included 42 strata and the Interior sample had 24.

A slightly different pattern resulted by consolidating the strata from which boards and timber cross sections were collected, but the principles followed were similar to those just described.

### Multiple-strata, regional, and general means

Mean values ($\bar{Y}$) of properties by areas, regions, and the total population were estimated by the following formula selected from Cochran (5):

$$\bar{Y}_i = \sum \frac{V_j \bar{Y}_j}{V_i}$$

The formula was used in compiling a mean value for the $i$ th region, where unweighted means of sample means for strata within the region ($\bar{Y}_j$) are weighted by the strata weights ($V_j$) based upon production of lumber within strata. By redefining subscripts and using applicable weighting factors, the formula also was used in compiling mean values for areas within regions, general mean values for the species, and mean values for specific gravity of boards and timber cross sections.

Weighting factors used were the estimates of daily production of Douglas fir lumber (in board feet) within strata and regions. These volume figures, expressed as percentages within regions and other subdivisions, are listed in column 4 of Table 2.

Probability sampling within each region in the survey was arranged so that estimated production of lumber for regions and strata within them was the basis for allocating samples to strata within regions. Therefore, estimates of lumber production, $V_j$ and $V_i$, appear in the equation just given. Because sampling was not proportionate to lumber production throughout the geographic range of Douglas fir (across regions), however, reweighting of individual regional means consistent with the scheme chosen for regions was applied when overall or general means for the species were calculated. Weighting factors were about 87 percent for the Coast region and 13 percent for the Interior region (column 6, Table 2).

The Coast sample was virtually self-weighted because allocation of samples was proportionate to estimated lumber production, and the size of samples was the same (seven pieces for testing) for nearly all samples. Therefore, number of tests of Coast material for each stratum and for the region could be substituted for $V_j$ and $V_i$ in the equation for calculating mean values. The Interior sample was not self-weighted, however, because the original allocation of samples to the Interior South (areas 16-19) was arbitrarily doubled to intensify the survey where lumber production is low. Because the Interior sample was, therefore, not self-weighted, and as the samples obviously were not self-weighted across the regions, the procedure was to use data on production from the original allocating scheme for calculating all average values.

Material of selected growth rate

Rules for separating certain structural grades of Douglas fir recognize relations between rate of growth and strength and between percentage of summerwood and strength. The relation between strength and growth rate was checked in a limited way. Average values were calculated after segregating test values into groups having four and more, and also six and more, annual rings to the inch. The percentage of summerwood was not measured.

Variance

Variance of the estimated mean of a property for a region was calculated from the following formula:

$$s^2_{\bar{Y}_i} = \frac{1}{V_i^2} \sum V_j^2 \cdot \frac{s_j^2}{n_j}$$

where $s_j^2$ and $n_j$ are variance among sample means and number of samples for the jth stratum, and the V's are weighting factors developed from volume of lumber production. Variances of estimated mean values for samples from the Interior North and Interior South were calculated by the same formula. The Coast sample was not partitioned into subregions, largely because practical boundaries could not be forecast when the survey was planned.

Estimates of standard error of means and measures of precision were obtained by conventional statistical procedures from knowledge of variances for regions and subregions. Tests for significance of differences between means for regions or subregions were made by the following relation for the t-test (14):

$$t = \frac{\bar{Y}_1 - \bar{Y}_2}{\sqrt{s^2_{\bar{Y}_1} + s^2_{\bar{Y}_2}}}$$

where subscripts 1 and 2 refer to regions being tested.

Degrees of freedom were sufficient so that t could be considered as a normal deviate. Probability, p, that the computed t-value will be exceeded only because of chance was determined from appropriate tables. A probability as high as 0.05 (5.0 percent) was understood to be "statistically significant." The t-test was applied to all properties observed, including specific gravity measured on samples of boards, but not including samples of cross sections from timbers.

Because the main objective of the survey was to develop unbiased estimates of means for properties of Douglas fir from each of the two regional sources, the precision to which means were estimated was important. Nearly equal precision of the estimates was required so that regional means could be compared statistically. A target for precision of 1 percent, or less, was set when the sampling plan was devised.

Standard deviations and exclusion values

Standard deviation, s, and coefficient of variation, CV, associated with a regional mean were calculated from the value for variance, from the relationship, $s^2 = s^2_{\bar{Y}} \cdot n$, where n is the number of samples for a region or other subdivision. The square root of $s^2$ is the standard deviation, s; coefficient of variation (in percent) is $100\ s/\bar{Y}$, where $\bar{Y}$ is the mean value. These statistics were expected to have values substantially smaller than are normally developed from test data for wood, because the component of variance reflecting variability among pieces within the samples was not included in the error term, $s^2_{\bar{Y}}$. Accordingly, these measures of dispersion were estimates only of variability among samples, each of which, in most instances, consisted of seven observations.

To obtain standard deviations that are comparable to the statistics found in literature on strength of wood, the error term just described was combined with the error associated with variability among pieces within the samples for a region. This estimate of "total error" is not quite the same as would be obtained from combining components of variance within and among trees for data developed from standard forest-sampling practice. By such procedure, a rather large, but variable, weight will be assigned to the within-tree component of variance and a comparatively small weight to the between-tree component, because the number of trees usually included in forest samples is limited. In sampling at mills, we usually obtained no more than one test specimen from a tree; therefore, the total error is presumed to reflect predominantly the variability among the large number of trees sampled in this study.

Variability in properties, expressed as the coefficient of variation, based on all specimens tested, was estimated from the following formula:

$$CV = \frac{\sqrt{V_1 s_1^2 + V_2 s_2^2}}{V_1 \bar{Y}_1 + V_2 \bar{Y}_2} \cdot 100$$

in which subscripts 1 and 2 refer to regions being combined, and $s^2$, $\bar{Y}$, and $V$ represent total variance as just defined, regional mean, and weight. Overall standard deviation is related to the mentioned $CV$, because $s = CV(\bar{\bar{Y}})/100$, where $\bar{\bar{Y}}$ is the overall weighted mean for a strength or related property.

Following conventional statistical procedures, the 5 percent exclusion values of properties were calculated from survey data pertaining to areas, regions, and the total population of Douglas fir.

## RESULTS AND DISCUSSION

### Mean values for regions and subregions

Mean values for samples of dimension lumber were greater for Coast than for Interior material for all properties except maximum shearing strength (Table 3).

A logical explanation for average shearing strength of Douglas fir from Interior-North sources being higher than for material from Coast sources could not be developed (Table 3). The difference was only 44 psi, but it was statistically significant. Because of the general relation of strength to specific gravity, shearing strength could be expected to fit into the pattern for other properties and to be higher for Coast than for Interior material.

