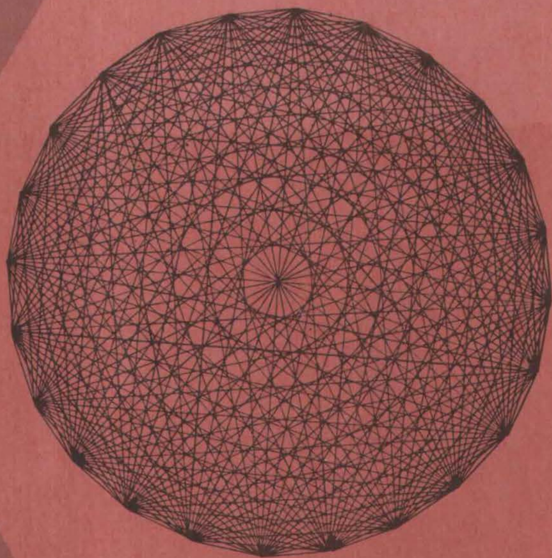

Proceedings of the Symposium on

DENSITY... A KEY TO WOOD QUALITY

HELD MAY 4–6, 1965 AT MADISON, WISCONSIN

ISSUED BY
FOREST PRODUCTS LABORATORY
FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE

SPEAKERS AND THEIR PRESENTATIONS

U.S. Forest Products Laboratory is maintained at Madison, Wis., in cooperation with the University of Wisconsin.

DENSITY--A KEY TO WOOD QUALITY

Scope

This symposium dealt primarily with one important aspect of wood quality, namely specific gravity as determined in standing timber by the increment core sampling method. It covered the status of research in this area, the importance of the work, present and potential uses for wood density data, and the need for further research. It also touched on other closely related aspects of wood quality.

Objectives

1. To encourage industrial users of wood to outline and discuss their needs for better data on the density and related wood-quality characteristics of our timber resources, including specific examples of how available data are being used to help solve urgent marketing and utilization problems.

2. To better inform key research personnel on the economic and technical problems, needs, and viewpoints of the major wood-using industries, as these relate to wood quality, in order that this information can be used to best advantage in planning future research.

3. To review the progress that has been made on wood density surveys and related studies since the In-Service Timber Quality Conference of 1957.

4. To learn more about the training and research in wood quality being carried on by the forestry schools, and thus provide a better basis for correlating forestry school and Forest Service efforts toward common goals.

Attendance

A special effort was made to have about equal representation from industry, the forestry schools, and the U.S. Forest Service. Also, to include within the industry group representatives of all major industrial users of wood--pulp and paper, lumber, plywood, laminated products, poles and piling, etc. Because of space limitations, participation was by invitation only.

AGENDA

DENSITY--A KEY TO WOOD QUALITY

A Symposium at the
Forest Products Laboratory
Forest Service, USDA, Madison, Wis.
May 4-6, 1965

May 4 (Tuesday) Session I - Chairman: V. L. Harper, In Charge of Research, Forest Service

A. Welcome and Introduction

1. Welcome — Edward G. Locke, Director, FPL
2. Introduction-Objectives — V. L. Harper
3. Industry Keynote — Alan T. Smith, Weyerhaeuser Company; (Chairman, Western Woods Technical Committee)

B. Progress Reports

1. Phase I of the Forest Service Western Woods Density Survey (collection of increment cores) — N. E. Metcalf, Project Leader, Forest Survey, Pacific Northwest Forest and Range Experiment Station
2. Phases II (increment core processing) and III (estimating tree specific gravity) — H. E. Wahlgren, Project Leader, Wood Quality Evaluation, FPL
3. Phase IV (specific gravity as a structural-property index) — R. L. Ethington, Project Leader, Fundamental Wood Properties, FPL

Session II - Chairman: T. E. Brassell, Director, Inspection Bureau, American Institute of Timber Construction

4. Progress in the Forest Service Southern Wood Density Survey — H. L. Mitchell, Chief, Division of Wood Quality Research, FPL
5. Progress in Wood Density Research at Schools — Eric A. Anderson, Chairman, Dept. of Wood Products Engineering, Syracuse College of Forestry
6. Progress in Research on Relationship between Density and Strength — J. A. Liska, Chief, Division of Wood Engineering Research, FPL

C. Uses of Density Data in Industry

1. Use of Data by the Pulp and Paper Industry — John C. Wollwage, Vice President, Kimberly-Clark Corp. (Past President of TAPPI)

2. Use of Western Wood Density Data by the Lumber and Plywood Industry — Richard G. Kimbell, Jr., Asst. Technical Director, Western Wood Products Association (Western Woods Technical Comm.)

May 5 (Wednesday) Session III - Chairman: Kenneth B. Chesley, Technical Secretary, Technical Association of the Pulp and Paper Industry

3. Interest by the Lumber-Laminating Industry in Wood Density and Related Strength Data — M. J. Rhude, Chief Engineer, Unit Structures, Inc.

4. Interest by the American Society for Testing and Materials in Wood Density and Related Data — Lyman Wood, Project Leader, Structural Utilization, FPL (Chairman, ASTM Committee D-7)

5. Use of Wood Density Data by the Southern Pine Plywood Industry — Tom Orth, Vice President, The Kirby Lumber Corp.

6. Needs and Opportunities for Industry and Others in Wood Quality Research — Robert J. Seidl, Vice President, Simpson Timber Company

Session IV - Chairman: Mason Bruce, Assistant Director, Division of Timber Management, Forest Service

7. Use of Wood Density Data in Industrial Forest Management — T. E. Bercaw, Forester, Crown Zellerbach Corp.

D. Some Related Aspects of Wood Quality Research

1. The Need for More Meaningful Information on the Quality of Hardwoods — W. R. Smith, Asst. Director, Economics, Marketing, and Utilization, Southeastern Forest Experiment Station

2. Framework of Qualitative Relationships in Wood Utilization — George Englerth, Project Leader, Lumber Quality Yields, FPL

3. Quality--A Link between Wood Processing and Materials and Markets — Harold Worth, Project Leader, Regional Utilization, Pacific Northwest Forest and Range Experiment Station

4. Progress on Commercially Feasible Methods for Evaluating the Strength of Individual Pieces of Plywood — John M. Hess, Director, Division for Product Approval, American Plywood Association

May 6 (Thursday) Session V - Chairman: H. O. Fleischer, Director, Division of Forest Products and Engineering Research, Forest Service

D. Some Related Aspects of Wood Quality Research (Cont.)

5. Commercially Feasible Methods for Evaluating the Strength of Individual Pieces of Lumber	H. B. McKean, Director of Research, Potlatch Forests, Inc.

E. Future Needs and Prospects

1. The Role of Forest Survey in Obtaining Better Information on Wood Quality	H. R. Josephson, Director, Division of Forest Economics and Marketing Research, Forest Service
2. Research Opportunities in Eastern Schools	Frank Kaufert, Director, School of Forestry, University of Minnesota
3. Research Opportunities in Western Schools	F. E. Dickinson, Director, California Forest Products Laboratory
4. Needs in the Forest Products Research Area	E. G. Locke, Director, FPL

Discussion

F. Summary	V. L. Harper, In Charge of Research, Forest Service.

ATTENDEES AT

WOOD QUALITY SYMPOSIUM

Anderson, Eric, New York State University, Syracuse, N.Y.
Baker, Gregory, University of Maine, Orono, Maine
Batey, Tom, American Plywood Association, Tacoma, Wash.
Beale, John, Wisconsin State Forester, Madison, Wis.
Bensend, D. W., Iowa State University, Ames, Iowa
Bercaw, T. E., Crown Zellerbach Corporation, Bogalusa, La.
Besley, Lowell, Pulp & Paper Research Institute of Canada, Montreal, Quebec
Boisfontaine, Albert, Southern Pine Inspection Bureau, New Orleans, La.
Brassell, Thomas E., American Institute of Timber Construction, Inspection Bureau, Palo Alto, Calif.
Bruce, Mason, U.S. Forest Service, Washington, D.C.
Cahal, R. R., Southern Pine Inspection Bureau, New Orleans, La.
Camp, Harry W., U.S. Forest Service, Berkeley, Calif.
Carpenter, Charles, Dallas, Tex.
Chesley, K. G., TAPPI, New York, N.Y.
Chudnoff, Martin, U.S. Forest Service, Puerto Rico
Crandall, L. W., University of Wisconsin, Madison, Wis.
Davenport, John, Western Forest Industries Association, Red Bluff, Calif.
Dickinson, Fred E., California Forest Products Laboratory, Richmond, Calif.
Dorr, Frederick J., U.S. Forest Service, Upper Darby, Pa.
Driver, Charles H., International Paper Company, Bainbridge, Ga.
Drow, John, U.S. Forest Service, Washington, D.C.
Einspahr, D. W., Institute of Paper Chemistry, Appleton, Wis.
Ellis, Everett, University of Michigan, Ann Arbor, Mich.
Ellwood, Eric L., North Carolina State, Raleigh, N.C.
Erickson, Harvey, University of Washington, Seattle, Wash.
Fassnacht, Donald L., U.S. Forest Service, New Orleans, La.
Finn, Raymond, U.S. Forest Service, Ames, Iowa
Fleischer, H. O., U.S. Forest Service, Washington, D.C.
Fordyce, David H., U.S. Forest Service, Ogden, Utah
Gaines, Edward M., U.S. Forest Service, Berkeley, Calif.
Glazebook, Thomas B., U.S. Forest Service, Portland, Oreg.
Guttenberg, Sam, U.S. Forest Service, New Orleans, La.
Hall, Gavin S., Yale University, New Haven, Conn.
Hanover, J. W., U.S. Forest Service, Moscow, Idaho
Harper, V. L., U.S. Forest Service, Washington, D.C.
Haygreen, John, University of Minnesota, St. Paul, Minn.
Hemming, C. B., U.S. Plywood Corporation, New York, N.Y.
Hess, John M., American Plywood Association, Tacoma, Wash.
Hitt, Robert G., U.S. Forest Service, Macon, Ga.
Hoadley, R. Bruce, University of Massachusetts, Amherst, Mass.
Hopkins, William C., Louisiana State University, Baton Rouge, La.
Hunt, George, Madison, Wis.
Johnson, J. W., Union Bag-Camp Paper Corporation, Savannah, Ga.
Jorgensen, Richard N., U.S. Forest Service, Upper Darby, Pa.
Josephson, H. R., U. S. Forest Service, Washington, D.C.
Kaufert, Frank H., University of Minnesota, St. Paul, Minn.
Kellogg, Robert M., Yale University, New Haven, Conn.
Kemp, Arne K., U.S. Forest Service, St. Paul, Minn.

Kennedy, D. E., Forest Products Research Branch, Ottawa, Ontario
Kimbell, R. G., Western Wood Products Association, Portland, Oreg.
King, Ed, American Plywood Association, Tacoma, Wash.
Koch, Peter, U.S. Forest Service, Alexandria, La.
Kotok, E. S., U.S. Forest Service, Ogden, Utah
Krahmer, Robert L., Oregon State University, Corvallis, Oreg.
Lyon, Malcolm G., Champion Papers, Hamilton, Ohio
Marden, Richard M., U.S. Forest Service, Wausau, Wis.
Markwardt, L. J., Southern Pine Inspection Bureau, Madison, Wis.
McGinnes, E. Allen, University of Missouri, Columbia, Mo.
McKean, Herbert B., Potlatch Forests, Incorporated, Lewiston, Idaho
Merz, Robert W., U.S. Forest Service, Carbondale, Ill.
Metcalf, Melvin E., U.S. Forest Service, Portland, Oreg.
Mueller, Lincoln A., U.S. Forest Service, Fort Collins, Colo.
Murphey, Wayne K., Pennsylvania State University, University Park, Pa.
Nicholson, G. W. E., Tennessee River Pulp and Paper Company, New York, N.Y.
O'Brien, Howard, Southern Pine Association, New Orleans, La.
Orth, Thomas M., Kirby Lumber Corp., Houston, Tex.
Panshin, A. J., Michigan State University, East Lansing, Mich.
Preusser, Henry M., Weyerhaeuser Company, Tacoma, Wash.
Rhude, Maurice, Unit Structures, Peshtigo, Wis.
Richardson, S. D., University of Wisconsin, Madison, Wis.
Sajdak, Robert L., Michigan Technological University, Houghton, Mich.
Schelhorn, F. B., Tennessee River Pulp and Paper Company, Counce, Tenn.
Seidl, Robert, Simpson Timber Company, Seattle, Wash.
Senft, John, Purdue University, Lafayette, Ind.
Smith, Alan T., Weyerhaeuser Company, Tacoma, Wash.
Smith, Walton R., U.S. Forest Service, Asheville, N.C.
St. Amant, Paul, U.S. Forest Service, Milwaukee, Wis.
Spada, Ben, U.S. Forest Service, Washington, D.C.
Sullivan, John D., Duke University, Durham, N.C.
Taras, Michael A., U.S. Forest Service, Athens, Ga.
Thomas, David P., University of Washington, Seattle, Wash.
Todd, Ray, West Coast Lumber Inspection Bureau, Portland, Oreg.
Troxell, Harry E., Colorado State University, Fort Collins, Colo.
Webb, Charles E., U.S. Forest Service, Macon, Ga.
Webster, Henry H., University of Wisconsin, Madison, Wis.
Williston, E. M., Weyerhaeuser Company, Longview, Wash.
Wollwage, John, Kimberly-Clark Corporation, Neenah, Wis.
Worth, Harold E., U.S. Forest Service, Portland, Oreg.
Yandle, David O., U.S. Forest Service, Asheville, N.C.

Forest Products Laboratory Participants

Edward G. Locke
H. E. Wahlgren
R. L. Ethington
H. L. Mitchell
J. A. Liska
L. W. Wood
George Englerth
W. G. Youngquist

WELCOME ADDRESS

TO SYMPOSIUM ON

DENSITY--A KEY TO WOOD QUALITY

By

EDWARD G. LOCKE, Director

Forest Products Laboratory, Forest Service
U.S. Department of Agriculture

Eight years ago this month, some of us here today gathered in this same room to tackle a problem that admittedly puzzled us much. In an effort to clarify our thinking, we asked ourselves some questions--five, all told--and sought some answers. That meeting, restricted to Forest Service personnel, had a simple title: We called it a Timber Quality Conference.

A lot of work went into that meeting--the kind of hard, struggling, exhausting work men often must do to fight through a dense forest filled with deadfalls, brambles, and other obstacles. Only this was a mental jungle that we set out to think our way through. In effect, we were trying to decide what quality is, with respect to timber and its products, why and to what extent it is important to growers and users of wood, and what, if anything, can be done about it. I don't believe any technical conference could take upon itself a more all-inclusive and at the same time nebulous and hard-to-pin-down subject.

The questions we posed as blaze marks through that largely uncharted jungle will give you some idea of what we struggled with. Here they are:

What is meant by quality timber, and what quality standards are now in use?

What is the outlook for supply and demand of high-quality timber?

How can we meet the future needs for high-quality timber through research aimed at the quality objective?

How can we meet the future needs for high-quality timber through national forest timber management programs aimed at the quality objective?

How can we meet the future needs for high-quality timber through State and Private Forestry programs aimed at the quality objective?

These questions were specifically aimed at three major branches of Forest Service activity--Timber Management, State and Private Forestry, and Research.

But they were, and remain, pertinent questions for everyone concerned with timber and its uses. The thinking done at that meeting went a long way toward clearing out the underbrush that too often snags thinking about wood quality. In a very real sense, then, I think we can say that it was the precursor of this symposium which we are beginning today. And we can thank the men who sweated through it for much that has developed since then both within and outside of the Forest Service--specifically, for making it possible to concentrate here on one aspect of the quality spectrum that has evolved so strikingly since that meeting. I refer to the main topic of our symposium--specific gravity as an index to quality.

It may therefore help to bring our assignment here into somewhat better focus if we briefly look back at what was done at that conference. For example, a committee assigned to brief down and make recommendations on the first session had this to say about quality:

"Quality is the resultant of physical and chemical characteristics possessed by a tree or part of a tree which enable it to meet the property requirements for different end products."

The committee followed this up with some salient thoughts, which I quote:

"The committee, aware of the wide diversity among the purposes for which timber quality classification is needed, doubts that any single classification will satisfactorily meet all needs. A system that might be satisfactory for Forest Survey or timber appraisal might be of no help at all to the geneticist who needs to know what specific properties should be improved. The classification needed by the geneticist might be completely useless to the Forest Survey field man.

"We accept as the ideal system of classification one which would relate the physical and chemical characteristics possessed by a tree, log, or bolt to the properties required by the different end products made of wood, and which would provide a digital or numerical grade based on those relations. However, its development, review, testing, acceptance, and application cannot be accomplished in a short time.

"Thus we recognize the immediate need of a workable, if imperfect, system of timber quality classification to serve such needs as those of Forest Survey, to aid in relating quality supply to quality demand, to serve as a guide in timber appraisal, and to give some direction to research in quality improvement. Accordingly we recommend:

"That the Forest Service develop a tree quality rating system along the lines proposed at the Conference; that this system be submitted to the field for review and testing; and that the tested system be considered by Forest Survey as an interim measure to meet immediate needs."

Numerous other recommendations affecting the broad spectrum of wood quality were made by this and other committees dealing with the topical questions that I have read to you. In this recommendation, however, we have the seed of what later blossomed into the Service-wide activity we have come to call the wood density survey. And which led, by a straight-line progression, to this symposium.

Even at the time of that conference, however, the concept of wood density in the standing tree as an indicator of timber quality was being tried out. The State of Mississippi was then being resurveyed, and Survey crews were making some observations in addition to those normally made. Among these was the taking of increment cores from southern pines of various diameter classes at various statistically chosen survey plots. These cores were sent to Madison for evaluation of their specific gravity. In his address to the Quality Conference, Harold Mitchell alluded to this work.

Results of that density survey of southern pine, as you know, led subsequently to its extension to other southern States, to Maine, and to 11 western States. The findings stirred strong interest not only among our Forest Service research people but outside the Service as well. And above all, industry was quick to recognize their significance with respect not only to lumber but to pulpwood and, most recently, plywood. I think it can be said with ample justification that we have learned things about our southern and western forests that would have been possible by no other means now available.

The 1957 symposium was productive in other ways, as will be brought out in this symposium. One of them was an analysis of past, current, and proposed research involving timber and related wood quality with the object of suggesting research needs in this area. This latter study, only now reaching completion, is also a direct outgrowth of that same recommendation of the 1957 conference for development of a tree quality rating system.