Values of differences between the two regions (Coast and Interior) were statistically significant (Table 4). Probabilities associated with the *t*-test of these differences were fractions of 1 percent, which indicated only the remotest possibility that differences were due to chance only. Tests of significance of differences between means for Coast and Interior-North material gave essentially the same results, except that differences were not so great, and probabilities were somewhat greater. A probability of nearly 6 percent pertaining to specific gravity of samples from dimension lumber was the most notable.

Tests of significance of differences between means for wood from Coast West and Coast East yielded nearly the same probabilities for each property as for material from the Coast region and Interior-North subregion (Table 4). Tests of significance of differences between means for materials from Coast East and Interior North indicated that the differences were nonsignificant for properties other than shearing strength (Table 4). The conclusion, therefore, is that wood properties in each of the subregions of the Coast region are two distinct populations. It is also possible that Coast East is really a part of Interior North.

Means for material from the Interior-South subregion and samples from the Interior North or the Coast were not tested for differences, statistically, because they were obviously different (Table 3). Yet, the influence of low values for Interior-South material on the Interior sample in general was small, because of the low volume of production, hence minor weight, for the southern subregion.

Although differences between regional means were statistically significant for all properties, percentage differences were not large. A summary of comparative values developed from three sources of information is given in Table 5. The most extensive previous study of properties of Douglas fir (7) revealed that averages for Coast material ranged from 1.05 to 1.26 times those of Interior material; the smallest ratio was for maximum shearing strength and the largest for modulus of elasticity. The ratio for specific gravity was 1.06. Our survey revealed that ratios ranged from 0.96 to 1.09; the largest was for modulus of elasticity. The ratio for specific gravity was 1.02.

The latest findings, compiled from Western Wood Density Survey (25), indicate that the ratios range from 0.96 to 1.13, with the ratio for specific gravity being almost 1.00. In that study, results from our mill-sample survey were merged, by the analytical technique known as double sampling, with data previously gathered from forest samples. The effect was to lower the ratios first mentioned because of a compromise with the small ratios found from the mill-sampling program. If we assume that this compromise now provides the most reliable estimates of mean values for the main regions producing Douglas fir, the largest ratio (1.13) for modulus of elasticity seemingly is the most critical. This ratio would be lowered to about 1.10 if the mean modulus of elasticity pertaining to the Interior-South subregion were removed from the analysis.

Mean values for total population

Mean values of strength properties for the total population of Douglas fir (Table 3) are valid under the assumptions that the separate regional samples in this study are recognized collectively as one population, an arbitrary decision; and that means for each regional sample were reliably estimated for the populations as defined. When similar assumptions are applied to the mean values for "total" Douglas fir given previously by Drow (7), our mill samples were higher in specific gravity, modulus of rupture, and modulus of elasticity, but lower in maximum crushing and shearing strengths. Percentage differences between Drow's general average values and our data are small, however. The small differences resulted primarily from finding from the mill samples that substantially higher strength prevails for Interior material than for Coast material, contrary to information previously reported. This finding, together with the effect of weighting of regional mean values developed from the mill samples, seems to explain the close overall agreement between studies. The latest data (25) on density of Douglas fir developed from an extensive sampling of commercial timber show that trees from the Coast and Interior North are almost identical in specific gravity (at about 0.45), and suggest that somewhat higher values of strength should have been detected for Douglas fir from the Interior by the mill samples, particularly for samples from Interior North. This was the finding, except that specific gravity of Interior-North material was about 0.44, and, theoretically, it should have been 0.45. The Coast sample, however, was also found to be about 0.44,

Table 3. Means and Related Data for Strength Properties of Dimension Lumber

| Area | Speci-mens | Specific gravity[1] | | | | Modulus elas- | | |
|---|---|---|---|---|---|---|---|---|
| | | Mean[2] | Stand-ard devia-tion[3] | Coeffi-cient of varia-tion[4] | Exclu-sion value[5] | Mean[2] | Stand-ard devia-tion[3] | Coeffi-cient of varia-tion[4] |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| | | | | % | | Mpsi | Mpsi | % |
| Coast West | | | | | | | | |
| 1 | 170 | 0.444 | 0.0488 | 10.9 | 0.364 | 1,615 | 295.6 | 18.3 |
| 2 | 105 | .444 | .0494 | 11.1 | .363 | 1,496 | 244.8 | 16.4 |
| 3 | 508 | .439 | .0519 | 11.8 | .354 | 1,528 | 323.7 | 21.2 |
| 4 | 119 | .471 | .0636 | 13.5 | .366 | 1,670 | 306.0 | 18.3 |
| 5 | 251 | .448 | .0541 | 12.1 | .359 | 1,498 | 291.1 | 19.4 |
| All | 1,153 | .445 | .0537 | 12.1 | .357 | 1,546 | 308.8 | 20.0 |
| Coast East | | | | | | | | |
| 6 | 40 | 0.419 | 0.0378 | 9.0 | 0.357 | 1,320 | 211.8 | 16.0 |
| 7 | 70 | .425 | .0527 | 12.4 | .338 | 1,373 | 301.0 | 21.9 |
| 8 | 252 | .456 | .0541 | 11.9 | .367 | 1,474 | 314.7 | 21.4 |
| 9 | 119 | .415 | .0598 | 14.4 | .317 | 1,290 | 301.7 | 23.4 |
| 10 | 35 | .419 | .0442 | 10.6 | .346 | 1,302 | 305.4 | 23.5 |
| All | 516 | .437 | .0566 | 13.0 | .344 | 1,395 | 312.2 | 22.4 |
| All Coast | 1,669 | 0.443 | 0.0547 | 12.4 | 0.353 | 1,499 | 317.7 | 21.2 |
| Interior North | | | | | | | | |
| 11 | 402 | 0.443 | 0.0482 | 10.9 | 0.364 | 1,458 | 258.1 | 17.7 |
| 12 | 363 | .437 | .0484 | 11.1 | .357 | 1,370 | 269.3 | 19.7 |
| 13 | 131 | .443 | .0488 | 11.0 | .363 | 1,398 | 277.4 | 19.8 |
| 14 | 119 | .413 | .0447 | 10.8 | .339 | 1,261 | 245.0 | 19.4 |
| 15 | 14 | .399 | .0347 | 8.7 | .342 | 1,191 | 260.0 | 21.8 |
| All | 1,029 | .437 | .0489 | 11.2 | .357 | 1,396 | 270.9 | 19.4 |
| Interior South | | | | | | | | |
| 16 | 14 | 0.380 | 0.0700 | 18.4 | 0.265 | 1,088 | 272.6 | 25.1 |
| 17 | 14 | .414 | .0576 | 13.9 | .319 | 1,031 | 190.5 | 18.5 |
| 18 | 35 | .392 | .0460 | 11.7 | .316 | 1,079 | 250.7 | 23.2 |
| 19 | 56 | .405 | .0488 | 12.1 | .325 | 1,170 | 218.8 | 18.7 |
| All | 119 | .402 | .0522 | 13.0 | .316 | 1,114 | 234.6 | 21.0 |
| All Int | 1,148 | 0.434 | 0.0505 | 11.6 | 0.351 | 1,373 | 280.0 | 20.4 |
| All areas | 2,817 | 0.442 | 0.0542 | 12.3 | 0.352 | 1,482 | 313.0 | 21.1 |

[1] Based on unseasoned volume and oven-dry weight.

[2] Each mean is a mean of sample means weighted by estimated total volume of lumber produced during 8-hour period (See columns 4 and 6 of Table 2 for weighting factors).

Table 3 (Continued)

| of ticity | Modulus of rupture | | | | Maximum crushing strength[6] | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Exclusion value[5] | Mean[2] | Standard deviation[3] | Coefficient of variation[4] | Exclusion value[5] | Specimens | Mean[2] | Standard deviation[3] | Coefficient of variation[4] | Exclusion value[5] |
| 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| M psi | Psi | Psi | % | Psi | | Psi | Psi | % | Psi |
| 1,129 | 7,770 | 1,275 | 16.4 | 5,670 | 172 | 3,660 | 654 | 17.9 | 2,580 |
| 1,093 | 7,590 | 1,131 | 14.9 | 5,730 | 105 | 3,540 | 575 | 16.3 | 2,590 |
| 996 | 7,410 | 1,226 | 16.5 | 5,390 | 511 | 3,460 | 655 | 18.9 | 2,380 |
| 1,167 | 8,240 | 1,302 | 15.8 | 6,100 | 119 | 3,830 | 708 | 18.5 | 2,660 |
| 1,019 | 7,630 | 1,229 | 16.1 | 5,610 | 251 | 3,560 | 689 | 19.3 | 2,430 |
| 1,038 | 7,610 | 1,256 | 16.5 | 5,540 | 1,158 | 3,560 | 670 | 18.8 | 2,460 |
| | | | | | | | | | |
| 972 | 7,020 | 1,096 | 15.6 | 5,220 | 40 | 3,280 | 487 | 14.9 | 2,480 |
| 878 | 6,940 | 1,234 | 17.8 | 4,910 | 70 | 3,320 | 740 | 22.3 | 2,100 |
| 956 | 7,800 | 1,264 | 16.2 | 5,720 | 251 | 3,680 | 689 | 18.7 | 2,550 |
| 794 | 6,830 | 1,351 | 19.8 | 4,610 | 119 | 3,120 | 687 | 22.0 | 1,990 |
| 800 | 6,790 | 1,025 | 15.1 | 5,100 | 35 | 3,050 | 577 | 18.9 | 2,100 |
| 881 | 7,340 | 1,335 | 18.2 | 5,140 | 515 | 3,430 | 720 | 21.0 | 2,250 |
| 976 | 7,530 | 1,286 | 17.1 | 5,420 | 1,673 | 3,520 | 688 | 19.6 | 2,390 |
| | | | | | | | | | |
| 1,033 | 7,610 | 1,095 | 14.4 | 5,810 | 400 | 3,500 | 576 | 16.5 | 2,550 |
| 927 | 7,300 | 1,107 | 15.2 | 5,480 | 363 | 3,340 | 584 | 17.5 | 2,380 |
| 942 | 7,240 | 1,085 | 15.0 | 5,460 | 133 | 3,260 | 614 | 18.8 | 2,250 |
| 858 | 6,670 | 986 | 14.8 | 5,050 | 118 | 2,930 | 565 | 19.3 | 2,000 |
| 763 | 6,350 | 956 | 15.0 | 4,780 | 14 | 2,750 | 357 | 13.0 | 2,160 |
| 950 | 7,340 | 1,125 | 15.3 | 5,490 | 1,028 | 3,340 | 608 | 18.2 | 2,340 |
| | | | | | | | | | |
| 640 | 5,980 | 1,148 | 19.2 | 4,090 | 14 | 2,510 | 516 | 20.6 | 1,660 |
| 718 | 6,370 | 833 | 13.1 | 5,000 | 14 | 2,800 | 345 | 12.3 | 2,230 |
| 667 | 6,160 | 1,122 | 18.2 | 4,310 | 35 | 2,750 | 542 | 19.7 | 1,860 |
| 810 | 6,580 | 1,028 | 15.6 | 4,890 | 56 | 2,800 | 467 | 16.7 | 2,030 |
| 728 | 6,390 | 1,061 | 16.6 | 4,640 | 119 | 2,760 | 487 | 17.7 | 1,960 |
| 912 | 7,260 | 1,156 | 15.9 | 5,360 | 1,147 | 3,290 | 623 | 18.9 | 2,260 |
| 967 | 7,490 | 1,270 | 17.0 | 5,400 | 2,820 | 3,490 | 680 | 19.5 | 2,370 |

[3]Value for individual specimen.

[4]Standard deviation expressed as a percentage of the mean.

Table 3. (Continued)

| Area | Maximum shearing strength[6] | | | | |
|---|---|---|---|---|---|
| | Speci- mens | Mean[2] | Stand- ard devia- tion[3] | Coeffi- cient of varia- tion[4] | Exclu- sion value[5] |
| 20 | 21 | 22 | 23 | 24 | 25 |
| | | Psi | Psi | % | Psi |
| Coast West | | | | | |
| 1 | 172 | 894 | 124 | 13.9 | 690 |
| 2 | 105 | 878 | 118 | 13.4 | 684 |
| 3 | 511 | 871 | 125 | 14.4 | 665 |
| 4 | 119 | 963 | 154 | 16.0 | 710 |
| 5 | 251 | 856 | 118 | 13.8 | 662 |
| All | 1,158 | 881 | 130 | 14.8 | 667 |
| Coast East | | | | | |
| 6 | 40 | 857 | 118 | 13.8 | 663 |
| 7 | 70 | 857 | 120 | 14.0 | 660 |
| 8 | 251 | 935 | 121 | 12.9 | 736 |
| 9 | 119 | 878 | 159 | 18.1 | 616 |
| 10 | 35 | 888 | 124 | 14.0 | 684 |
| All | 515 | 904 | 136 | 15.0 | 680 |
| All Coast | 1,673 | 888 | 131 | 14.8 | 673 |
| Interior North | | | | | |
| 11 | 403 | 929 | 113 | 12.2 | 743 |
| 12 | 362 | 968 | 140 | 14.5 | 738 |
| 13 | 133 | 917 | 114 | 12.4 | 729 |
| 14 | 119 | 860 | 111 | 12.9 | 677 |
| 15 | 14 | 828 | 67 | 8.1 | 718 |
| All | 1,031 | 932 | 127 | 13.6 | 723 |
| Interior South | | | | | |
| 16 | 14 | 764 | 121 | 15.8 | 565 |
| 17 | 14 | 861 | 96 | 11.1 | 703 |
| 18 | 35 | 794 | 131 | 16.5 | 604 |
| 19 | 56 | 819 | 108 | 13.2 | 641 |
| All | 119 | 818 | 117 | 14.3 | 626 |
| All Int | 1,150 | 923 | 132 | 14.3 | 706 |
| All areas | 2,823 | 893 | 131 | 14.7 | 678 |

[5] Value corresponding to the lower 5-percentage point in a normal frequency distribution.