You are going to look closely at the things we have learned during this symposium. And so once again I want to welcome you as representatives of the Forest Service, of educational institutions, and of industry. There is much to talk about and think about. I hope and trust that you will give it your best.

INTRODUCTION-OBJECTIVES

By

V. L. HARPER, In Charge,
Forest Service Research

Forest Service, U.S. Department of Agriculture

My purpose is to introduce the subject of this meeting in broad, general terms, in order to provide the proper background against which the narrower subject under immediate scrutiny may be considered. The subject of wood quality is the broad background against which we are going to discuss wood density.

In recent years, we have recognized that the subject of wood quality has far broader implications than we formerly attributed to it. Many new and different aspects of the subject are coming to light. At the moment, it seems impossible even to agree on a definition of what the term means.

To the timber grower, or timber-land manager, quality may mean thrifty growth. To the log scaler, it means volume of usable material. The timber appraiser visualizes dollar returns from converted products. The purchaser of dense hardwood species for use in furniture manufacture may put high value on less than average density, for he seeks soft texture, freedom from stresses, and stability in his working material. On the other hand, the pulp buyer looks for maximum pulp yield which is associated with high density. Once one grasps the idea that wood quality means more than mere tree or log diameter, an almost limitless field is opened up.

Research scientists are accustomed to formulating today's research programs with an eye to future needs. To those concerned with research on wood, there appear intriguing possibilities of improving quality through the manipulation of forest stands. Possibilities exist in the choice of species and growing stock having selected or even improved hereditary traits and through influencing the growth environment, that is, the site and the growing conditions.

Many complications arise when one attempts to develop a long-range plan for improving the forest products of the future. One of the big difficulties is the lack of knowledge of what future demands will be. Who can predict with certainty what the relative demands will be for dense structural lumber, for plywood, for lumber siding, for fire-retardant treated shingles, and for a whole host of other products? When we speak of wood quality in the long-range picture, therefore, we must not over-emphasize specifics such as high density versus low density or light color versus dark color. Rather, we must concentrate on the general intrinsic characteristics that will be important wherever wood is to be used in modern industry: uniformity of growth, size, grain, and structure; straightness of stem and grain; thrifty growth; freedom from defects such as excessive taper, knot size, crook, and sweep.

For the present, we would do well to concern ourselves with timber quality as we find it. Today's forest stands will have to support our forest products industries for many years to come. There is an urgent need right now for detailed study of the quality of existing timber supplies if they are to be used to best advantage for the manufacture of various qualities of lumber, plywood, and pulp and paper products.

Before the task of inventorying our timber resources--adequately with respect to quality--can be undertaken, certain basic questions must be answered: What properties or qualities shall be measured? How shall they be measured? Is it possible to evaluate standing trees in terms of certain properties that are desired in the finished wood product?

In certain wood products, high strength meeting prescribed standards is a prerequisite. It is not possible, under today's technology, to measure the strength of wood in standing trees directly. Nor have techniques for nondestructive continuous testing of lumber products apparently been perfected to the point where they are generally accepted, although such methods would be preferable. Indirect methods must be considered. Density has been found to be reasonably well correlated with strength, more or less in a direct relationship. Relatively simple means have been devised for estimating density in standing trees, using the core gravity method.

Density has the further advantage of being a good estimator of the quantity of wood substance, for example the yield of pulp. Thus, by a single indirect method estimates of various kinds are obtainable for potential uses of timber.

For these and other reasons, density has become one of the most widely discussed wood quality properties in recent years and has occupied a large share of the time that our research scientists have been able to allocate to quality studies. For certain uses, such as structural lumber and plywood and for pulp, it is at present a key factor. Yet, it is only one of many factors that must be known to evaluate fully the use potential of our timber resources.

A much broader timber quality program--Log and Tree Grade Research--is represented by the work carried on under six different projects in the Forest Service at five of our Forest Experiment Stations and at our Forest Products Laboratory. This program has as its purpose the development of log and tree grading systems for the commercially important species. The technique employed is to establish the analytical relationships between visible characteristics and dollar value of measured yields of end-products. It is thus possible to write specifications that group logs or trees into three or more grade classes. In application, an examination of visible external features of logs and trees enables estimation of potential yields of a variety of products, both in quantity and in quality. Based on grades and prices of products currently existing in the market, it then is possible to determine the highest value end-use of the timber and to allocate raw materials accordingly.

Originally this research employed product values only in terms of lumber. Within the past year, studies have been made that consider a host of alternative products, such as lumber, poles, piling, pulp, and veneer. Information obtained from research of this kind should aid both the buyer and the seller of timber in getting the greatest possible profit from the resource--the processor in allocating material to alternative plants, the forest manager in determining and controlling quality of growing stock--and also provides the basis for a product-oriented survey. There remain, however, several problems in the quantification of tree quality.

Perhaps the ultimate in the use of timber quality data will be attained when we learn how to use such information in analyzing and making decisions about entire production systems, from stump to market. Rapid strides with respect to some industries are being made in operations research and systems analysis using the most modern mathematical tools. Methods are being developed to aid industry managers in making wise decisions regarding day-to-day production problems. Analyses of various operations that make up a production system, each considered simultaneously with every other operation, lead to decisions as to the best combinations for overall optimization of the system and for the attainment of maximum profits.

Obviously, variations in the quality of the timber raw material fed into such a system will have a bearing on decisions regarding a forest product industry's production line operations and must be taken into account in the decision-making process. An inadequate timber quality index may well be the "weakest link in the chain"--to use an old cliche. Conversely, production requirement data from the factory can be fed back to the forest to provide daily guidance in the selection of raw material that goes into the production line. In the Forest Service research organization, leadership for such "operations research" will be centered at our Pacific Southwest Forest Experiment Station in Berkeley, Calif.

The term "product quality"--applied to products manufactured from wood--is not synonymous with "timber quality" and "wood quality," although some have attempted to equate the terms. Product quality, whether it be the quality of a piece of lumber, a glued plywood panel, or a sheet of paper, is a sum of certain characteristics possessed by the product, that are only in part dependent on the quality of the raw material used in the manufacture of that product.

Product quality is affected by a multitude of factors, some accidental, others based on human acts of choice and judgment. For example, the best pole timber may be down graded in strength by the application of too much heat in the pressure treating process. The use of inadequate glues or gluing procedures in making plywood will adversely affect the performance characteristics of the glued product. Sticker stain developed in drying lumber may down grade it for use in furniture, no matter how selective the log buyer may have been. The manufacturer of wood products must not expect the timber grower or supplier to solve all his product quality problems for him.

Insofar as possible, it is desirable that the quality of wood products should be measured directly on product samples, or better yet, continuously on all products flowing from a production line. This will require the development of nondestructive test methods for strength, glue line quality, and the like, that can be applied quickly and economically. Although some methods are already available for nondestructive testing of lumber, the whole subject appears to offer a fruitful field for further research efforts, both basic and applied.

Having considered some of the general aspects of the wood quality picture, we now propose that we limit our considerations for the duration of this meeting to the rather limited subject: Density--A Key to Quality. Let us not wander widely over the entire field of timber quality. Nor should we delve deeply into product quality problems. To the extent possible, let us stick to the subject of Density--A Key to Quality.

We hope that our various speakers will be able to tell us about the importance of density, each from his particular viewpoint; we hope to get a better picture of who uses this information and how he uses it; how well does it fit his needs? Who could use the information? Who is not now doing so? What alternatives are there to "density" for approximating the true quality values that we want to know?

The papers presented at this meeting will be reproduced and made available to all who are in attendance and to the general public. Each speaker should leave with us a copy of his manuscript for use in reproduction. We do not propose to record verbatim the floor discussion, but we do hope to summarize the discussion and to reproduce and distribute the summaries along with the formal papers.

I would like to express my thanks to all of you who have come from your jobs, some from great distances, to contribute to our deliberations. We in the Forest Service are vitally interested in timber quality, wood quality, and product quality, as are all of you in attendance. We are interested in inventorying the quality of existing timber stands, with developing ways of using our timber resources to best advantage and, through both utilization and marketing research, to help provide high quality products at a competitive price.

To us in research, this meeting will be of great value. It will help us to better orient future research programs to quality problems. We hope that it will be equally worthwhile to representatives from industry and academic circles. In fact, the proceedings of this meeting should be of interest to all those who are concerned with quality problems and the application of the results of research on these problems.

INDUSTRY KEYNOTE:

DENSITY--A KEY TO WOOD QUALITY

By

ALAN T. SMITH[1]

Weyerhaeuser Company

I feel very honored to have been selected as the Industry Keynote Speaker for this important conference, particularly since I know there are many of you in the audience who are much more qualified to speak on this subject than I am. In reality, the twenty or so men who have been associated with me in the Western Woods Technical Committee are the ones who should really be on this platform. Their knowledge and understanding of the recently completed Density Study in the West is, I believe, as great as any group in the country. Later on in your program several of these men will share with you the knowledge that our Committee has developed. Therefore, I will not attempt to cover the technical side of density studies; rather, I would like to briefly relate the history of the Western Density Study, since this history clearly indicates the value the Density Study has been to the Western Lumber and Plywood Industry. The fact that my remarks will be primarily concerned with lumber and plywood should not be interpreted as indicating that the benefits of density studies are limited to these two products. As I'm sure some of the other speakers on this program will point out, any wood product can benefit from a study of this kind.

In the West, however, interest in density studies came largely from lumber and plywood producers. If lumber and plywood products are to be used efficiently, the assignment of accurate strength properties to them is a necessity. Many years ago when costs were low, the strength properties of wood were relatively unimportant. Often it was cheaper to use extra wood than it was to spend engineering time on more efficient structural design; however, now that wood is more costly, efficient structural design is a necessity if wood is to successfully compete with other structural materials. In fact, today, the strength of any lumber or plywood product is usually the most important single factor in determining the price that product will command.

Since the war, one controversy after another has erupted in the West over the question of wood strength properties. Often the problems were both aggravated and complicated by the lack of adequate technical data. Thus, sincere efforts to provide answers were often ignored, and other methods, including political pressures, were sometimes used to force the kind of technical decision wanted.

This, then, was the climate in the West when the Density Study was proposed some four years ago. It is not quite factual to say the Density Study was proposed, since the Forest Service was already engaged in taking a comprehensive survey of the National Forests. Density data was an important part of this forest survey work; however, it was estimated that it would take ten years for the Forest Service alone to gather all the necessary data on the commercially important Western species. Realizing that ten years was too long to wait for settlement of the disputes over strength properties, the Western plywood and lumber industry offered to contribute $300,000 over a three-year period to

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[1] Chairman, Western Woods Technical Committee.

the Forest Service to accelerate the density portion of the forest survey on nine Western species. The Forest Service accepted this offer, and then proceeded on an expeditious basis to develop the required density and strength data. The work is now done, and I am happy to report that the Density Study has made a real contribution in settling some of the controversies we had. The Density Study forced us to reason rather than argue, and in this process of reasoning we came up with some answers which, I believe, may be useful to some of you.

As you can imagine, lumber and plywood producers don't part easily with $300,000. Once they had spent their money they wanted some results, and this is how they organized themselves to produce these results.

There were originally three associations that supported the Density Study. These were the American Plywood Association, the West Coast Lumbermen's Association, and the Western Pine Association. These three organizations recognized that technical competence would be necessary if the density data was to be used effectively. They, therefore, pooled their technical talent in an organization called the Western Woods Technical Committee. This Committee was assigned the job of determining how best to utilize the information that would eventually come from the Density Study.

After some preliminary evaluation of various statistical techniques, it soon became evident to the Committee that new procedures were needed if the density data were to be converted into reliable strength data. After a great deal of debate, study, and consultation with outside experts, a procedure was finally evolved. This procedure has now been converted to written form and has been submitted to ASTM Committee D-7 for consideration as a tentative standard.

Right here I would like to pause, however, and specially recognize the considerable help the Western Woods Technical Committee got from the Forest Service Experiment Station in Portland and the Forest Products Laboratory here in Madison. I wish time would permit me to identify each of the many individuals who went out of their way to help us. They made a real contribution to our effort, and we gratefully acknowledge the expert assistance that was provided.

After the procedure was finalized and the density data became available, the Western Woods Technical Committee turned its attention to the various combinations of geographic areas and combinations of species that our associations wanted to consider. Each alternative was carefully evaluated and the results presented in outline form to the associations we represented. These associations are now in the process of deciding which of these alternatives is best for them.

As you might expect from an industry that covers the 12 Western States, some disagreement still exists. Almost any decision is bound to disappoint someone; however, with the adequate data we now have, it is much easier to develop the understanding necessary for a workable solution. Most of the emotion is now gone, and attention is being focused on determining what's best for the industry rather than trying to bias technical facts.

However, we are not through with the Density Study. We expect the information derived from this work to stimulate product development as well as eventually provide better, faster-growing trees for our industry to work with.

In closing, I know this is going to be a worthwhile seminar. The interchange of ideas that occurs at conferences like this is needed in the Wood Products Industry, and I hope the Forest Products Laboratory will continue to sponsor such gatherings.

If the forest products industry has a failing, it is its tendency to look more at its past achievements rather than focusing attention on what lies ahead. In addition, I doubt that anyone could question how important science and technology will be to the future of our industry. We must expand our knowledge about wood, and learn to apply this knowledge if the forests of the future are to be marketed with the same success as they are grown. The next few days will, I am sure, provide an important part of the knowledge our industry will need as it faces the future.

Forest Service Western Wood Density Survey:

PHASE I - COLLECTION OF SAMPLE INCREMENT CORES AND RELATED DATA

By

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Phase I consisted of the physical task of collecting increment cores from sample trees and gathering related data concerning the trees and their environment. The data were collected on sample plots distributed over the commercial forest area of 12 Western States.

Actual collection of cores and related data under Phase I started in 1960 in the States of Idaho, Montana, South Dakota, Utah, Wyoming, Washington, and Oregon and was completed in all these States plus Arizona, Colorado, California, and New Mexico by the fall of 1962. Some additional cores for selected species in southwestern Washington were later collected by the Forest Survey project in the summer of 1963. In all a total of 30,326 cores were collected from 4,225 plots.

The original "Plan for Cooperative Wood Density and Related Studies of Western Timber," developed in December 1959 stated that the primary objective from the standpoint of immediate industry needs is to obtain adequate data on (1) average wood density (specific gravity) of each species, (2) the magnitude of the differences between species, and (3) the range of variation between species for commercial timber stands in five western States. Although not designed specifically for this purpose, the contemplated study should also provide some valuable information on the extent to which wood density varies with: (1) tree age, (2) tree growth rate, (3) basal area per acre, (4) latitude, (5) longitude, (6) altitude, (7) aspect, and (8) other factors known to affect or suspected of affecting wood density.

The specific purposes of Phase I as stated in the original plan were:

1. To obtain a sample of increment cores from merchantable trees of western timber species throughout the range of each species in Washington, Oregon, California, northern Idaho, and western Montana.

2. To obtain information on latitude, longitude, altitude, aspect, and stand density at each location where increment cores are obtained.

3. To complete the field collection of increment cores in 2 years.

It was proposed that the study be carried out through the combined efforts of forest industry and State and Federal agencies through the Forest Survey units at the Pacific Northwest Forest and Range Experiment Station at Portland, Oreg., for the States of Oregon and Washington; Pacific Southwest Forest and Range Experiment Station at Berkeley, Calif., for the State of California; and the Intermountain Forest and Range Experiment Station at Ogden, Utah, for the States of Idaho, Montana, Wyoming, Colorado, Arizona, New Mexico, Utah, Nevada, and western South Dakota.

The original plan further stated that:

> A systematic grid sample of ground location based on the Forest Survey inventory grid will be used. Such a systematic grid is expected to provide an unbiased sample of the distribution of wood density by species throughout their range. The spacing and mechanics of establishing the grid will vary among the Forest Survey units according to their inventory sampling grids.

The original plan further proposed that at each gravity sample location two variable-radius plots 2 chains apart be established for collecting sample cores. The goal was to obtain an average of approximately 10 cores per plot for a total of about 36,000 cores of all species. Trees to be bored for sample cores were to be chosen by means of a wedge prism or other variable-radius plot device.

The Forest Service, with some help from the Bureau of Land Management and the States of Oregon and Washington, began the collection of sample cores and related data under the original plan in 1960. In those areas where current Forest Survey or National Forest working circle inventories were being carried on, the work was absorbed as part of these regular inventory projects. In the remaining areas, special crews were used, financed out of Federal funds allocated by the Forest Products Laboratory. Some 723 plots were established and 4,250 cores collected in this first field season, and, at this rate, it would have taken 7 or 8 years to complete Phase I and longer to complete the other phases.

Late in 1960, therefore, the western wood-using industries asked the Forest Service to develop a new plan that would assure the availability of data for Douglas-fir and certain associated high-priority species within 3 years and offered to finance Phase I and certain other phases of the accelerated program. A revised plan to meet this new timetable was drafted, submitted to and approved by the industry groups, and became a part of a formal cooperative agreement entered into by the West Coast Lumbermen's Association, the Western Pine Association, the Douglas Fir Plywood Association, and the U.S. Forest Service in May 1961. This cooperative agreement set June 30, 1964, as the target date for a draft report covering the information called for in the cooperative agreement. The revised plan, which was put into effect at the beginning of the 1961 field season, called for a revision of the area to be covered and specified nine high-priority species to be sampled. This was necessary in order to meet the deadline specified by the industry cooperators and stay within the financing available from Federal and industry sources.

The revision of area to be covered called for reducing the program for the State of California by about one-half, or to approximately 500 field plots well distributed throughout the range of Douglas-fir, white fir, and California red fir. These plots were to be drawn from previously measured Forest Survey plots expected to contain trees of any or all of these species. The revised plan also provided that the program in Colorado, Wyoming, Utah, and eastern Montana be reduced to a total of about 160 field plots, with these plots to be selected from previously measured Forest Survey plots known to contain Douglas-fir trees. Actually in the end it was possible to expand the program in these States and to add Arizona and New Mexico because of extra funds made available through the Forest Products Laboratory. No revision was made in the original program for the States of Oregon, Washington, Idaho, and western Montana. The nine high-priority species specified in the agreement were:

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)
White fir (*Abies concolor* (Gord. & Glend.) Lindl.)
California red fir (*Abies magnifica* A. Murr.)
Pacific silver fir (*Abies amabilis* (Dougl.) Forbes)
Grand fir (*Abies grandis* (Dougl.) Lindl.)
Noble fir (*Abies procera* Rehd.)
Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)
Western larch (*Larix occidentalis* Nutt.)
Black cottonwood (*Populus trichocarpa* Torr. & Gray)

The organization and supervision of Phase I was carried out by the Forest Survey projects at the three western Forest and Range Experiment Stations. In all cases, the system used was closely correlated with the Forest Survey inventory system in use in that area. The same information concerning trees, cores, and tree environment was collected in all cases. Table 1 shows the data collected on all wood density plots.