[6] Parallel to the grain.

Table 4. Tests of Significance of the Difference between Means for Regions and Subregions.

| Statistic | Specific gravity | Elasticity modulus | Rupture modulus | Crushing strength | Shearing strength |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| Coast and Interior | | | | | |
| Difference between means, psi, col 3-6 | 0.009 | 126,000 | 270 | 230 | -35 |
| Difference between means,[1] percent | 2.0 | 8.4 | 3.6 | 6.5 | 3.9 |
| t-value | 3.046 | 7.885 | 4.331 | 6.624 | 4.634 |
| Degrees of freedom | 339 | 339 | 339 | 339 | 339 |
| Probability for t-value found, percent | 0.2 | $<0.1$ | $<0.1$ | $<0.1$ | $<0.1$ |
| Coast and Interior North | | | | | |
| Difference between means, psi, col 3-6 | 0.006 | 103,000 | 190 | 180 | -44 |
| Difference between means,[1] percent | 1.4 | 6.9 | 2.5 | 5.1 | 5.0 |
| t-value | 1.899 | 6.217 | 2.971 | 4.980 | 5.626 |
| Degrees of freedom | 328 | 328 | 328 | 328 | 328 |
| Probability for t-value found, percent | 5.9 | $<0.1$ | 0.3 | $<0.1$ | $<0.1$ |
| Coast West and Coast East | | | | | |
| Difference between means, psi, col 3-6 | 0.008 | 151,100 | 270 | 130 | -23 |
| Difference between means,[1] percent | 1.8 | 9.8 | 3.5 | 3.6 | 2.6 |
| t-value | 1.903 | 6.380 | 3.061 | 2.546 | 2.146 |
| Degrees of freedom | 198 | 198 | 198 | 198 | 198 |
| Probability for t-value found, percent | 6.0 | $<0.1$ | 0.3 | 1.1 | 2.0 |
| Coast East and Interior North | | | | | |
| Difference between means, psi, col 3-6 | 0.000 | 1,000 | 0 | 90 | -28 |
| Difference between means,[1] percent | 0.0 | 0.1 | 0.0 | 2.6 | 3.1 |
| t-value | 0.010 | 0.035 | 0.016 | 1.801 | 2.779 |
| Degrees of freedom | 187 | 187 | 187 | 187 | 187 |
| Probability for t-value found, percent | 75.0+ | 75.0+ | 75.0+ | 7.0 | 0.5 |

[1] Based on first-named region or subregion.

when it should have been 0.45. The surprisingly high value for specific gravity of Interior-South timber, 0.43, reported in the Density Survey (25) cannot be confirmed either by published data from tests of strength, or by our data from mill samples.

Properties of material of selected growth rate

Neither means applicable to a geographic subdivision nor general means changed much when test results were deleted for material having wide growth rings. To explain this result, individual values within the upper and lower 10 percentage points of distributions were examined. Enough high values occurred to balance the low values associated with wide-ringed wood and to maintain about the same averages regardless of growth-rate restrictions. Therefore, for practical purposes, averages for properties of Douglas fir are not increased significantly by imposing restrictions on rate of growth.

Although some specimens of high as well as of low strength and elasticity were culled when rate-of-growth restrictions were applied, effective truncation of the distribution of values occurred in the range where values were low. Theoretically, this truncation would serve to improve reliability of the material or to increase the strength value at, for example, the 5 percent exclusion level. We did not determine the magnitudes of increase in strength. Data previously reported by Drow (8), however, suggest that increases of 6-7 percent are justified for modulus of rupture.

Mean specific gravity from samples of boards

Subregional, regional, and general means for the specific gravity of boards were the same as those for dimension lumber, after values were rounded to the nearest 0.01 unit. Boards from the Interior South had the lowest average specific gravity. Specific gravities for areas 6, 7, 9, and 10 of the Coast region were lower than for other Coast areas and were slightly lower than areas 11, 12, and 13 of the Interior North (Figure 1). These results were so similar to those obtained from samples of dimension lumber that we have not included details.

Mean specific gravity from samples of timbers

The survey of specific gravity of timbers was limited, because the number of samples gathered in each stratum depended upon chance availability of material. Only 417 samples were collected; most were from the Coast region. No samples could be obtained from areas of the Interior South. Comparing subregional and general means for specific gravity of timbers with those for dimension lumber and boards showed that timbers had slightly lower values by about 0.01 unit: This result was not surprising, because many of the cross sections cut from timbers contained boxed pith and substantial amounts of wide-ringed wood characteristically low in specific gravity.

Table 5. Ratios[1] of Average Values for Coast Region to Average Values for Interior Region of Specific Gravity and Strength Properties Obtained by Three Sampling Methods.

| Property | Sampling method | | | | | |
|---|---|---|---|---|---|---|
| | Mill samples[2] | | Forest samples[3] | | Density-strength regression[4] | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Specific gravity | 1.02 | 1.01 | 1.06 | 1.05 | 1.00 | 1.00 |
| Modulus of elasticity | 1.09 | 1.07 | 1.26 | 1.19 | 1.13 | 1.10 |
| Modulus of rupture | 1.04 | 1.03 | 1.14 | 1.10 | 1.05 | 1.03 |
| Crushing strength | 1.07 | 1.05 | 1.23 | 1.20 | 1.12 | 1.10 |
| Shearing strength | 0.96 | 0.95 | 1.05 | 1.05 | 0.96 | 0.96 |

[1] Values in columns 2,4, and 6 were calculated as ratios of Coast average to Interior average. Values in columns 3,5 and 7 were calculated when data for the Interior-South subregion were omitted. See Figure 1.

[2] Based on data from Table 3.

[3] Based on data from Drow (7).

[4] Based on data from _Western Wood Density Survey_ (25).

General variability

Variability of samples was considered for regions and areas and analyzed with respect to components of variance within and among samples for strata Estimates also were made of standard deviations and lower 5 percentage points of distributions of individual values.

Sampling was planned so that there would be minimum error in differences between means for regions. These differences have been discussed. The standard errors of regional means, together with related information, are shown in Table 6. Standard error of regional means for each of the two primary populations, Coast and Interior, was less than 1 percent of the mean value for each property studied. But errors were slightly lower for the Coast sample than for the Interior sample. Evidently, variability is somewhat more likely in Interior material than had been assumed when samples were allocated to regions. That the assumed parameter of variability was too low seems clear now from information (25) not available when this study was planned, and from more accurate knowledge (gained partly through this study) of the importance of the component of variability among trees. Planners were misled to some extent by estimates of coefficients of variation for Interior Douglas fir on record a few years ago. Those estimates are now thought to be low.

Table 6. Measures of Dispersion and Precision.

| Statistic | Specific gravity | Elasticity modulus | Rupture modulus | Crushing strength | Shearing strength |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| Samples | | | | | |
| Coast region | 240 | 240 | 240 | 240 | 240 |
| Interior North | 148 | 148 | 148 | 148 | 148 |
| Interior South | 17 | 17 | 17 | 17 | 17 |
| Interior region | 165 | 165 | 165 | 165 | 165 |
| All | 405 | 405 | 405 | 405 | 405 |
| Mean,[1] psi, (col 3-6) | | | | | |
| Coast region | 0.44264 | 1,498,654 | 7,527 | 3,517 | 888 |
| Interior North | .43738 | 1,395,684 | 7,338 | 3,342 | 932 |
| Interior South | .40184 | 1,114,508 | 6,391 | 2,755 | 818 |
| Interior region | .43450 | 1,372,889 | 7,262 | 3,294 | 923 |
| All | .44156 | 1,482,002 | 7,492 | 3,488 | 893 |
| Standard deviation, psi (col 3-6) | | | | | |
| Coast region | 0.02771 | 172,519 | 628 | 341 | 77 |
| Interior North | .02572 | 149,149 | 596 | 333 | 75 |
| Interior South | .02085 | 95,868 | 430 | 175 | 49 |
| Interior region | .02550 | 146,677 | 589 | 326 | 73 |
| All | .03167 | 196,778 | 718 | 390 | 88 |
| Coefficient of variation, percent | | | | | |
| Coast region | 6.3 | 11.5 | 8.3 | 9.7 | 8.7 |
| Interior North | 5.9 | 10.7 | 8.1 | 10.0 | 8.0 |
| Interior South | 5.2 | 8.6 | 6.7 | 6.4 | 6.0 |
| Interior region | 5.9 | 10.7 | 8.1 | 9.9 | 7.9 |
| All | 7.2 | 13.3 | 9.6 | 11.2 | 9.9 |
| Standard error, psi (col 3-6) (among-sample means) | | | | | |
| Coast region | 0.00179 | 11,136 | 41 | 22 | 5 |
| Interior North | .00211 | 12,260 | 49 | 27 | 6 |
| Interior South | .00505 | 23,252 | 104 | 43 | 12 |
| Interior region | .00198 | 11,419 | 46 | 25 | 6 |
| All | .00157 | 9,778 | 36 | 19 | 4 |
| Precision of estimate of mean,[2] percent | | | | | |
| Coast region | 0.40 | 0.74 | 0.54 | 0.63 | 0.56 |
| Interior North | 0.48 | 0.88 | 0.67 | 0.82 | 0.66 |
| Interior South | 1.26 | 2.09 | 1.63 | 1.54 | 1.47 |
| Interior region | 0.46 | 0.83 | 0.63 | 0.77 | 0.62 |
| All | 0.36 | 0.66 | 0.48 | 0.56 | 0.49 |

[1]Means weighted by estimated total volume of all lumber produced during 8-hour period (See columns 4 and 6 of Table 2 for weighting factors.)

[2]Standard error expressed as percentage of the mean.

Variability among areas

Variation of mean values among areas within regions is seen from data in Table 3. These areas (multiple-strata subdivisions) are large geographically, but many were sampled intensively. Where sample sizes were comparatively large for individual areas, the array of mean values indicates the apparent heterogeneity within populations that were sampled. Further statistical analysis of the data was not applied at the area level because standard errors of means for the areas were not uniform, and their lack of uniformity was expected to mask the meaning of statistical tests.

Areas constituting the Interior South and certain areas east of the Cascade Mountains in Oregon and Washington seem to have similarities, although individual areas in these groups varied with respect to strength properties. Of particular interest, however, is the corridor composed of areas in California, together with areas in central Oregon and central Washington bounded on the east by 120° west longitude. Known as the Intermediate, or Interior West, subregion relative to type of Douglas fir (7, 24), but called Coast East in our study, this territory technically has been considered part of the Coast region because properties of standard forest samples collected from it were close in value to those for samples from the traditional sector defined by Drow (7), which we called Coast West subregion. In contrast, results from our mill samples showed that there are substantial differences between average values of material from Coast West and Coast East (Table 7).

Coast East is an important source of Douglas fir. About 27 percent of all Douglas fir lumber produced was estimated to come from there in 1959; this was the weight assigned to the group of areas included (Table 7). By contrast, weight assigned to areas of the Interior-North subregion was about 12 percent, based on estimated lumber production in 1959. Results based on numerous tests of mill samples showed close compatibility of average values for Coast East and Interior North, but there was not close agreement of average values for Coast West and Coast East. It seems just as reasonable to combine values for the Interior-North and Coast-East subregions as to combine values for the Coast-East and Coast-West subregions.

The relative importance of the four subregions listed in Table 7 makes it evident that a significant subpopulation of material has been included with the high-rated Coast-West material for some years. If these facts reasonably indicate the true situation, the lack of equity in past grouping of recognized subdivisions of Douglas fir requires attention. Further analysis is needed to guide the proper assignment of the important Coast-East production to either Coast-West or Interior populations. An approach to resolving this problem has been suggested by procedures outlined by the American Society for Testing and Materials (3).

Table 7. Estimates of Average Specific Gravity and Strength Properties for Four Subregions of the Range of Douglas Fir.[1]

| Area[2] | Specific gravity | Modulus of elasticity | Modulus of rupture | Maximum crushing strength | Maximum shearing strength | Proportion within range | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lumber[3] | Timber[4] |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| | | M psi | Psi | Psi | Psi | % | % |
| Coast West | | | | | | | |
| 1-5 | 0.445 | 1,546 | 7,610 | 3,560 | 881 | 59.6 | 54.5 |
| Coast East | | | | | | | |
| 6-10 | .437 | 1,395 | 7,340 | 3,430 | 904 | 27.1 | 24.0 |
| Interior North | | | | | | | |
| 11-15 | .437 | 1,396 | 7,340 | 3,340 | 932 | 12.2 | 18.0 |
| Interior South | | | | | | | |
| 16-19 | .402 | 1,114 | 6,390 | 2,760 | 818 | 1.1 | 3.5 |

[1] Consolidation of data from Tables 2 and 3.

[2] See Figure 1.

[3] Based on estimated production of lumber in 1959.

[4] Based on estimated cubic-foot volume of standing timber in 1963.