Table 1.--Field data collected

Plots	Trees	Cores
State County Latitude (to 15 minutes) Longitude (to 15 minutes) Elevation (to 100 or 200 feet) Aspect Site tree Topographic site Basal area per acre	Species Diameter (to 1/10 inch) Bark thickness (to 1/10 inch) Total height (or cubic volume)	Length (to 1/50 inch) Diameter[1] to 1/1000 inch Radial growth, last 10 years in Washington, Oregon, and California (to 1/20 inch)

[1]The bore diameter of all increment borers used was measured with a taper gauge and this measurement recorded as the core diameter.

A brief description of the principal features of the system used in each of the areas follows.

Intermountain (Arizona, Colorado, Idaho, Montana, New Mexico, South Dakota, Utah, Wyoming)

The sampling design varied from State to State; however, all wood density samples were taken at Forest Survey inventory location--either previously established or in the process of being established by Forest Survey and National Forest inventory crews. National Forest inventory crews collected cores on National Forests in Idaho and Utah in the course of regular forest inventories in these areas. Forest Survey inventory crews collected cores in Arizona, New Mexico, and Utah, while cooperative Region 2 Forest Survey crews collected cores in eastern Wyoming and western South Dakota in the course of regular forest inventories in these areas. In the remaining areas where regular forest inventories were not currently underway, special wood density crews financed by special cooperative funds collected samples in western Wyoming, southern Idaho, Colorado, and Montana, from locations established in past Forest Survey inventories.

The method of selecting sample trees varied between the plots established under the regular inventory program by Forest Survey and National Forest Administration crews and those established by the wood density crews. On National Forest and Forest Survey inventory plots, merchantable trees 5 inches d.b.h. and larger that were bored for the growth sample were also used for the wood density sample. This growth sample consisted of the first tree in each 2-inch diameter class on each plot.

The wood density crews, on the other hand, relocated sample plots established in previous forest inventories. At each location, two variable-radius subplots located 2 chains apart were surveyed. The center of the first subplot coincided with the center of the plot established previously for the inventory, and the second was 2 chains north. At each subplot, all live merchantable softwood trees 5 inches d.b.h. and larger, that were selected by means of wedge prism, were sampled. One increment core up to 10 inches in length was extracted at breast height. Each tree was bored according to procedures used in the Pacific Northwest. A prism with a BAF (basal area factor) of 10 was used in poletimber stands, and a 20 BAF was used in sawtimber stands.

Montana.--In western Montana (west of Continental Divide) sample plots were selected from the systematic grid established for forest inventory by Forest Survey and NFA. The sampling intensity was one sample location at 4- by 8-mile grid intersections. A total of 374 locations were sampled.

In eastern Montana, a special sample of Douglas-fir was made. Ninety-four samples were randomly selected for forest inventory plots classified as the Douglas-fir type. Eighty-nine out of 94 were found and sampled.

Special wood density crews collected the data in all of Montana.

Idaho.--In northern Idaho, samples were selected from the systematic grid established for forest inventory by Forest Survey and NFA. The sampling intensity was one sample location at approximately 4 by 8 miles. Southern Idaho did not have a systematic grid. Sample plots were randomly selected from those established previously by Forest Survey and NFA. In northern Idaho, Forest Survey and Region 1 NFA crews collected wood density data during the course of the regular forest inventory. In southern Idaho, Region 4 crews collected similar data on the Cache, Salmon, and Challis National Forests, whereas wood density crews surveyed all the remaining area.

Western South Dakota.--On the Black Hills National Forest, samples were selected from the systematic grid established for forest inventory. On a 6- by 6-mile spacing, 58 plots were sampled. On the forest area outside the National Forest, wood density samples were taken on all of Forest Survey's 30 field locations. The collection of data was absorbed as part of the regular forest inventory project.

Colorado.--A special sample of Douglas-fir was made. Twenty-five locations were selected at random from the list of Forest Survey inventory plots containing Douglas-fir. Wood density crews collected the data.

Wyoming.--Sample plots were selected at random from forest inventory plots. Wood density crews surveyed plots on the Medicine Bow, Bighorn, Bridger, Teton, and Targhee National Forests, whereas Forest Survey inventory crews collected wood density data on the Shoshone National Forest and all samples outside the National Forests. A total of 298 wood density plots were sampled.

Utah.--As part of the regular inventory program, Forest Survey collected wood density data on areas outside the National Forest. Region 4 inventory crews and wood density crews collected similar data on all of the National Forests. A total of 172 wood density plots were taken, selected at random from forest inventory plots.

Arizona and New Mexico.--Special crews and regular Forest Survey crews collected cores from a total of 184 wood density plots in Arizona and 109 in New Mexico.

Pacific Southwest (California)

Sample plots for the Wood Density Survey were selected from Forest Survey plots containing Douglas-fir, white fir, or red fir already established on commercial forest land throughout California on a 4.75-mile systematic grid. Douglas-fir, white fir, and red fir, either individually or in combination, occurred on 1,100 of them. From these, 500 were selected as wood density sampling locations. Sampling locations were chosen to obtain the greatest possible geographical and altitudinal distribution. An additional 39 plots were later established, without reference to the basic grid, to increase the inadequate sample of red and white fir and the geographical and elevational range of these species. All plots were witnessed on the ground and location descriptions prepared so that they could be relocated if necessary.

Wood density sample plots consisted of two variable-radius subplots located 2 chains apart. The center of the first subplot coincided with the pinpricked location on the aerial photo; the second subplot was 2 chains north of the first, unless the second subplot fell in an area without trees. In such case, the plot was relocated by turning in a clockwise direction by 45° intervals from north (from the center of subplot 1) until the second subplot center fell in timber at 2 chains distance. At each subplot, the trees measured, tallied, and bored were selected by means of a wedge prism. The objective was to obtain a combined total of at least 10 cores on the two subplots. The appropriate prism was chosen after making a trial run. In general, a prism with a BAF of 10 was used for small poletimber and sparse open stands, BAF 20 for larger poletimber and/or fairly open stands, a BAF 30 for small sawtimber, and a BAF 40 for large sawtimber stands. One increment core was extracted according to procedures used in the Pacific Northwest. Cores were taken from all softwood species except pinyon pines, California torreya (nutmeg) (Torreya californica Torr.), Pacific yew (Taxus brevifolia Nutt.), juniper (Juniperus sp.), and cypress (Cupressus sp.). Neither red alder nor black cottonwood occurred on any of the sample plots.

The number of plots installed in California was 297 in 1961 and 242 in 1962, making a total of 539 for the State. A total of 4,960 sample cores were obtained from 18 softwood species and sent to the Forest Products Laboratory for analysis. Of the total number of cores collected, 20.2 percent were Douglas-fir, 31.3 percent were white fir, and 13.5 percent were red fir. The remaining 35 percent was distributed among the 15 associated softwood species.

Pacific Northwest (Oregon and Washington)

The sampling design used for the Wood Density Survey in Oregon and Washington was based on the systematic grid established for forest inventory work in these two States by the Forest Survey and National Forest Administration. The sampling intensity of the Wood Density Survey was one field plot every 6.8 miles. A total of 1,878 plots from the sample grid were located on photos as potential Wood Density Survey plots in these two States. Of this total, 1,512 plots yielded sample cores. An additional 124 plots were later established without reference to the basic grid to obtain sample cores from species which were missed or too lightly sampled by the basic grid, bringing the total number of plots to 1,636. All field plots, except the 124 extra plots, were pinpricked on aerial photos and witnessed on the ground so that they could be relocated if necessary.

Two different collection procedures were used in these States. The first was used in 1960 on plots established by Forest Survey, the Bureau of Land Management, and the States of Oregon and Washington in the course of their regular forest inventories.

Under these first procedures, the Wood Density Survey plots consisted of two variable-radius subplots located 2 chains apart. The center of the first subplot coincided with the pinpricked location on the aerial photograph; the second subplot was 2 chains north of the first. At each subplot the trees to be tallied were selected by means of a wedge prism. A prism with a BAF of 40 was used for all plots west of the crest of the Cascade Range and a prism with a BAF of 25 was used for all plots east of the crest of the Cascade Range. One sample core was taken from every live, sound tree 5.0 inches d.b.h. and larger. Cores were taken from trees of all softwood species except whitebark pine (Pinus albicaulis Engelm.), subalpine larch (Larix lyallii Parl.), Pacific yew (Taxus brevifolia Nutt.), and juniper (Juniperus sp.), and taken from three hardwood species--red alder (Alnus rubra Bong.) black cottonwood (Populus trichocarpa Torr. & Gray), and bigleaf maple (Acer macrophyllum Pursh).

Each tree was bored to the center or until 10 inches of wood were obtained, whichever came first. If a sample core contained rot, pitch pockets, limb wood, or was too badly broken, the tree was rebored. No core with less than 5 inches of sound wood was accepted, provided the diameter of the tree was large enough for this. All of the information previously mentioned concerning the core, the tree, and plot was recorded. A total of 215 plots were established in 1960 under these procedures, 44 in Oregon and 171 in Washington.

The second set of procedures was used beginning in 1961 for all the remaining Wood Density Survey plots established in Oregon and Washington. The plot design and procedures for selecting the trees to be tallied on the plot were identical to those adopted in that year by the Forest Survey for its forest inventories. Under these procedures, each plot consisted of 10 variable-radius sample points systematically distributed over an acre. A wedge prism or angle gauge with a BAF of 80 for plots west of the crest of the Cascade Range or a BAF of 50 for plots east of the crest was used to select the trees at each sample point. The first tree tallied at each point, of suitable size and species, was bored to obtain the Wood Density Survey sample core. If this tree failed to produce a satisfactory core, the second tree tallied was bored. Otherwise the procedures and data recorded were the same as in 1960.

By the end of Phase I a total of 30,326 cores had been collected from 4,225 plots. A total 15,311 of these cores were from the 9 high-priority species and the remainder from other species, including all other commercial softwoods encountered and two other hardwoods, red alder and bigleaf maple. Table 2 shows the total number of sample plots and sample cores by States and table 3 shows the number of cores from high-priority species by broad geographic areas.

Table 2.--Number of sample plots and cores by States

State	Sample plots	Sample cores
Arizona	184	1,254
California	539	4,960
Colorado	25	211
Idaho	711	5,114
Montana	463	4,284
New Mexico	109	672
Oregon	849	5,622
South Dakota	88	397
Utah	172	1,152
Washington	787	4,774
Wyoming	298	1,886
Total	4,225	30,326

Table 3.--Number of sample cores from high-priority species

Species	Geographic area			
	Coast[1]	Interior[2] North	Interior[3] South	Total
Douglas-fir	4,077	4,460	596	9,133
White fir	1,589	338	223	2,150
California red fir	804	36	---	840
Grand fir	59	803	---	862
Pacific silver fir	265	65	---	330
Noble fir	158	---	---	158
Western hemlock	912	128	---	1,040
Western larch	---	678	---	678
Black cottonwood	112	8	---	120
Total	7,976	6,516	819	15,311

[1]Western Washington, western Oregon, and California.
[2]Eastern Washington, eastern Oregon, Idaho, Montana, and Wyoming.
[3]Arizona, New Mexico, Colorado, Utah, and Nevada.

Forest Service Western Woods Density Survey:

PHASES II (INCREMENT CORE PROCESSING) AND III (ESTIMATING TREE SPECIFIC GRAVITY)

By

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The Western Wood Density Survey is part of a systematic Nationwide survey to determine the specific gravity and related quality characteristics of all commercially important coniferous species. Basically, the purpose is to develop better information on the quality of our Nation's forest resource.

The Western Density Survey I am going to discuss, the Southern Survey findings that Mr. Mitchell will present, and any other density survey have the same four objectives. They are:

1. To obtain, by systematic sampling, adequate data on the average specific gravity and related quality characteristics of each major species, the magnitude of the differences between species, and the variation within species.

2. To seek out, through systematic sampling, living trees that are superior in wood quality as well as form, growth rate, pest resistance, and other desirable characteristics, so they may be used in breeding studies and to provide scion material for seed orchards.

3. To learn more about the effects of environmental and other factors on specific gravity and related wood quality characteristics so forest managers can put this information to practical use in growing higher value trees.

4. When existing test data are deficient, to conduct such destructive sampling and laboratory testing as are necessary to better establish, for each of the commercially important species over the range of specific gravities found in the survey, the relationships between specific gravity and the strength and stiffness of clear wood specimens. Sound data on specific gravity-strength relationships are basic to the establishment of basic stresses and working stresses for structural application.

With these objectives in mind we can return to the subject of this presentation. The U.S. Forest Service initiated the Western Wood Density Survey in the spring of 1960, the workings of which logically divided into four phases:

Figure 1.--Sawing sample disk from 40-inch Douglas-fir in northern California.

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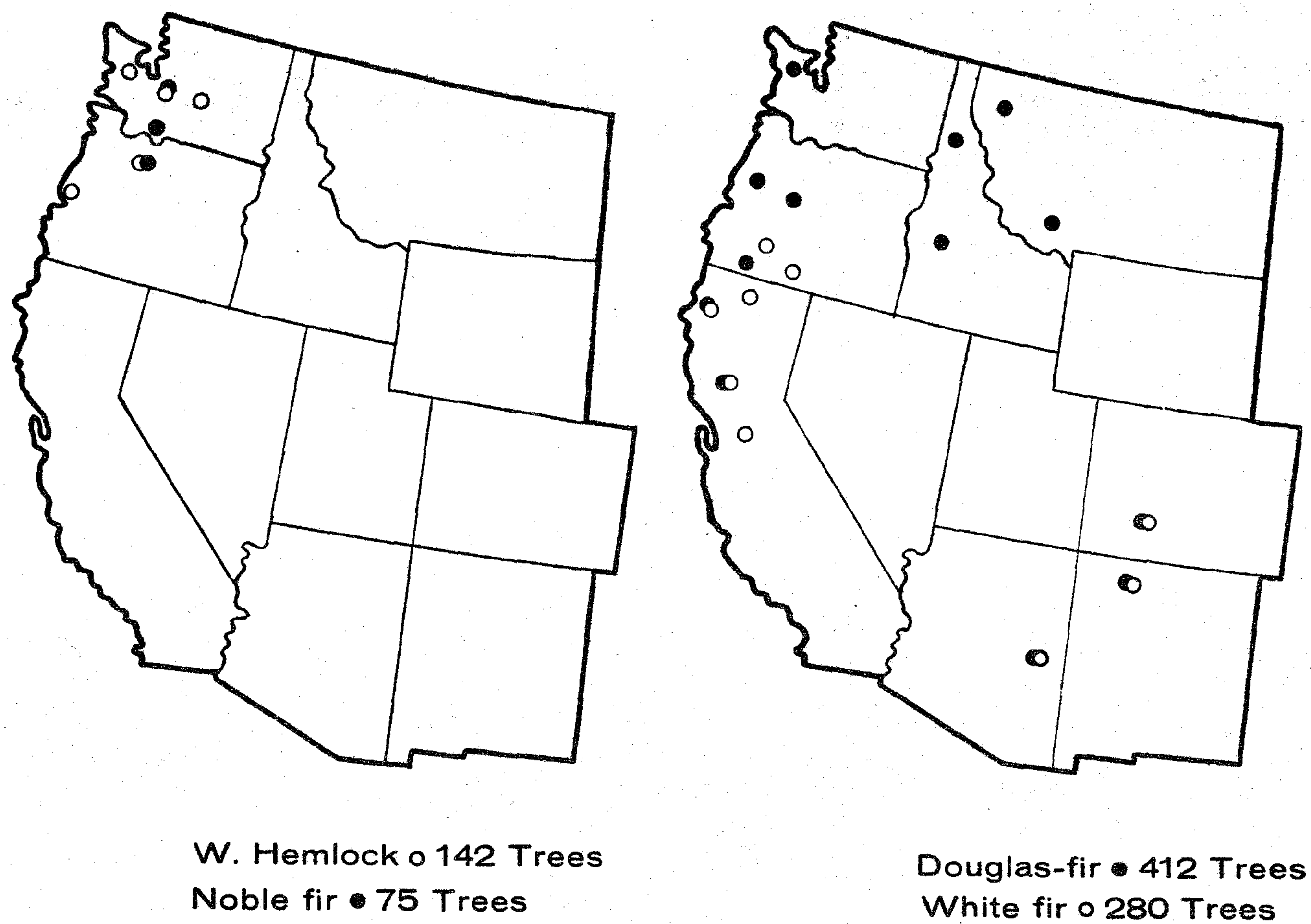

Figure 2.--Phase III sample areas for western hemlock, Douglas-fir, noble fir, and white fir.

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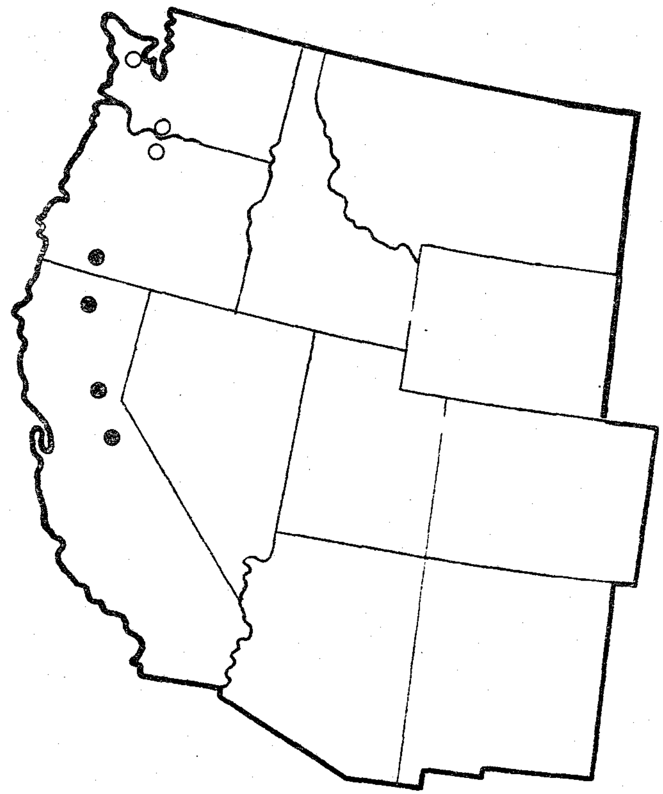
Grand fir ⊖ 209 Trees
W. Larch o 162 Trees
Blk. Cottonwood ● 78 Trees



Pac. Silver fir o 90 Trees
Calif. Red fir ● 157 Trees

Figure 3.--Phase III sample areas for grand fir, Pacific silver fir, California red fir, western larch, and black cottonwood.