Standard deviations of sample means

Standard deviations of sample means (standard errors), calculated by formulas already described, and the associated coefficients of variation are shown in Table 6. These parameters are useful in gaining an idea of variation among samples when the within-sample component has been removed. As would be expected, they are smaller numerically than if compiled by including the within-sample component. Standard deviations for Coast samples were always larger than for Interior samples. Differences ranged from 5 to 18 percent of values for Interior samples. The largest difference, for modulus of elasticity, was only 2 percentage points lower than the general value of 20 percent that was assumed to pertain to all properties when the survey was planned.

Standard deviations of individual specimens

Standard deviations of strength properties for individual specimens were compiled by including total variance from the samples, and are given in Table 3. Estimates of the lower 5 percentage points (so-called exclusion values) of distributions of individual values, with distributions assumed to be normal, are also given in this table. Standard deviations can be compared with the published values often used to describe variability, which have been derived from test values taken among the pieces in standard forest-sampling procedures. (See Drow (7)). Our measurements showed variability larger for regional samples (Coast and Interior) and for all properties than was shown by previous data; consequently, estimated 5 percentage points may be somewhat lower than currently recognized. Furthermore, standard deviations based on our data ranged only from 1 to 13 percent greater for Coast material than Interior material. These percentages are substantially smaller than those calculated from data on forest samples gathered within each region. In a study made in Canada by McGowan (18), standard deviations derived from mill samples also were larger than for samples gathered in forests.

These findings suggest that there is larger variation among specimens for clear wood cut from samples of lumber than would be forecast from data of standard forest samples. Also, the comparative variability of clear wood from Coast sources is not so different from that from Interior sources as previously thought, but is, nonetheless, somewhat higher for Coast material. These contentions, although supported by results of the survey itself, also seem logical from a theoretical point of view. Standard forest samples are most likely biased toward low estimates of the between-tree variability; therefore, total variance from such samples will be somewhat too small. This condition could be reflected in standard deviations prepared from the samples, even though past samples from forests are assumed to provide accurate estimates of means for forest-tree populations.

Variability among pieces from the mill samples, on the other hand, does not include a component of variance from within trees, for it consists entirely of an among-tree effect determined from single observations on a large number of trees. A wide range of factors related to site and locality of growth (not separable by analysis) that influence quality and strength of wood in trees is most likely reflected in our estimates of variance. It cannot be proved that variances reported here are necessarily exact for application to all kinds of Douglas fir products, because samples were taken only from lumber mills. There is a strong possibility, however, that these variances are more nearly representative for clear Douglas fir than are the values developed from previous data.

Frequency distributions

Distributions of individual test values for properties were approximately normal, at least for the large samples. Low probability points were determined by calculations (normality of distribution assumed) and by counting actual values included. Limited data at extremes (tails) of distributions resulted in discrepancies between calculated and observed values at low probability points, such as the 5 percent point of distribution. Also, because of differences among means and among standard deviations of the subsamples within regional samples, the 5 percent point in the distribution of values for a property often coincides with higher or lower percentage points of distributions of that same property for other groups of areas. This situation characterized relations of exclusion values for areas when compared with exclusion values associated with regions, and for similar comparisons across regions.

To cite an extreme example, the 5 percent point of the distribution of values for modulus of rupture of the overall Coast sample nearly coincided with the 20 percent point of the distribution for the same property for the Interior-South subregional sample. This finding suggests that four times as many pieces with a modulus of rupture below the exclusion value for modulus of rupture for Coast wood would be expected to come from the Interior South, if equal numbers of pieces were produced in and distributed from that region and subregion. Because total production of Coast Douglas fir lumber exceeds production of Interior-South Douglas fir lumber by about 80 times, however, (based on our estimates, or about 20 times according to volume of standing timber), the greatest number of pieces with minimum strength obviously must come from Coast sources.

The facts mentioned do not necessarily constitute an argument for grouping Douglas fir from all sources. It may be possible, but not always practical, to separate certain unique subpopulations of material when they can be clearly identified. Drawing boundaries to segregate types of Douglas fir is the classic example. However, a question can be raised as to whether such separations have been equitable, because nonconforming subpopulations may occur within large groupings that are assumed to be fairly homogeneous with respect to mechanical properties. Practical means need to be found to cope with the awkward facts of heterogeneity within the general population of Douglas fir--in fact, any species whether now grouped, ungrouped, or otherwise preferentially treated. Such procedures should be applied objectively and uniformly and should provide for consideration of the smallest unit within a population for which reliable data can be developed.

## Regressions

Regressions of strength properties on specific gravity were prepared with the least-squares-fitting technique and conventional linear model, $y = a + bx$. Results are given in Table 8. A brief analytical study was made to determine if curve-fitting to observed data would re-

Table 8. Data from Regression Analysis for Three Strength Properties (y) on Specific Gravity (x) Using Linear Model y = A + Bx.

| Area[1] | Specific gravity[2] | Modulus of rupture | | | | Modulus of elasticity | | | | Maximum crushing strength | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | ($r^2$) | Error | A | B | ($r^2$) | Error | A | B | ($r^2$) | Error |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| | | Psi | Psi | | Psi | M psi | M psi | | M psi | Psi | Psi | | Psi |
| Coast | | | | | | | | | | | | | |
| 1 | 0.443 | -2,224 | 22,529 | 0.744 | 647 | -391 | 4,522 | 0.557 | 197.2 | -781 | 10,023 | 0.556 | 439 |
| 2 | .446 | -1,412 | 20,189 | .664 | 659 | 141 | 3,043 | .322 | 202.6 | -562 | 9,187 | .531 | 396 |
| 3 | .439 | -1,696 | 20,770 | .773 | 584 | -293 | 4,153 | .443 | 241.7 | -937 | 10,031 | .634 | 396 |
| 4 | .471 | -884 | 19,352 | .752 | 651 | 142 | 3,235 | .380 | 242.0 | -819 | 9,866 | .662 | 413 |
| 5 | .448 | -1,131 | 19,554 | .740 | 628 | -145 | 3,667 | .464 | 213.6 | -934 | 10,032 | .620 | 426 |
| 6-7 | .422 | -2,163 | 21,570 | .759 | 582 | -338 | 3,985 | .489 | 195.4 | -1,089 | 10,387 | .569 | 434 |
| 8 | .456 | -1,566 | 20,556 | .775 | 602 | -330 | 3,957 | .462 | 231.7 | -984 | 10,235 | .649 | 409 |
| 9-10 | .417 | -1,500 | 20,012 | .779 | 605 | -178 | 3,538 | .440 | 226.5 | -885 | 9,585 | .667 | 384 |
| All | .443 | -1,700 | 20,837 | .769 | 619 | -254 | 3,957 | .455 | 234.8 | -979 | 10,156 | .639 | 413 |
| Interior North | | | | | | | | | | | | | |
| 11 | .444 | -239 | 17,606 | .621 | 662 | 54 | 3,169 | .347 | 209.4 | -690 | 9,398 | .483 | 469 |
| 12 | .437 | -993 | 18,977 | .689 | 618 | 2 | 3,130 | .317 | 222.9 | -943 | 9,794 | .658 | 342 |
| 13 | .443 | -1,336 | 19,395 | .760 | 533 | -22 | 3,214 | .320 | 229.7 | -1,110 | 9,904 | .621 | 379 |
| 14-15 | .411 | -942 | 18,442 | .675 | 563 | -239 | 3,633 | .418 | 188.8 | -824 | 9,043 | .435 | 454 |
| All | .437 | -911 | 18,821 | .680 | 630 | -66 | 3,341 | .361 | 217.1 | -1,002 | 9,904 | .566 | 424 |
| Interior South | | | | | | | | | | | | | |
| 16-19 | .399 | -67 | 16,113 | .628 | 650 | 69 | 2,634 | .343 | 190.9 | 45 | 6,784 | .529 | 335 |

[1] Sample sizes for an area are almost the same as shown in Table 3. A few areas were combined to obtain an effective sample. See Figure 1 for locations of the areas.

[2] Simple (unweighted) mean of all values included for an area. Means vary slightly from those listed in Table 3 because of minor effects of weighting.

duce the standard error of estimated strength properties and thus increase the reliability of predictions. Fitting was done to a general polynomial equation that included the first six powers of specific gravity, again by the least-squares approach. Although curves were obtained that appeared to fit data points slightly better than did straight lines, standard errors of estimate were not reduced to any useful extent, and further analysis was abandoned.

Inspection and statistical testing of regressions led to the conclusion that original data might be segregated (for purposes of regression) into as many as four groups with respect to geographic origin of test specimens. Communication with the U.S. Forest Products Laboratory revealed that the same general findings were under consideration with respect to application of data from the Western Density Survey. Data from mill samples eventually were merged with data from previous standard tests of forest samples. Evidence and discussion pertaining to this decision are given in Western Wood Density Survey (25).

Applicability of mill sampling to other species

Mill sampling was a quick, easy means of obtaining a large volume of test material from throughout sampling strata where Douglas fir lumber is produced. Applying mill-sampling procedures to yield valid and reliable results was helped by the ready identification of Douglas fir within a mix of species. Douglas fir also is produced over its wide range of natural growth in proportion to the available volume of standing timber. Thus, we claim that our test material was authentic and representative of the species.

Some species of limited range and volume and sparse, scattered distribution could not be sampled so efficiently as Douglas fir. Stratification and selection of mills and specimens would have to be altered. Furthermore, geographic delineation of areas probably would not be so simple as for Douglas fir. Discontinuity of distribution would require careful planning to develop proper sampling strata.

The established productive capacity of mills sawing Douglas fir lumber is closely related to volume distribution of standing timber of the species within and between sampling strata, as was demonstrated. This is a condition that is not satisfied for all species, and would have to be considered when planning surveys of other species. Data obtained in mill sampling may not be a reliable indicator of stand characteristics within a stratum, if lumber production capacity, and hence sampling intensity, is not related to timber-stand volumes within the same stratum.

A practical problem that might be encountered is accurate identification of the wood of a species having minute or gross characteristics similar to other species of the same genus, or even of other genera. The true firs and the southern pines are groups that might cause difficulty. For example, several species of true firs have overlapping ranges, so that a mixture of logs of those species might be processed at a mill. Unless the logs were identified and tagged in the forest, identification of the wood of individual species at the sorting chain by gross appearance, or in the laboratory by microscopic features, would be virtually impossible. The problem of identification arose infrequently in the study of Douglas fir and only required care in separating Douglas fir and western larch when both appeared on the sorting chain at an occasional sawmill.

Kinds of products being manufactured from a species might dictate changes in the procedure for selecting test material at a sawmill, and also limit the kinds of tests that could be performed. If only boards were being produced, and not dimension lumber, then the standard specimen for testing in bending, or the slightly modified version of it used in our study, could not be prepared. Thick stock for testing purposes could be cut to order at a sawmill. However, if the intent is to sample and test only material that is normally produced for consumer use, then special test pieces would have to be made, or totally different approaches to collection of material would have to be taken.

## CONCLUSIONS

1. Mean values for modulus of elasticity, modulus of rupture, compression parallel to the grain, and specific gravity were higher for clear, unseasoned wood of Douglas fir from Coast sources than from Interior sources. In contrast, the value for shear parallel to the grain was higher for wood from Interior sources. Among these properties, the largest difference between values for Coast and Interior wood was about 9 percent for modulus of elasticity, and the smallest was about 2 percent for specific gravity, based on means for Interior wood. Shearing strength of Interior wood was 4 percent greater than for Coast wood.

2. The difference between regional averages for each property was shown statistically to be of such magnitude that the respective regional populations are not identical, that is, there is an effect of locality. Probabilities for error associated with such statistical conclusions were generally less than 1 percent. Note that statistical proof of a significant difference between regions does not necessarily imply that observed differences in physical properties were sufficiently large to be of practical importance in specifying and using wood. Conclusions pertaining to this question were not within the scope of our study.

3. Within the Interior region, two subregions were defined: Interior North and Interior South. Douglas fir from the Interior-South subregion was weaker, less stiff, and lower in specific gravity, than that from the Interior-North subregion, or from the Coast region. All differences between averages for these subdivisions were statistically significant.

4. Examination of subregional averages, supported by statistical testing, indicates that there are two distinct subpopulations within the Coast region. Douglas fir from a sector previously designated as Interior West (our Coast East) exhibited values for strength, stiffness, and specific gravity distinctly lower than those for Coast West, the remainder of the Coast region. Values for wood properties in the Coast East were of the same, or slightly less, magnitude than those for the Interior-North subregion. Considerable Douglas fir lumber is produced in each of the latter subregions.

5. Regional and overall averages for all strength properties and specific gravity were increased only slightly by deleting values for specimens having fewer than six rings to an inch. About 11 percent of pieces sampled from Coast sources, and about 1 percent of pieces from Interior sources had fewer than six rings to an inch.

6. Some of the differences in values for strength and specific gravity between areas within regions were larger than the differences between regions.

7. Variability of all properties studied was somewhat greater than was shown by previous tests of clear Douglas fir representing regional sources. Clear wood from Interior sources was less variable than that from Coast sources, but the difference was not so great as had been anticipated before the survey was initiated.

8. Close agreement was shown between calculated values of a low probability point of distributions of all values for regions, despite less close agreement between regional average values.

9. Average values and variability were not at all constant for small samples within the large regional samples, and divergent subpopulations possibly exist for small areas. Therefore, procedures for grouping or isolating portions of a timber species when establishing strength properties should include proper analysis of such unique subpopulations within the large classifications.

10. Specimens from three kinds of lumber--dimension, boards, and timbers--yielded essentially similar estimates of specific gravity for comparable subdivisions.