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Phase I.--As Mr. Metcalf just reported, Phase I was concerned with the planning and collection of increment cores and related data from sample trees on plots distributed throughout the commercial forest area of the 12 Western States. The Forest Survey units of the western U.S. Forest and Range Experiment Stations planned and directed this phase.

Phase II.--Included in Phase II was the laboratory processing of the sample increment cores and the statistical analyses and interpretation of the results. The FPL had this responsibility.

Phase III.--This phase involved the destructive sampling to determine, for each species over its natural range, the relationship between increment core specific gravity at breast height and the average (tree) specific gravity for the merchantable volume of the whole tree.

Phase IV.--Phase IV of the study was aimed at utilizing the wood density data derived from the earlier phases to obtain more reliable estimates of strength properties.

Early in 1961, because of their urgent need for the data, the western forest industries entered into a cooperative agreement with the Forest Service to greatly accelerate work on nine high-priority species. To help defray costs, and assure completion by July 1, 1964, a total of $300,000 was contributed over a 3-year period by the West Coast Lumberman's Association, the Western Pine Association, and the Douglas Fir Plywood Association.

A Western Woods Technical Committee, appointed by the three cooperating trade associations, was formed to work closely with the Forest Service on planning, coordination, review of progress, interpretation of results, and other matters of mutual interest. The full committee met with representative of the Forest Service at least once each year for the duration of the study. To facilitate even closer cooperation, this industry committee formed a small task group, composed of experienced technical specialists. This group met more frequently and worked very closely at the technical level with their counterparts in the Forest Service. As a result, the project benefited greatly from this working relationship.

The field sampling contemplated in the accelerated cooperative program was completed on schedule. This involved the collection of 30,326 increment cores from individual trees on 4,225 systematically located plots in 11 States. From each tree sampled, one increment core was taken at breast height, to a depth of 10 inches (or to the pith), oriented to the plot center.

Core-to-Tree Specific Gravity Relationships

Phase III studies, for the nine high-priority species, involved the falling and destructive sampling (fig. 1) of 1,423 trees from 47 locations in 8 States and the laboratory processing of some 8,000 sample disks. Trees were selected on plots throughout the western United States to insure a representative sample of the natural distribution and volume of each of the nine priority species (figs. 2 and 3). All sampling locations were in areas of active logging operations; as such, they involved significant contributions of time, materials, and equipment by private loggers and other representatives of industry and District Rangers and Experiment Station personnel of the Forest Service. At each location a number of trees were bored at breast height with a calibrated increment borer, bark to pith or to a maximum length of 10 inches. Final selection of about 20 to 40 trees for each location was made by two-way stratification, using 5-inch d.b.h. classes (e.g. 5.0-9.9 inches) and 0.050 specific gravity classes (e.g. 0.300-0.349). These trees were felled and logs (16 feet long) cut progressively, starting at a point 4.5 feet above ground, to a merchantable top diameter (usually 10 inches inside bark).

Clear disks were cut from the butt end of each log and from the top of the last log. The average specific gravity for each log was estimated from the mean specific gravity of its terminal disks; and the average specific gravity for each tree was weighted for proportional representation of the log volumes.

The relationship of core specific gravity (X) and other tree characteristics to tree specific gravity (Y) was examined by multiple regression analysis. Data for sample trees from all areas were combined for each species in these analyses. In all, 10 independent variables were examined, including diameter at breast height (X_1), age of tree (X_3), core specific gravity (X_6), and merchantable volume (X_4).

For simple linear regressions, the only variable that was significant at the 5 percent level of probability for all species was core specific gravity. Graphic representations of these simple linear relationships for four species are shown in figure 4.

The next "best" independent variable for eight of the nine species was d.b.h. The addition of d.b.h. resulted in a significant reduction in the residual sum of squares (probability, P = 0.05) for all species.

The uniformity and because only limited tree data were available from the systematic sampling, the multiple regression equations for estimating tree specific gravity were all calculated with core specific gravity and d.b.h. as independent variables. The final equations for the nine species are shown in table 1. These multiple regression equations provide an acceptable basis for estimating merchantable tree specific gravity from a single increment core, taken at breast height, to a maximum depth of 10 inches.

Table 1.--Multiple regressions predicting tree specific gravity using core specific gravity and d.b.h.

Species	Equation	R^2 [1]	Standard deviation from regression
Douglas-fir	$Y = 0.17219 + 0.63623X_6 - 0.00107X_1$	0.6100	0.023
White fir	$Y = 0.13559 + 0.63528X_6 - 0.00062X_1$	.6095	.019
California red fir	$Y = 0.18053 + 0.47318X_6 - 0.00045X_1$	.4859	.023
Grand fir	$Y = 0.01876 + 0.80654X_6 - 0.00054X_1$	.6681	.024
Pacific silver fir	$Y = 0.14388 + 0.64930X_6 - 0.00096X_1$	.6492	.026
Noble fir	$Y = 0.29638 + 0.28141X_6 - 0.00161X_1$	.5887	.016
Western hemlock	$Y = 0.25630 + 0.47233X_6 - 0.00220X_1$	.7022	.023
Western larch	$Y = 0.27429 + 0.43400X_6 - 0.00199X_1$	.4394	.023
Black cottonwood	$Y = 0.14364 + 0.54095X_6 - 0.00055X_1$	.4828	.019

[1] The "coefficient of determination" (R^2) indicates the proportion of the variation in Y that is associated with the regression.

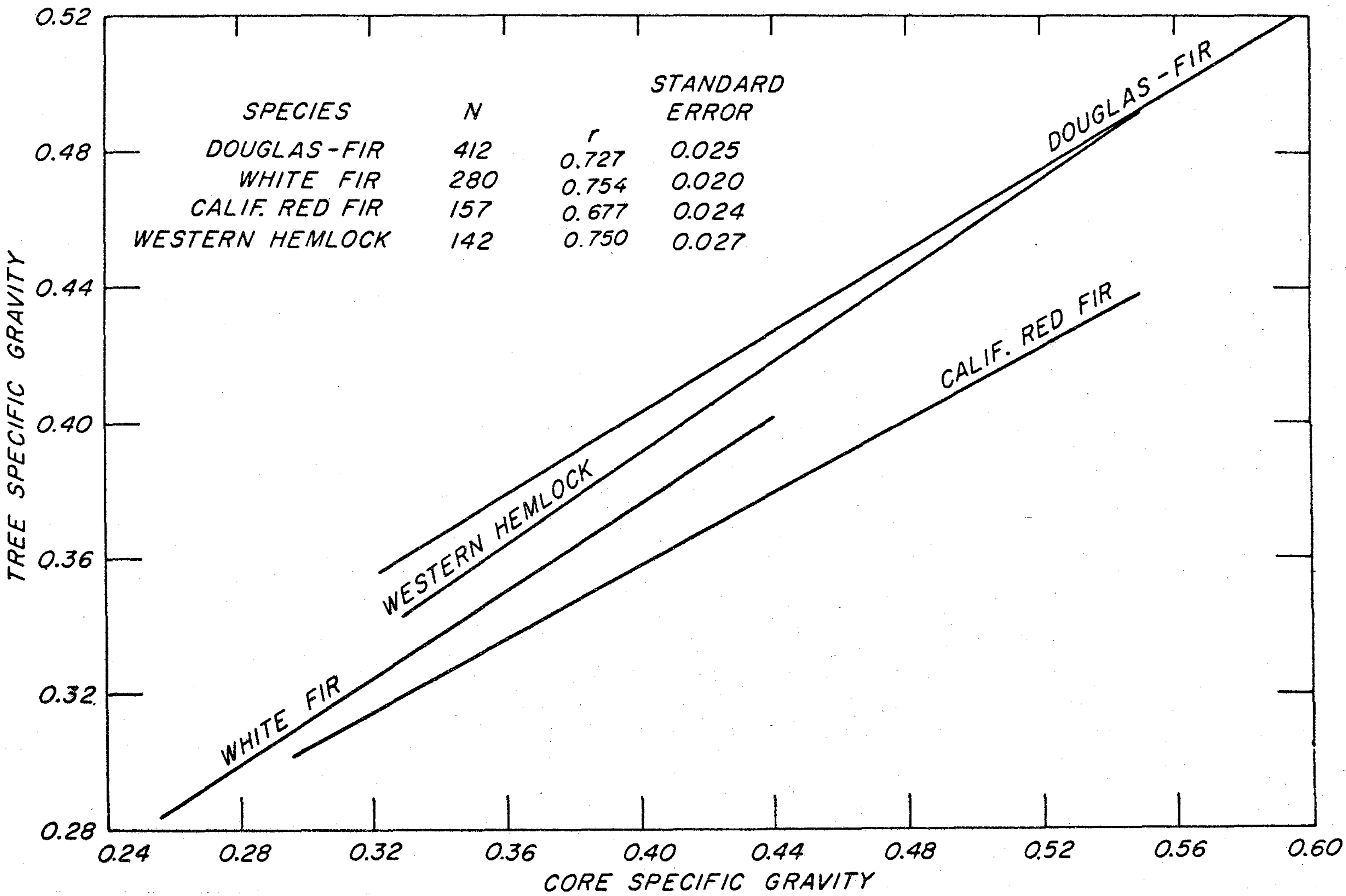

Figure 4.--Relationship between 10-inch increment core specific gravity at breast height and tree specific gravity for Douglas-fir, white fir, California red fir, and western hemlock.

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Specific Gravity Means and Range of Variation

Increment cores and accompanying field data sheets collected in Phase I activities were mailed to the Laboratory from the Experiment Stations. The data gathered at the Laboratory included an estimate of age, sapwood thickness, and increment core specific gravity, which was added to the field data and punched on an automatic data processing (ADP) card--one card for each tree sampled.

The ADP cards containing field and laboratory data were used as a basis for the preparation of "working" data cards for the nine priority species. These cards contained, in addition to the collected data, an estimate of tree specific gravity computed in Phase III work. Also, latitude and longitude minutes were converted to degree equivalents and the following growth functions computed: d.b.h./age, volume/age, and rings per inch. Replicated basic and working data cards were furnished to industry and Experiment Station cooperators.

Some of the more pertinent resulting data for all priority species are summarized in table 2, including mean specific gravity, range of variation in specific gravity, number of trees sampled, and Wood Handbook values for specifc gravity. Density Survey mean specific gravity values for species like Douglas-fir, which have been extensively sampled in the past, are in close agreement with values reported in the Wood Handbook. On the other hand, the new values for some of the less extensively sampled species, such as western hemlock and western larch, are significantly different from the Wood Handbook values (table 2).

Table 2.--Estimated tree specific gravity[1] for priority species

Species	Mean specific gravity	Range of specific gravity	Number of trees sampled	Wood Handbook average specific gravity
Douglas-fir	0.45	0.33-0.59	9,133	----
West Coast	.45	.34- .59	4,323	0.45
Coast	.45	.34- .59	2,770	----
Interior west	.46	.34- .59	1,553	----
Interior north	.45	.33- .59	4,214	.41
Interior south	.43	.33- .55	596	.40
White fir	.37	.26- .54	2,150	.35
California red fir	.36	.31- .46	840	.37
Grand fir	.35	.24- .55	862	.37
Pacific silver fir	.40	.28- .55	330	.35
Noble fir	.37	.26- .44	158	.35
Western hemlock	.42	.30- .52	1,040	.38
Western larch	.48	.38- .54	678	.51
Black cottonwood	.31	.28- .40	120	.32

[1] Tree specific gravity values are estimated from core specific gravity and d.b.h. values. Specific gravity is on a green volume-ovendry weight basis.

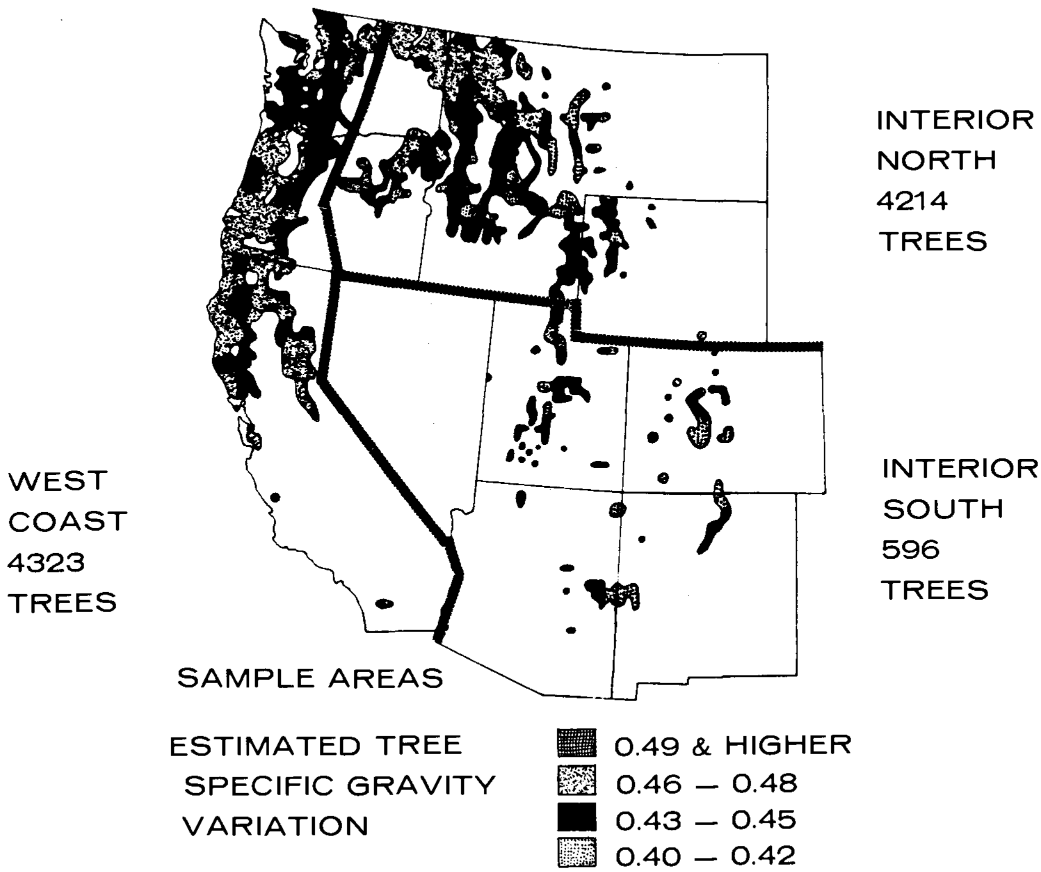
Because of time limitations I will confine the more detailed data reporting to one species--Douglas-fir. Table 3 presents the average estimated tree specific gravity and its standard error, the average core specific gravity, and average diameter for sampled trees by Forest Survey units. The specific gravities presented in tables 2 and 3 are the best estimates of specific gravity available for the nine priority species. It is the first time specific gravity data were collected systematically and intensively over the entire natural range of the species in this country.

Histograms of estimated tree specific gravity, along with a sampling area map, for Douglas-fir, by various regions, are shown in figures 5, 6, 7, and 8. The geographic regions in figures 5 and 6 are primarily a breakdown based upon recognized botanical and physiographic differences. A second breakdown subdivides the West Coast area into Coast and Interior west regions (figs. 7 and 8). This was done because there is evidence that the strength property-specific gravity relationship is different between the two subdivisions. Note that only the Interior South has a mean specific gravity that is significantly different from the other regions or from the population as a whole.

Table 3.--Specific gravity of Douglas-fir by Forest Survey Units

Forest Survey Units	Average estimated tree specific gravity[1]	Standard error of estimated average tree specific gravity	Number of trees sampled	Average core specific gravity	Average d.b.h. for sample trees
					In.
Arizona	0.435	0.0053	86	0.440	19.4
California:					
Eastside Sierras	.438	.0052	39	.457	19.5
Westside Sierras	.454	.0030	273	.478	20.1
Coast Range Pine	.451	.0035	325	.484	23.9
Redwood-Douglas-fir	.467	.0039	378	.506	29.0
Southern California	4.94	-----	6	.548	25.1
Colorado	.429	.0028	149	.423	11.6
Idaho, North	.452	.0023	605	.467	15.0
South	.434	.0018	1,175	.442	17.4
Montana, West	.455	.0018	1,109	.469	12.9
East	.432	.0020	538	.428	12.9
New Mexico	.430	.0033	125	.436	18.1
Oregon, West	.452	.0016	1,861	.491	28.2
East	.446	.0029	350	.465	18.6
Utah	.436	.0044	236	.440	14.7
Washington, West	.437	.0022	962	.462	21.1
East	.451	.0022	683	.473	16.9
Wyoming	.434	.0028	233	.435	14.9

[1] Specific gravity estimates are given to three digits to permit further computations with minimum round-off error.



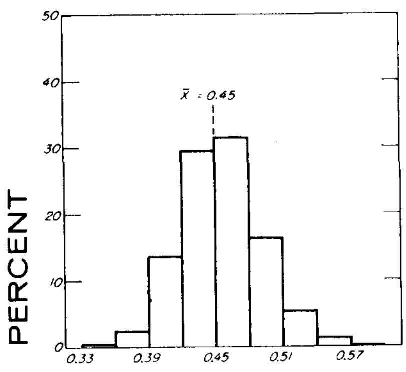


Figure 5.--Douglas-fir estimated tree specific gravity and variation.

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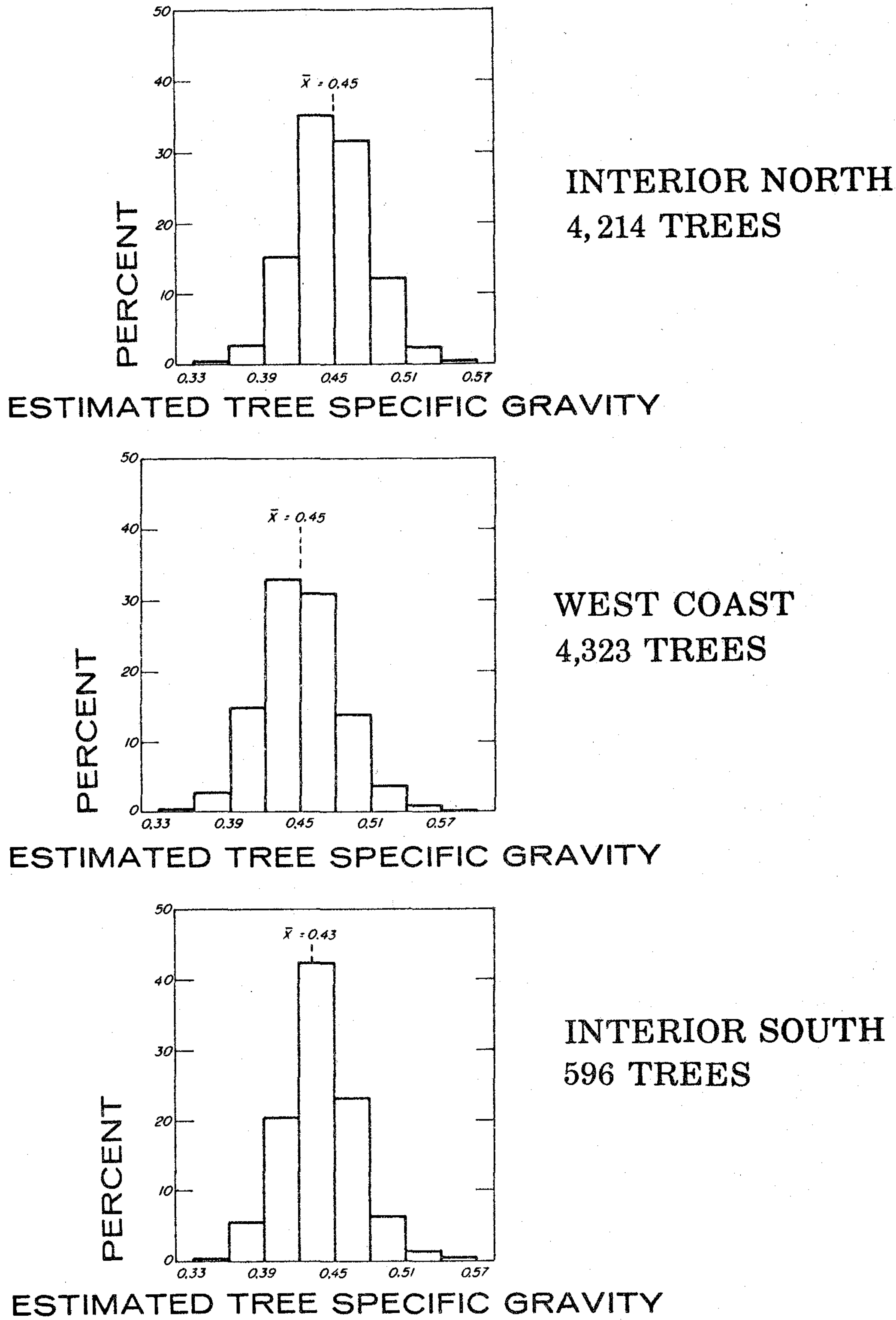

Figure 6.--Douglas-fir specific gravity by regions.

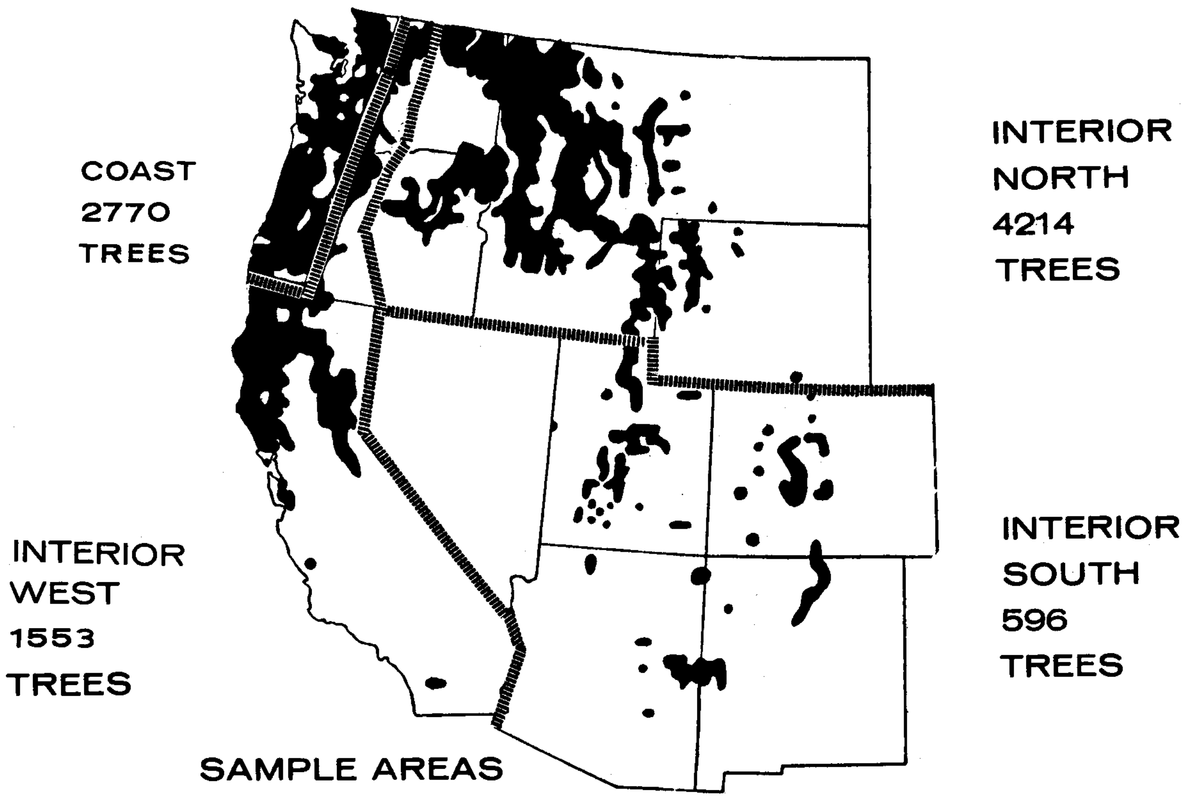

Figure 7.--Douglas-fir by strength property-specific gravity regions.

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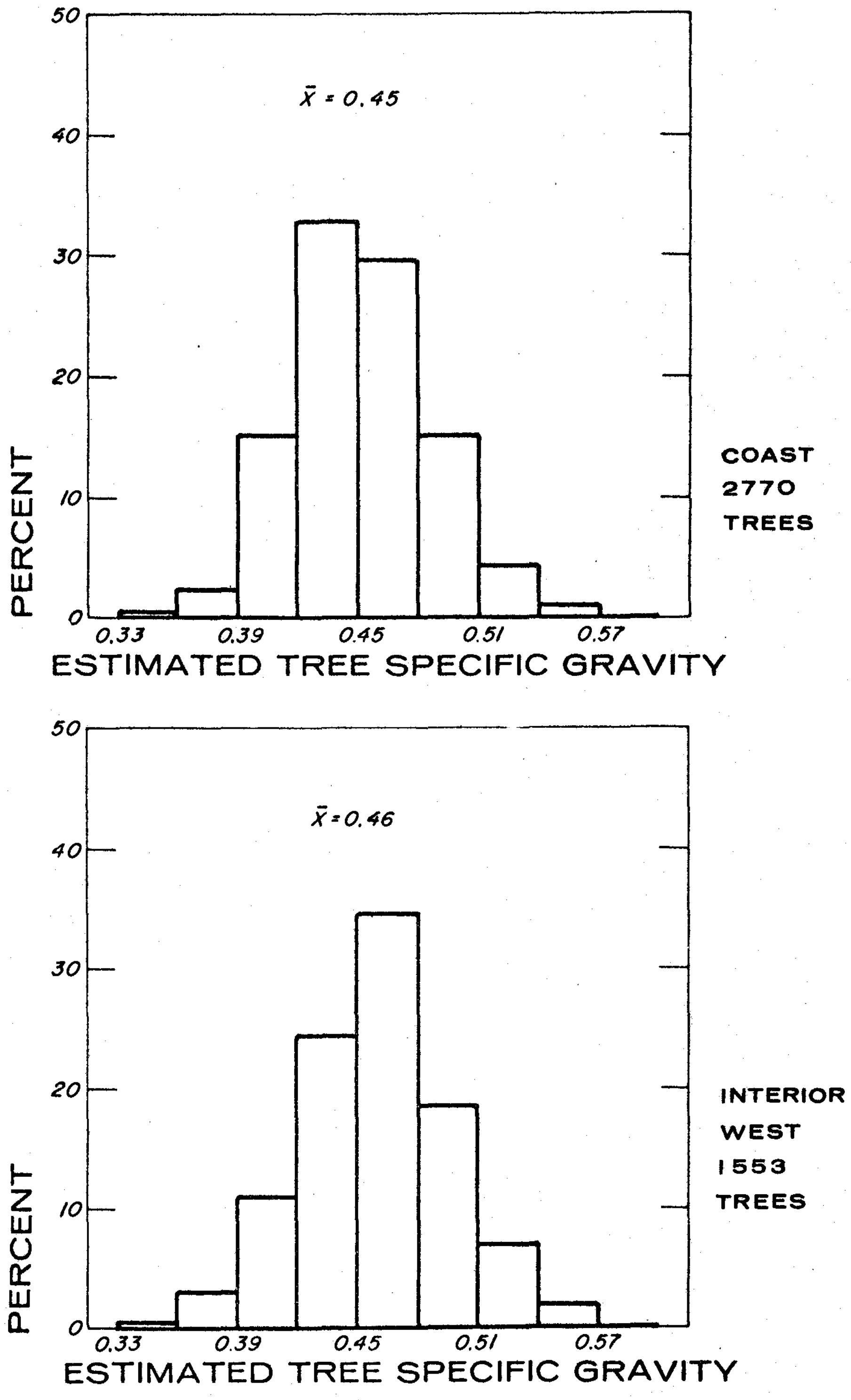

Figure 8.--Douglas-fir specific gravity by Coast and Interior West regions.

M 127 584

The western softwoods show about the same range of variation in specific gravity as the southern pines. As suggested by the histograms, quite a few individual trees having higher than average specific gravity were located during the survey. None of these potentially elite trees has as yet been "ground-checked" by forest geneticists, but on the basis of past experience some will no doubt show sufficient promise to justify their inclusion in breeding experiments.

Sources of Specific Gravity Variation

One of the objectives of a density survey, you may recall, was to investigate the climatic and physiographic factors with which variations in wood specific gravity may be associated. Accordingly, multiple regression techniques were used to explore the relationships between specific gravity and latitude, longitude, elevation, age, d.b.h., volume, growth rate, and certain other variables.

Douglas-fir does not show the clear-cut patterns of geographic variation found in southern pines. There is a slight trend toward increasing gravity from north to south along the coast, west of the Cascade and Sierra ranges, and a reverse trend in the interior. These trends are, however, weak and of little practical significance. The patterns of specific gravity variation for the species is more of the patchwork nature, as shown in figure 5.

Of the variables investigated, the reciprocal of age is by far the most important, accounting for 16 percent of the specific gravity variation of Douglas-fir in the West Coast region. Next in order of significance are elevation and latitude. The nine "best" independent variables jointly account for 28 percent of the variation.

For some of the true firs, which grow over a more limited range of climatic and site conditions, up to 36 percent of the specific gravity variation can be accounted for by some combination of age, latitude, diameter, elevation, and growth rate.

The natural range of Douglas-fir spans the entire western United States with its many diverse climatic and physiographic provenances. It seemed desirable, therefore, to study this species intensively over a smaller, more homogeneous area in hopes of "explaining" more of the observed variation in specific gravity. The area selected was the western slope of the Cascade Range in Washington and Oregon where data were available on 1,402 sample trees. In this area, the climatic gradient from north to south with respect to precipitation, temperature, and day length is small, if one exists. The east-west gradient, on the other hand, is one of extremes even though the distance involved is only 50 to 100 miles. These extremes are associated with the elevational change from sea level or less than 1000-foot elevation in the Willamette Valley to 6000-8000 feet at the crest of the Cascades.

Multiple regression analysis were again used to explore the relationships between core specific gravity and various functions of latitude, age, diameter, and elevation. The percentages shown in table 4 indicate the degree of association between specific gravity and the various independent variables.

It is evident that for Douglas-fir west of the Cascades, no more than 30 percent of the total variation in core specific gravity can be accounted for by the variables investigated. There are, however, other environmental factors such as precipitation, soil, and expressions of tree vigor and growth such as crown class, site index, and live crown ratio which may be important. Data on these factors are, unfortunately, very limited or nonexistent for this study.

In view of the fact that up to 70 percent of the observed variation in the specific gravity of Douglas-fir and certain other western softwoods remains unaccounted for, further research is needed.

On the other hand, from the standpoint of meeting the primary objectives of the Western Wood Density Survey--the determination of reliable mean specific gravities by species and areas--the results of the study provide a much sounder and more defensible basis for engineering applications than anything previously available. The next speaker, Robert Ethington, will explain how the survey data were utilized for determination of strength properties for the nine priority species.

Table 4.--Coefficients of determination showing significant (P = 0.01) improvement by successive inclusion of variables for Douglas-fir on the west slope of the Cascade Range.

Number of variables showing significant (P = 0.01) increase in R^2	Independent variables												
	Latitude	Elev.	Dia.	Age	1/age	Dia/age	Vol/age	1/elev	$Elev^2$	$Elev^2$/age	Dia^2	Dia^2/age	R^2
	ALL SAMPLE DOUGLAS-FIR ON WEST SLOPE OF CASCADES												
1					X								0.16
2					X				X				.21
3	X	X			X								.26
4	X	X			X					X			.27
5	X	X			X	X				X			.28
6	X	X			X		X			X		X	.28
7	X	X	X			X	X			X	X		.29
8	X	X	X		X	X	X			X	X		.30
	AGES 5-34												
1				X									.13
2						X	X						.18
3			X	X			X						.22
	AGES 35-74												
1		X											.06
	AGES 75-149												
1									X				.06
2	X								X				.10
	AGES 150-249												
1									X				.26
2	X	X											.38
	AGES 250 AND OVER												
1		X											.11
2	X	X											.19
3	X	X	X										.28
4	X	X	X					X					.29

Forest Service Western Woods Density Survey

PHASE IV, SPECIFIC GRAVITY AS A STRUCTURAL PROPERTY INDEX[1]

By

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The mechanical properties of major structural interest are modulus of rupture and modulus of elasticity in flexure, maximum crushing strength in compression parallel to the grain, and maximum shearing strength parallel to the grain. Efforts to estimate these properties by species are compounded by the wide variation in the properties encountered over the producing range of the species. The users of the properties, which include building code writers, designers, engineers, and the developers of stress-graded lumber, are impatient with the problems of trying to establish properties in the face of variation. They desire a simple tabulation of properties which are reliable, efficient, and safe.

The Forest Products Laboratory has been interested in property estimation for more than one-half century. A major project was established in 1910 to evaluate average mechanical properties of species which eventually numbered about 175. The planners of that evaluation were faced with forests wherein much of the timber was relatively inaccessible, and with the need to develop sampling plans and testing techniques. The methods used are published as ASTM Designation D 143. The results of the program of species evaluation were published in 1935 as U.S. Department of Agriculture Technical Bulletin 479. Since 1935, research attention has been focused on using the average property estimates to utilize wood more efficiently; from that research has come such important developments as stress-grading structural lumber and design of laminated timber construction. Our methods of utilizing property data have reached such a degree of sophistication that we now ask ourselves if the property estimates themselves are sufficiently precise. Species of relatively little commercial importance in the first third of the Twentieth Century, which were not heavily sampled, have become quite important today. The current cost of sampling by means of the earlier techniques seems high with respect to the amount of new information acquired.

The fourth phase of the Western Wood Density Survey was designed to permit the incorporation of new data acquired by less expensive means with the earlier data on a sound technological basis that would yield a characterization of property distributions, rather than averages alone. An effort was made to insure that the sample distributions reliably represented the populations being sampled. Recognizing that most foresters exhibit geographic heterogeneity with respect to their properties, methods were worked out to provide a measure of this heterogeneity. Finally, guidelines were desired for assigning properties to groups of species, where groupings might seem desirable.

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[1] A summary. A more complete treatment is given in the paper, "Structural Property Estimation from Density Samples for Western Woods," presented at the annual meeting of the Forest Products Research Society, June, 1965.

The basis for the entire method is called double sampling. In the context of double sampling, the mechanical property data already available are used to provide a correlation between each property and specific gravity. If, then, the wood density survey can be used to provide reliable estimates of average specific gravity, these estimates are combined with the correlation to provide estimates of average mechanical properties.[2]

To cope with the problem of geographic heterogeneity, the species range was systematically subdivided into small parts, called unit areas, according to a set of arbitrary, objective rules. By definition, a unit area contains at least 1 percent of the species volume and at least 20 tree specific gravity samples. It is assumed that each unit area is more homogeneous than is the entire species growth range with respect to mechanical properties. Now it is possible to determine average specific gravity for each unit area, and using the property-gravity correlation, it is also possible to predict average mechanical properties for each unit area. Unit areas have no significance by themselves since it is inconceivable that wood could ever be segregated in the market places by unit areas. It is therefore desirable to recombine the unit areas into larger geographic groups. This can be done by calculating a simple volume weighted average of each mechanical property for any desirable unit area combination. The geographical heterogeneity for any combination of unit areas at the critical or lower end of the property distribution is described by the variability index. The variability index is defined as the average property for the group of unit areas, divided by the average property for the lowest unit area distribution contained therein.

To completely prescribe the property distribution for each group of unit areas, under the assumption that these distributions are normal, a variance is required. Variance estimates have been made from a suitable combination of the earlier Forest Products Laboratory mechanical property data and the newer wood density survey specific gravity data.[3]

For each group of unit areas, and each property, the distribution is completely prescribed by a mean and variance, and an additional bit of information is given on the nature of the geographical heterogeneity associated with low properties by the variability index. For marketing purposes it may be desirable to define combinations of these groups. Once the group distributions are known, this may be done in an entirely rigorous fashion, leading to a heterogeneous distribution.[4] Heterogeneous distributions are in general non-normal.