11. Estimates of regional means were unbiased statistically and of high precision. Accuracy of the results of this study, as for any similar study, cannot be measured exactly because the true population parameters, perforce, remain unknown. Because of the unbiased nature of the sampling plan, broad scope of the survey, and high precision achieved, however, we believe that the data represent the best estimate available to date of the true population parameters of Douglas fir.

12. The general feasibility of mill sampling was substantiated by the large body of useful information obtained with ease and rapidity and at low cost compared with other procedures.

## REFERENCES CITED


1. American Society for Testing and Materials. Standard Methods of Testing Small Clear Specimens of Timber. ASTM D143- 52. (Adopted 1948; revised 1949, 1950, 1952; reapproved in 1964 without change). 1964.

2. American Society for Testing and Materials. Tentative Methods for Establishing Structural Grades of Lumber. ASTM D245-64T. (Issued 1949; revised, 1957, 1962, 1964). 1964.

3. American Society for Testing and Materials. Tentative Methods for Establishing Clear Wood Strength Values. ASTM D2555-66T. 1966.

4. Barrett, J. W. Regional Silviculture of the United States. Ronald Press, New York. 669 pp. 1962.

5. Cochran, William G. Sampling Techniques. John Wiley & Sons, Inc., New York. 1953.

6. Crow, C. C., Publications, Inc. Crow's Buyers and Sellers Guide of the Western Lumber and Plywood Industries. 1959.

7. Drow, John T. Relationship of Locality of Growth to Density and Strength of Douglas Fir. U.S. Forest Products Laboratory, Report No. 2078. 1957.

8. Drow, John T. Reevaluation of Basic Stresses for Douglas Fir Structural Lumber. U.S. Forest Products Laboratory, Report No. PE-141. (Limited distribution). 1957.

9. Göhre, K. Die Douglasie und ihr Holz. Akademie-Verlag, Berlin. 595 pp. 1958.

10. Harris, J. M., and Hellawell, C. R . The Physical and Mechanical Properties of Rewarewa. Forest Research Institute, New Zealand, Research Paper No. 25. 1958.

11. Harris, J. M., and Orman, H. R. The Physical and Mechanical Properties of New Zealand-grown Douglas Fir. Forest Research Institute, New Zealand, Research Paper No. 24. 1958.

12. Hellawell, C. R., and Warren, W. G. The Sampling of Timber for Standard Mechanical Tests. New Zealand Forest Service, Forest Research Institute, Forestry Research Notes, No. 7. pp. 1-12. 1956.

13. Isaac, L. A., and Dimock, E. J.II. Silvical Characteristics of Douglas Fir. U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Silvical Series No. 9. 1958.

14. Li, Jerome C. R. Statistical Inference, Volume I. Edwards Brothers, Inc., Ann Arbor, Michigan. 1964.

15. Little, E. L., Jr. Check List of Native and Naturalized Trees of the United States (including Alaska). U.S. Department of Agric., Agric. Handbook No. 41. 1953.

16. Littleford, T. W. Variation of Strength Within Trees and Between Trees in a Stand of Rapid-growth Douglas Fir. Forest Products Laboratories of Canada, Report V-1028. 1961.

17. Markwardt, L. J., and Wilson, T.R.C. Strength and Related Properties of Woods Grown in the United States. U.S. Dept. Agric. Tech. Bull. 479. 1935.

18. McGowan, W. M. Strength and Related Properties of Small, Clear Specimens of Douglas Fir Cut from Stress-graded Lumber. Department of Forestry, Forest Products Research Branch, Canada, Publication No. 1025. 1963.

19. Nair, K. R., and Mukerji, H. K. "A Statistical Study of the Variability of Physical and Mechanical Properties of Tectona grandis (Teak) Grown at Different Localities of India and Burma and the Effects of the Variability on the Choice of the Sampling Plan." Indian Forest Records, Statistical, 1(1), 49 pp. 1957.

20. Nair, K. R., and Mukerji, H. K. "Classification of Natural and Plantation Teak (Tectona grandis) Grown at Different Localities of India and Burma with Respect to its Physical and Mechanical Properties." Sankhya; The Indian Journal of Statistics 22(1 & 2). 1960.

21. Pearson, R. G. "The Sampling of Timber for Standard Mechanical Tests." Australian Journal of Applied Science. 3(1): 25-52. 1952.

22. Pearson, R. G., and Williams, E. J. "A Review of Methods for Sampling Timber." Forest Products Journal 8(9): 263-268. 1958.

23. The Lumberman and the Timberman. Handbook and Directory of the Forest Industries. 41st annual edition. 1960.

24. U.S. Forest Products Laboratory. Wood Handbook. U.S. Dept. Agric., Agric. Handbook No. 72, 528 pp. 1955.

25. U.S. Forest Products Laboratory. Western Wood Density Survey, Report No. 1. U.S. Forest Service Research Paper, FPL-27. 1965.

26. West Coast Lumbermen's Association. _Directory and Manufacturing Facilities of Member Mills_. 1960.

27. Western Pine Association. _Sources of Supply and Directory of Membership_. 1960.

28. Williams, E. J. "Applications of Component Analysis to the Study of Properties of Timber." _Australian Journal of Applied Science_ 3(2): 101-118. 1952.

ADVISORY COMMITTEES provide counsel on programs of research in Forest Management and Forest Products at Oregon State University.

The Forest Products Research Advisory Committee, composed of men from representative interests, helps guide the research program in forest products. Present members are:

| | |
|---|---|
| CHARLES KREIDER, Chairman<br>NEAL I. PINSON, Alternate | Western Wood Products Association (WPA) |
| PHILIP BRIEGLEB, Principal<br>JOHN B. GRANTHAM, Alternate | Pacific Northwest Forest and Range Experiment Station |
| RALPH CASSELMAN, Principal<br>JOHN M. HESS, Alternate | American Plywood Association |
| LARRY E. CHAPMAN, Principal<br>VAL GARDNER, Alternate | Willamette Valley Lumbermen's Association |
| C. R. DUFFIE, Principal<br>DR. HERMAN AMBERG, Alternate | Pulp and Paper Industry |
| GEORGE C. FLANAGAN, Principal<br>JOHN E. HANSEN, Alternate | Southern Oregon Timber Industries Association |
| J. R. GATES, Principal<br>RAY L. TODD, Alternate | West Coast Lumber Inspection Bureau |
| DONALD W. PLEIER, Principal<br>CHARLES W. BEST, Alternate | Western Wood Preservers Institute |
| W. J. RUNCKEL, Principal<br>T. K. MAY, Alternate | Western Wood Products Association (WCLA) |
| FRED SOHN, Principal<br>S. H. ELLINGSON, Alternate | Western Forest Industries Association |

EVERETT L. ELLIS, Secretary