The fourth phase of the Western Wood Density Survey offers a method for improving our estimates of mechanical property distributions by merging Forest Products Laboratory shipment or similar data on mechanical properties and more readily obtainable specific gravity information. It makes possible the grouping of species according to marketing considerations and provides an indicator of the lowest property that may generally be expected for an entire purchase of wood from a single small geographic area.

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[2] Additional information on double sampling may be found in "Elementary Forest Sampling," by Frank Freese, published in 1962 by the U.S. Department of Agriculture as Agriculture Handbook 232.

[3] The methods for estimating variance are beyond the scope of this summary. Details may be found in "Western Wood Density Survey," Report No. 1, U.S. Forest Service Research Paper FPL 27, 1965.

[4] Heterogeneous distributions are discussed by A. Hald in "Statistical Theory with Engineering Applications," John Wiley & Sons, Inc., New York, N.Y. 1952.

HIGHLIGHTS OF RESULTS OF THE SOUTHERN WOOD DENSITY SURVEY

By

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U.S. Department of Agriculture

Introduction

This paper briefly summarizes all presently available information on the Southern Wood Density Survey. Included are new data released for the first time in the 1965 status report (11),[1] as well as information published in full or in part in earlier reports (6,7,14).

The southern wood density study is part of a systematic Nationwide survey to determine the specific gravity and related quality characteristics of all commercially important coniferous species. The overall objective is to develop better information on the quality of the Nation's forest resources. All phases of the work are conducted by the U.S. Forest Service in close cooperation with industry and the States. The calibrated increment borer technique used in this work, and other now widely adopted specialized methods and procedures, evolved from research on southern pines and were given their first large-scale test in Mississippi in the mid-1950's. Normally all field work, including increment core sampling, is carried on in connection with the regular activities of the Nationwide Forest Survey.

The pulp and paper industry early recognized the existence of major differences in specific gravity between species, as reflected in pulp yields, and also noted that wood from certain areas produced higher yields than pulpwood of the same species procured in other localities. The density survey data, to the extent now completed, provides a basis for estimating average pulp yields by species, diameter classes, and areas.

Producers of structural lumber, plywood, laminated arches and beams, and of high-quality transmission poles and piling are equally concerned with the density of their raw material. Their interest, of course, stems from the well-established relationship between specific gravity and the strength and stiffness properties of solid wood and laminated products. Because their product is judged on the performance of individual pieces, they may be as much concerned with the variation in specific gravity among individual trees as with average values.

[1] Underlined numbers in parentheses refer to Literature Cited at the end of this report.

Objectives

The objectives of the Southern Wood Density Survey as presently conceived and conducted are as follows:

1. To obtain, by systematic sampling, adequate data on the average specific gravity and related quality characteristics of each major species of southern pine, the magnitude of the differences between species, and the variation within species.

2. To seek out, through systematic sampling, living trees that are superior in wood quality as well as form, growth rate, pest resistance, and other desirable characteristics, so that they may be used in breeding studies and to provide scion material for seed orchards.

3. To learn more about the effects of environmental and other factors on specific gravity and related wood quality characteristics so that forest managers can put this information to practical use in growing higher value trees.

4. When existing test data are deficient, to conduct such destructive sampling and laboratory testing as are necessary to better establish, for each of the commercially important species over the range of specific gravities found in the systematic survey, the relationships between specific gravity and the strength and stiffness of clear wood specimens. Sound data on specific gravity-strength relationships are basic to the establishment of basic stresses and working stresses for structural applications.

Assignment of Responsibilities

The Southern Wood Density Survey divides logically into four phases, as follows:

Phase I.--This phase is concerned with the planning and collection of increment core and related data from sample trees on plots distributed throughout the commercial forest area of the Southern States. The Forest Survey units of the Southern and Southeastern Forest Experiment Stations collect these data as a part of their regular survey work.

Phase II.--Included in this phase are the laboratory processing of the sample cores and the statistical analysis of the resulting data. These two tasks are the responsibility of the Forest Products Laboratory. Interpretation of the results and report writing are handled jointly by FPL and the two Experiment Stations.

Phase III.--This task consists of studies to determine, for each major species over its natural range, the relationship between increment core specific gravity at breast height and the average (tree) specific gravity for the merchantable volume of the whole tree, or various portions thereof. Included are presampling in the field, the felling and destructive sampling of over a thousand selected trees, the collection of sample disks at various intervals up the bole from stump to a variable merchantable top diameter, laboratory processing of the disks, and statistical analysis and interpretation of the resulting data. In the South, planning and field work are handled jointly by FPL and the two Stations; laboratory processing of the sample material and statistical analysis of the resulting data are the responsibility of FPL; and interpretation of results and report writing are jointly handled by FPL and the Stations.

Phase IV.--This phase of the study is aimed at utilizing the wood density data derived from the earlier phases to obtain more reliable estimates of strength properties. The exact nature and magnitude of Phase IV cannot be precisely determined until substantially complete data on the other phases become available for inspection and comparison with existing information on specific gravity-strength relationships for clear wood specimens of the species concerned. If deemed adequate, then existing specific gravity-strength relationship data will be so combined with the systematic survey data as to develop more reliable estimates of strength properties for the various species and major producing areas. The procedures to be followed are essentially similar to those discussed in Report No. 1 of the Western Wood Density Survey (12). Precise estimates of the strength and stiffness of clear wood specimens are basic to the establishment of basic stresses and working stresses for structural applications. The FPL will do this phase of the work.

Sampling Design

In Florida, Georgia, and North Carolina, wood density was sampled at every fifth forest inventory plot. Initially the forest inventory plots were selected from a systematic grid printed on every third aerial photograph in alternate flight lines, using an interval which would provide sufficient plots to meet specified limits of error for volumes estimates.

In Mississippi, wood density was sampled at all forest inventory locations at the intersections of a 3- by 3-mile grid extending over the State.

In Alabama, Arkansas, and Louisiana, wood density samples were taken at forest inventory locations positioned at the intersections of 12- by 12-mile grids extending over the States. In Arkansas and Mississippi, two wood density plots were sampled at each wood density location.

Sample Tree Selection

Using point sampling procedures, sample trees were selected with frequency proportional to basal area. The basal area factors, the number of points sampled per location, and the minimum tree d.b.h. class included were as follows:

State	Plots per location	Sampling points per plot	Basal area factor (Sq. ft.)	Minimum d.b.h. class included (Inch)
Alabama	1	10	37.5	5
Arkansas	2	1	10	3
Florida	1	1	10	4
Georgia	1	1	10	4
Louisiana	1	10	37.5	5
Mississippi	2	1	10	3
North Carolina				
Coastal Plain	1	1	10	4
Piedmont	1	4	37.5	4

Core Sample

In all states sampled, one core was extracted from each sample tree on the side of the tree facing plot center. In Alabama and Arkansas a second core was taken at a position 90° clockwise from the first core.

Cores were obtained from a boring extending as nearly to the pith center at d.b.h. as permitted by the length of the borer and the size of the tree. The bark, pith, and the most recent incomplete season's growth, were removed by trimming. The length of the core was then carefully measured. The bore diameter of the increment borer, previously determined with a taper gage, was recorded as core diameter. Each core was placed in a paper straw and properly labeled. As the surveys progressed, accumulated cores were sent to the FPL, where specific gravity determinations were made.

The number of trees sampled by species and states is shown below:

State	Loblolly	Shortleaf	Longleaf	Slash	Total
Alabama	609	209	99	84	1,001
Arkansas	259	393	---	---	652
Florida	35	---	167	307	509
Georgia	1,247	599	337	760	2,943
Louisiana	500	138	45	36	719
Mississippi	3,752	2,815	992	576	8,135
N. Carolina	1,311	407	109	---	1,827

The number of trees shown above includes only the principal species, loblolly, shortleaf, longleaf, and slash. Cores were also collected from other southern pine species occurring in the sample.

Increment Core Processing

Increment cores and accompanying field data sheets were mailed to the FPL by the Experiment Stations. To prevent loss or breakage during shipment, the cores are placed in individual drinking straws and then packed in specially designed corrugated containers.

At the Laboratory, routine determinations are made of age, by ring count, and of specific gravity. Use of individually calibrated increment borers of known diameter, and measurement of green core length in the field (and of the resoaked core again in the laboratory), permit direct calculation of the green volume of each core. Ovendrying and weighing to 0.001 gram is the final step in the determination of specific gravity on a dry weight-green volume basis. The procedures followed have been described in detail by Mitchell (5). See also Zobel et al (16).

As time permits, determinations are also made of percentage of summerwood, cell dimensions, and other wood quality characteristics. In addition, selected cores are subjected to complete chemical analysis.

To facilitate statistical analysis, all pertinent field and laboratory data are punched on automatic data processing (ADP) cards--one card for each tree sampled.

Results of Pilot Study in Mississippi

Relative Effect of Age and Other Variables

The results of the initial wood density survey have been published in detail (6,7,14), so only the highlights will be presented here as background for discussion of new information. Of the variables studied, age had the greatest effect on specific gravity. This is shown by the curves in figure 1. It is also evident that the five species of pine in Mississippi fall into three distinct and significantly different specific gravity groups.

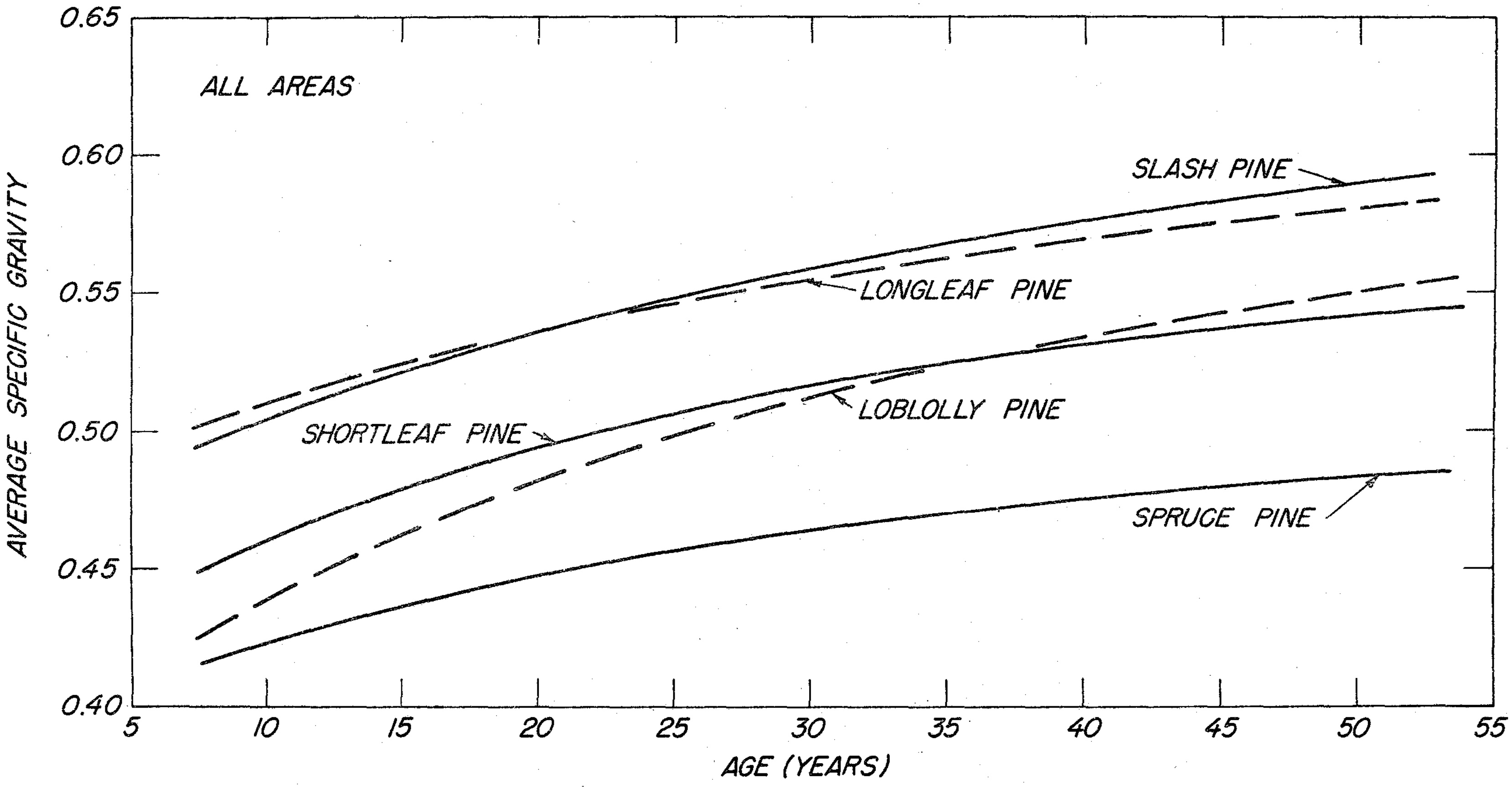

Figure 1.--Relationship between age and core specific gravity at breast height for five species of pine in Mississippi. Number of trees in sample: slash, 576; longleaf, 992; shortleaf, 2,815; loblolly, 3,752.

M 113 302

The Mississippi specific gravity data for the four principal species of pine were analyzed with the IBM 704 regression program developed by Grosenbaugh (2). Listed in figure 2 are the nine independent variables tested, together with a summary of the results of the regression analysis. The reciprocal of age accounts for from 63 to 81 percent of the total variation explained by the nine variables. Each of the other five tree and stand variables reflects the effect of age when used as a single variable in estimating equations. However, when nine-variable regressions were computed for each species, volume, d.b.h., and stand basal area (the latter with the expection of slash pine (Pinus elliottii Engelm.)) did not significantly contribute to the estimating equations. The total variation explained by the nine variables ranged from 69 to 73 percent for the four species.

Patterns of Variation

By holding constant the six variables other than latitude, longitude, and latitude times longitude, it is possible to calculate the effect of geographic location on specific gravity. The specific gravity isograms thus developed for loblolly (Pinus taeda L.) and shortleaf (Pinus echinata Mill.), the two most widely distributed Mississippi pines, are shown in figures 3 and 4. Note the strong trend of increasing specific gravity from northwest to southeast, and especially the magnitude of the differences. A similar pattern was found by Larson (4) for slash pine over a more limited area.

The practical significance of these differences is well illustrated by the fact that a 0.02 increase or decrease in specific gravity is reflected in a change of about 500 pounds per square inch in the modulus of rupture of clear wood specimens, based on established density-strength relationships for southern pine. Or, in terms of pulp yields (fig. 5), an increase or decrease of only 0.02 in specific gravity means an increase or decrease of 100 pounds in the dry weight of a cord of pulpwood, or 50 pounds of dry processed pulp obtainable from a cord. This is the basis for the strong trend toward marketing pulpwood by weight instead of volume (9). In the South, even saw logs are now being sold by weight (3,8) in some areas.

It is, of course, true that geographic location does not in itself affect specific gravity. It is important only to the extent that it reflects environmental factors that do have a more direct influence on wood density: that is, soil, rainfall, length of growing season, mean temperature, etc. In this connection, compare the warm-season rainfall chart shown in figure 6 with the specific gravity isograms. There appears to be a good relationship, and this assumption is supported by the significant correlations found in subsequent studies in other southern states (7). Further research may show that other factors (such as the moisture-holding capacity of the soil) that influence the availability of water during the period when the heavier summerwood is laid down are strongly correlated with specific gravity.

Estimating Tree Gravities from Core Gravities for Mississippi Pines

In southern pines, specific gravity tends to decrease with height in the tree. Thus, an increment core specific gravity taken at breast height normally overestimates the average for the total merchantable volume of the tree. To develop equations for converting core gravities to tree gravities, Wahlgren and Fassnacht (13) felled and destructively sampled 100 trees of each species over a range of sites in Mississippi. The resulting curves of tree specific gravities over core gravities are shown in figure 7, together with the regression equations, correlation coefficients, and standard errors of estimate. It is evident that tree gravities can be thus estimated from core gravities with good precision.

Subsequent, more comprehensive, studies of this kind made in Arkansas, Texas, Georgia, North and South Carolina, and Virginia have strengthened and further improved the precision of regression equations for estimating tree gravities from core gravities for the major southern pine species (1,10,11). Regressions based on the pooled data are discussed in a later section of this paper.

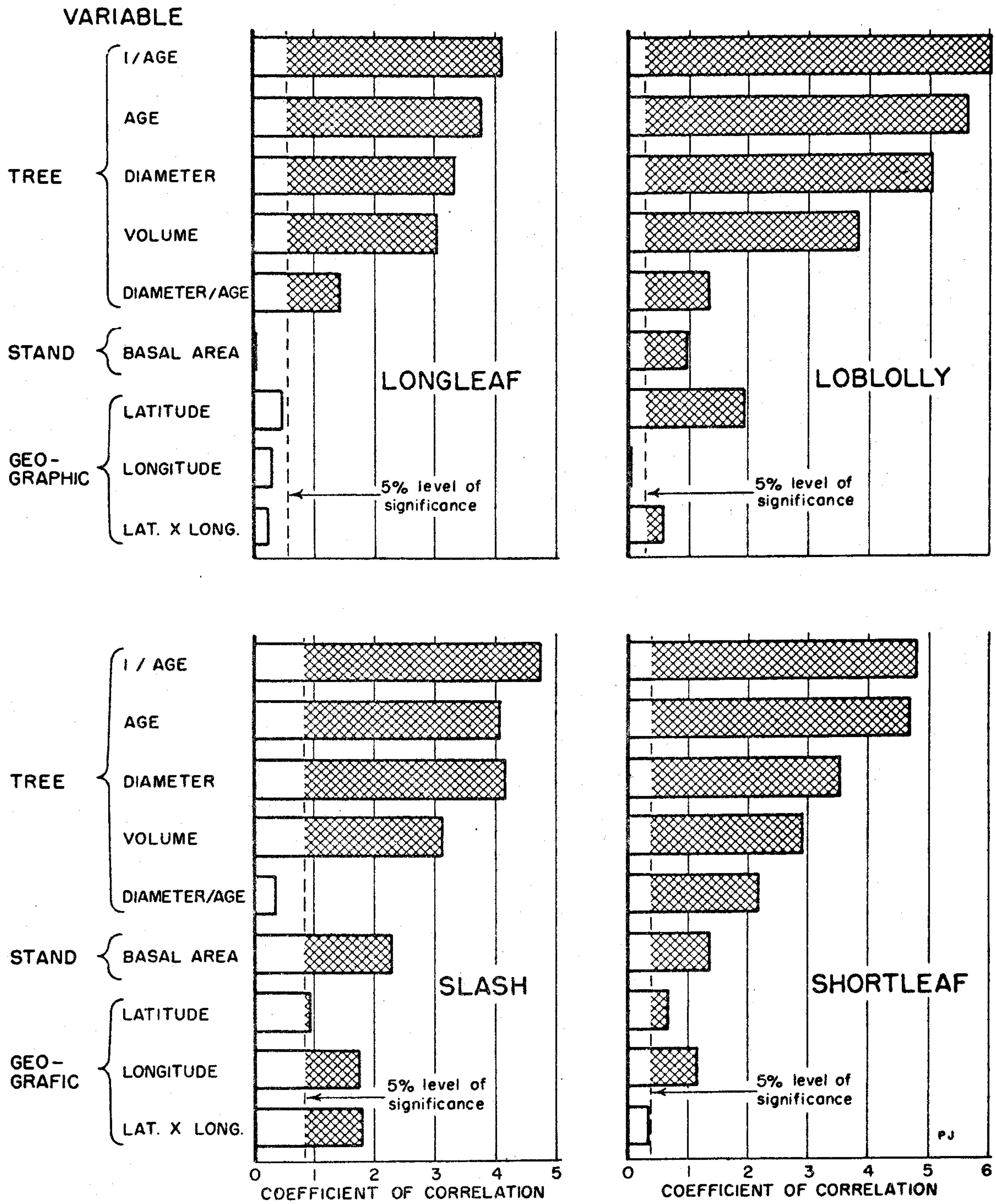

Figure 2.--Relationship between core specific gravity and each of the variables tested for four species of pine in Mississippi.

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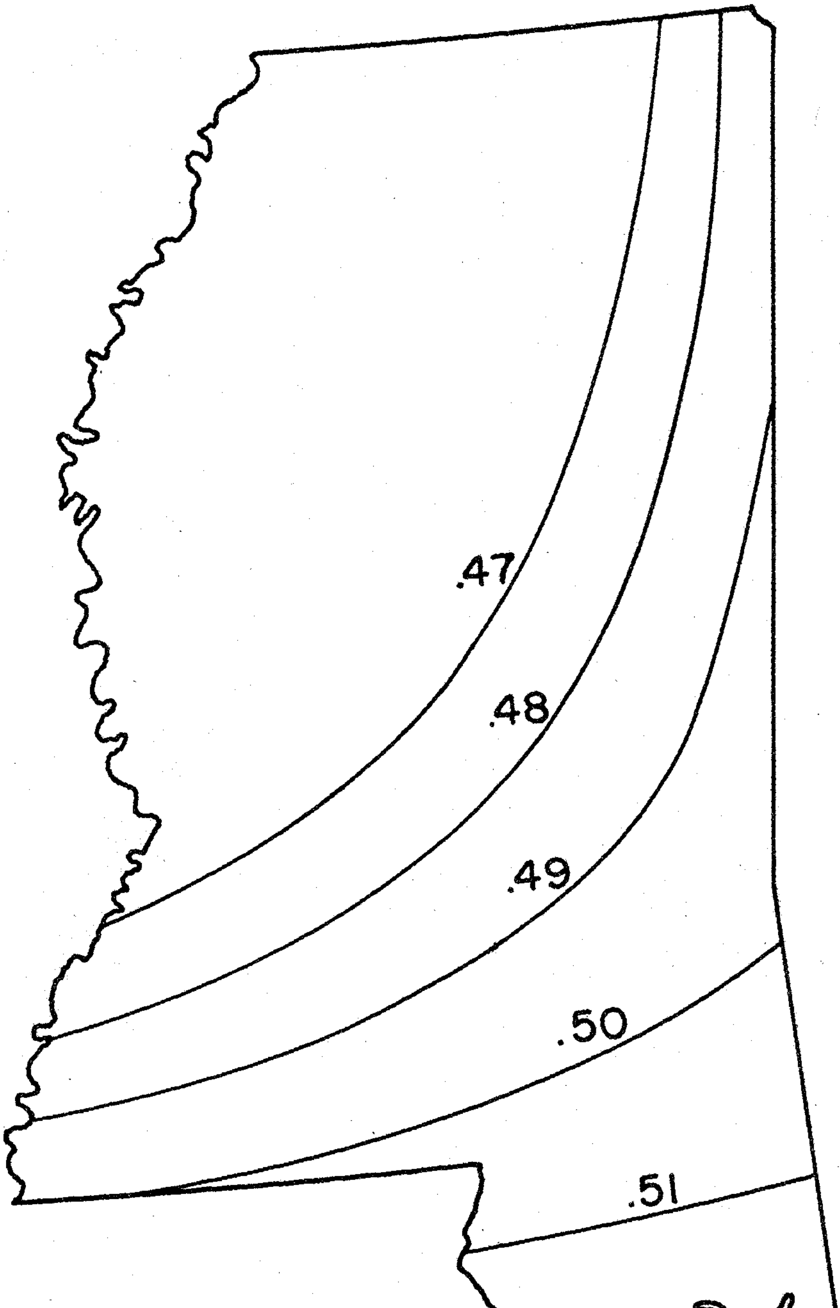

Figure 3.--Isograms of average core specific gravity for loblolly pine in Mississippi.

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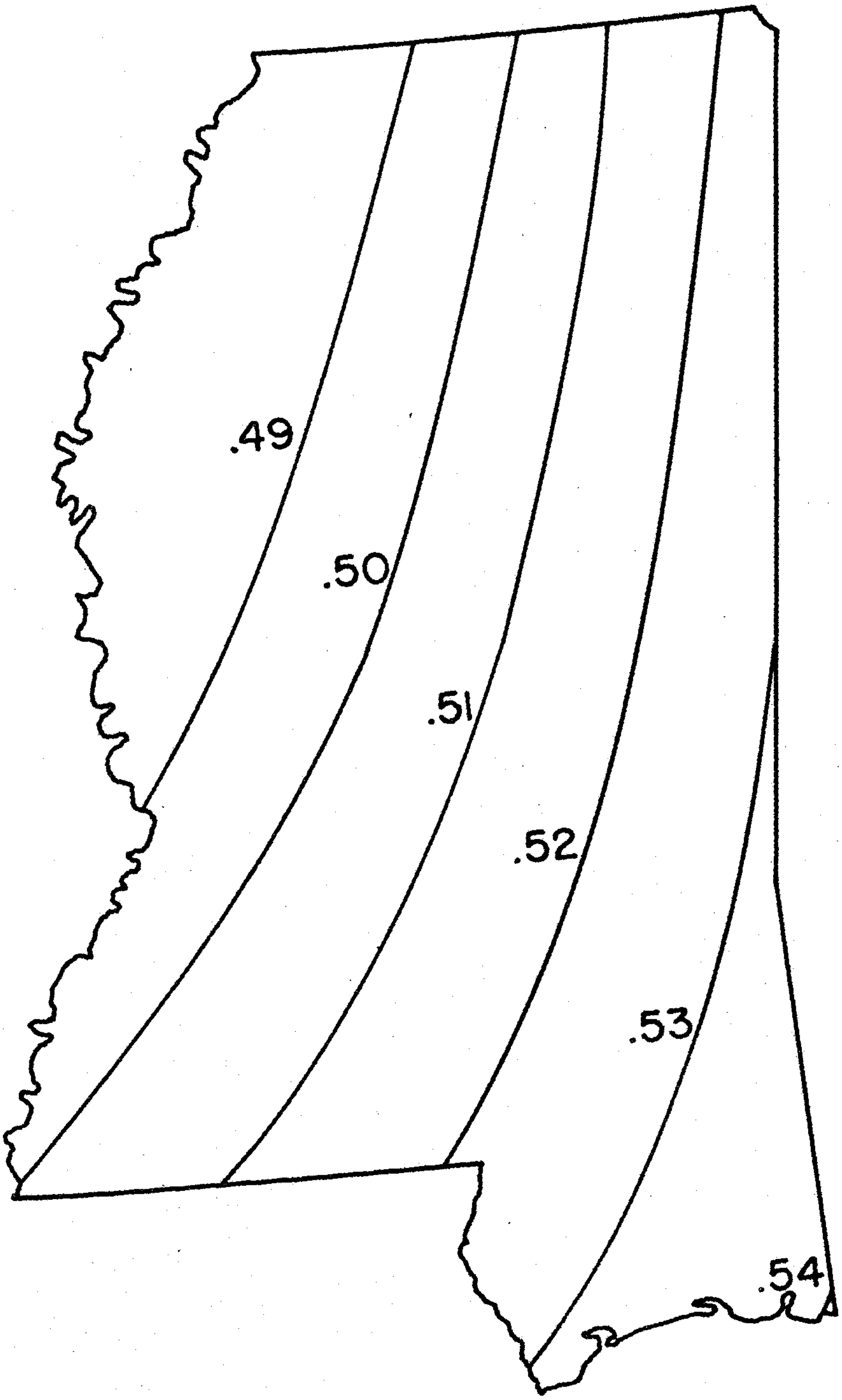

Figure 4.--Isograms of average core specific gravity for shortleaf pine in Mississippi.

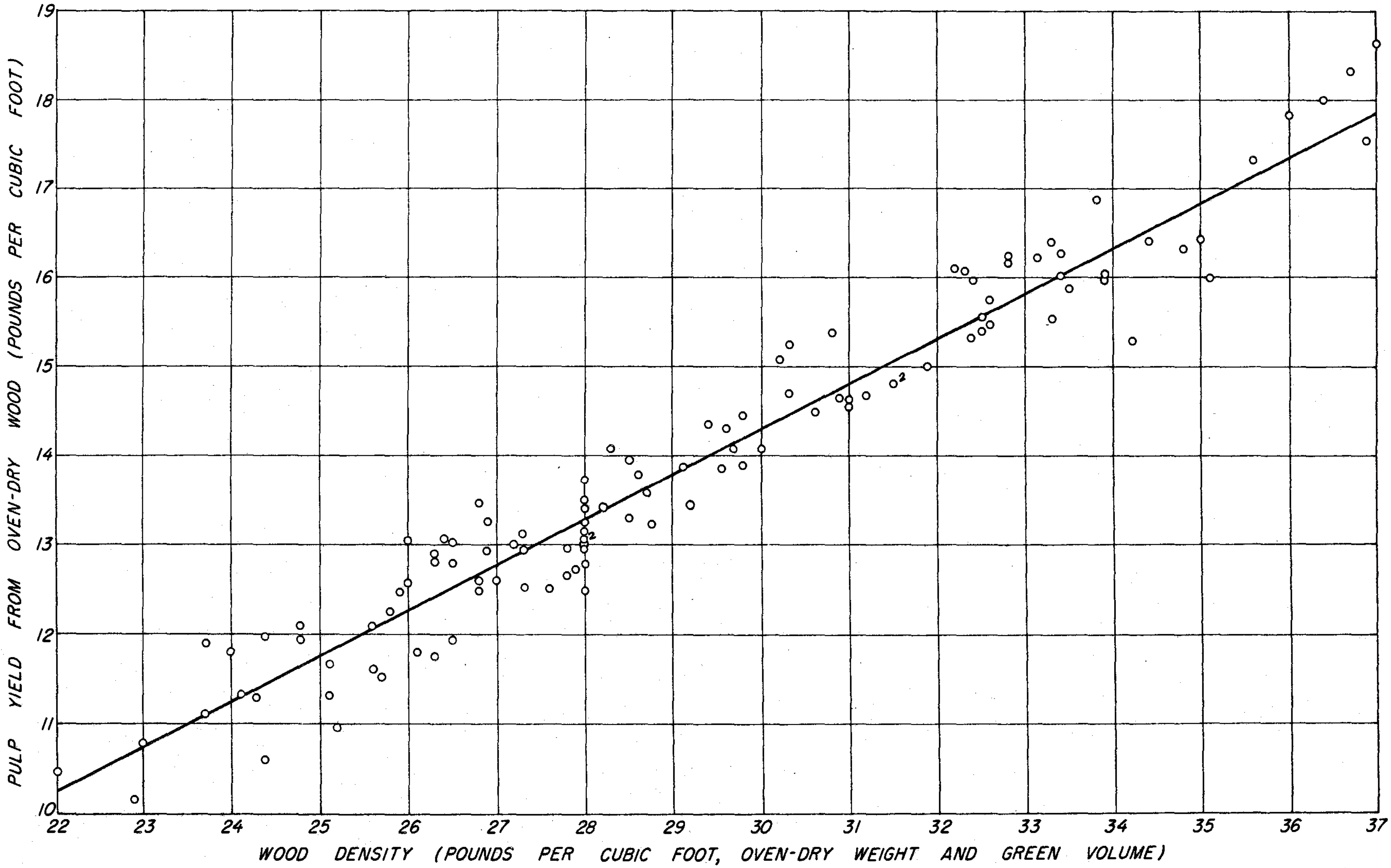

Figure 5.--Relationship between wood density and kraft pulp yields of southern pine plywood.

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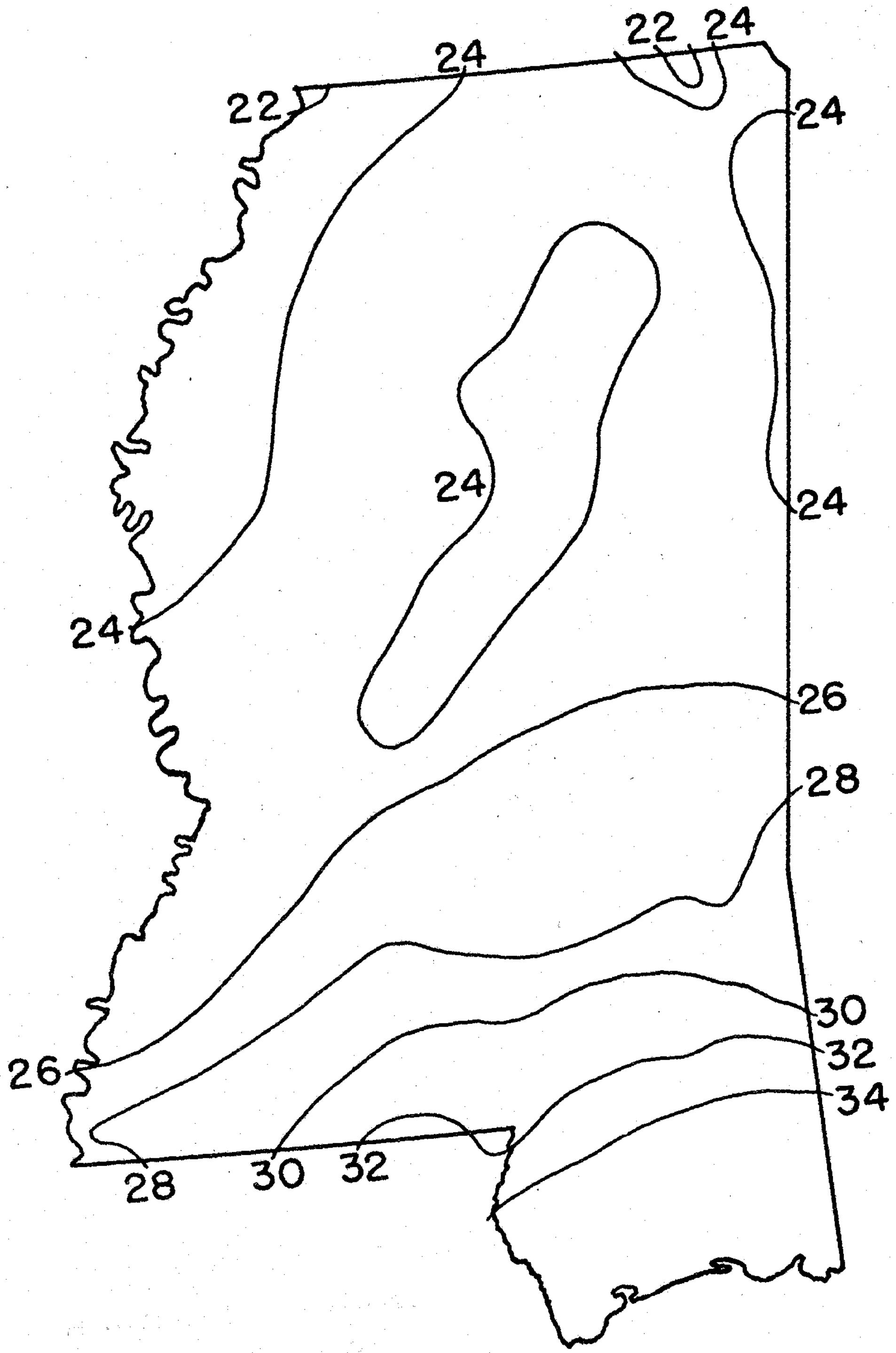

Figure 6.--Average warm-season rainfall (inches) in Mississippi.

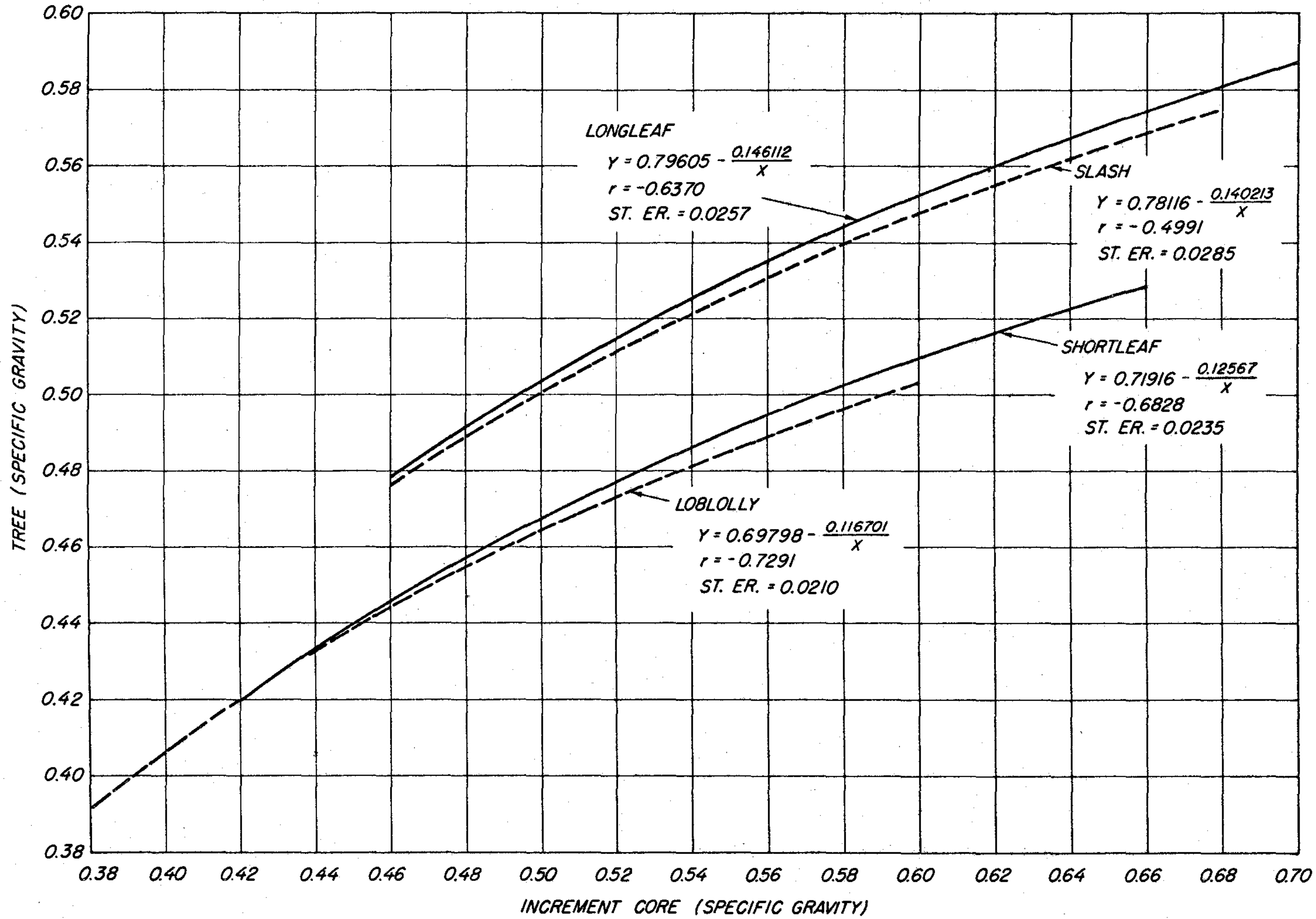

Figure 7.--Simple regressions of tree specific gravity on reciprocal of increment core specific gravity for the four species of southern yellow pine in Mississippi.

M 114 597

Dry Mass Comparisons and Yield Curves for Mississippi Pines

Some interesting comparisons can be made by applying the estimated tree gravities to average cubic volumes attained by various species at a given age. The product of the two variables represents the dry mass of merchantable wood produced by an average tree in a given period of time. On this basis, as shown in figure 8, loblolly is definitely superior to shortleaf in both northern and southern parts of the State, and to the other species where they occur in the South, to which slash, longleaf (*Pinus palustris* Mill.), and spruce (*Pinus glabra* Walt.) pine are largely limited. Since loblolly ranks only fourth in core specific gravity at age 30 (fig. 1), and also in tree density, its superiority in dry mass is due largely to its greater volume increment in this period of time. Perhaps even more surprising is the showing made by the lowly spruce pine, which ranks at the bottom of the wood density scale. However, its average volume increment per tree in 30 years, which is second only to loblolly, is sufficient to put it ahead of the other three species in terms of dry weight produced per tree at that age.

Through the years, foresters have accumulated a large amount of information on the volume of wood produced by various species at different ages over a range of site qualities. Now, because of the trend in marketing practices, it becomes important to have similar information on dry weight. Data from the pilot study in Mississippi provided the first extensive information of the kind needed for the development of what might be called dry mass (or weight) yield curves. Preliminary dry weight curves for Mississippi pines are shown in figure 9. Similar curves can now be developed for certain other States for which adequate density data are available.

Spotting Exceptional Trees

The systematic sampling of the wood density surveys is perhaps the best method yet devised for locating trees that are superior in wood quality as well as form, growth rate, and other desirable characteristics. In the Mississippi study, for example, a number of outstanding trees were located, including a 34-year-old longleaf pine with a specific gravity of 0.75--until then the highest on record for any native, living softwood of good form and growth rate (fig. 10). Such trees occur in nature with a frequency of only about 1 in 10,000, and are thus difficult to spot except by systematic mass screening. This is the kind of tree needed in breeding studies and to provide scion material for seed orchards. Additional outstanding trees have been pinpointed during density surveys of other Southern States.

Summary of Results for Other Southern States Completed to Date

Basic Data

The specific gravity and related information obtained to date for all Southern States, including Mississippi, is summarized in tables 2 through 25 of the recently issued status report (11). Each table presents the information for a single species and state. Within each table the data are arranged by diameter classes and Forest Survey units. For each of these categories the following information is given: (1) sample size; mean diameter (outside bark at b.h.) of sampled trees; mean increment core specific gravity; standard error of mean core gravity; standard deviation of the core specific gravity; estimated mean tree specific gravity, by product (pulpwood and saw log) categories; standard error of the mean tree specific gravity; and total cubic foot volume by size class, species, and Survey Unit.

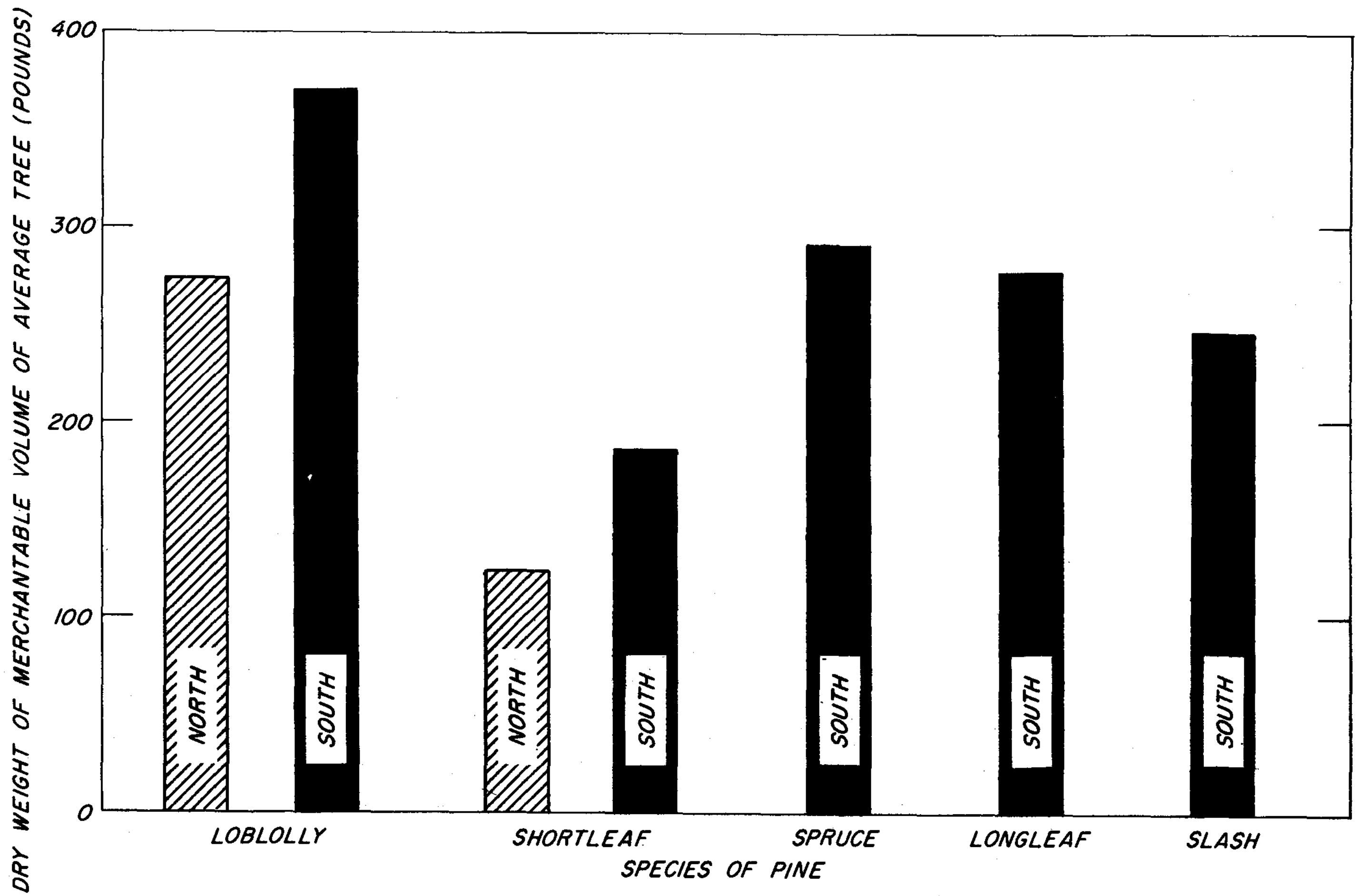

Figure 8.--Average merchantable dry weight per tree at age 30 for various species and areas in Mississippi.

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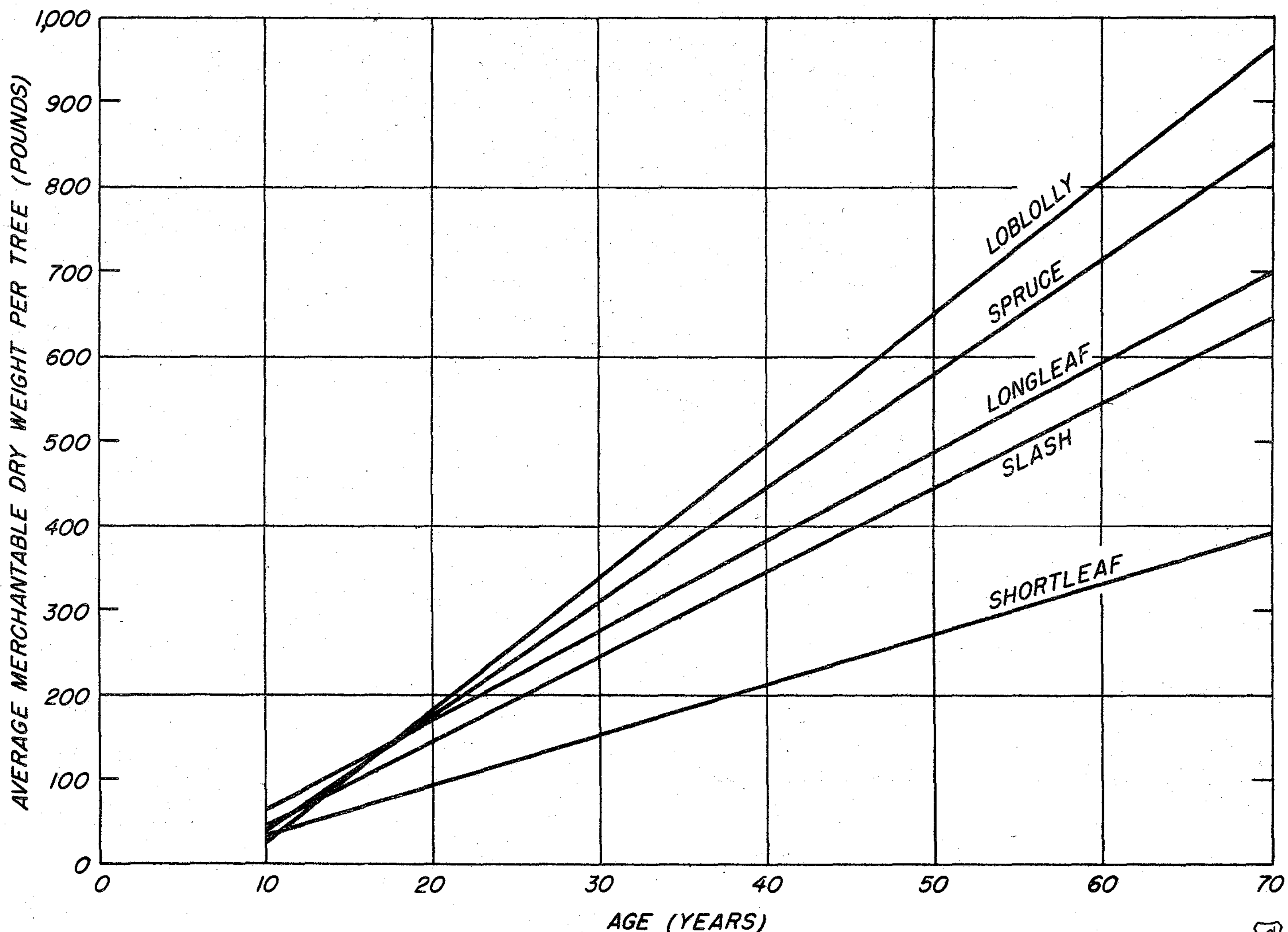

Figure 9.--Average relationship between age at breast height and merchantable dry weight per tree (in pounds) for five species of pine in Mississippi.

M 114 674

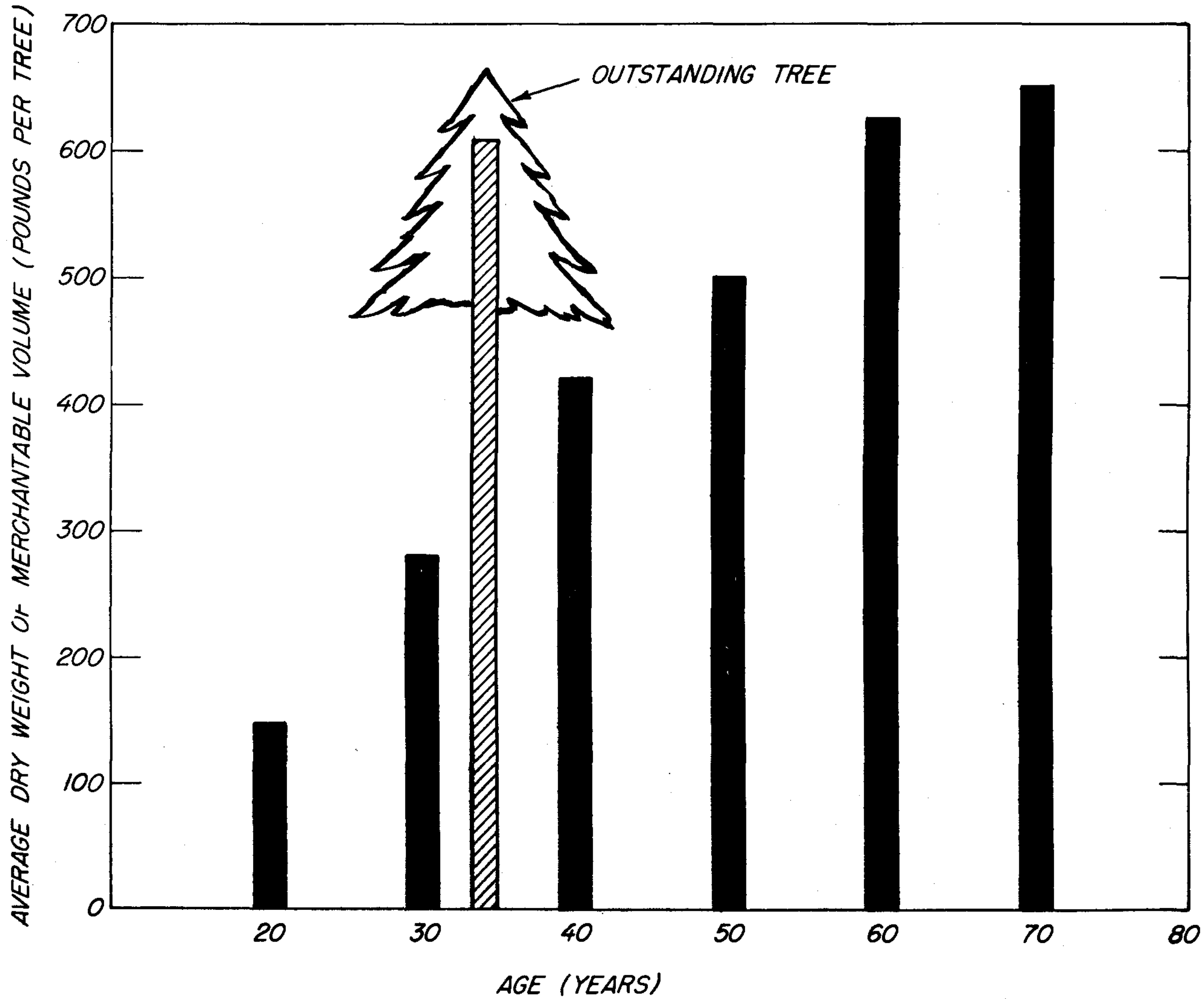

Figure 10.--Merchantable dry weight of outstanding longleaf tree 34 years of age compared with dry weights of average longleaf trees at various ages.

M 114 682

As an example of the kind of information available, the basic data for one species (loblolly pine) and one State (Georgia) are shown in table 1 of this report. In addition, as a further example, core and tree specific gravity data for loblolly pine in all states thus far covered are shown in figures 11 and 12. Comparable text figures for the other three species are included in the detailed report (11).

Table 1.--Specific gravity data for loblolly pine in Georgia

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity; mean and standard error	Approximate timber volume
In.		No.	No.	In.				Million cu.ft.
3.0- 4.9	Northern (5)	6	7	4.4	0.436(.020)	0.052	0.45(.014)	-----
	N. Central (4)	16	25	4.5	.426(.008)	.041	.44(.009)	-----
	Central (3)	41	56	4.4	.445(.010)	.046	.46(.007)	-----
	Southwest (2)	2	2	4.2	.443(.014)	---	.46(.024)	-----
	Southeast (1)	4	6	4.5	.515(.039)	.099	.50(.016)	-----
5.0- 8.9	Northern (5)	15	37	6.9	.449(.009)	.052	.44(.006)	103.6
	N. Central (4)	47	113	6.9	.461(.006)	.053	.45(.004)	288.5
	Central (3)	105	243	6.7	.462(.005)	.083	.45(.003)	597.0
	Southwest (2)	14	27	7.1	.479(.013)	.050	.46(.006)	22.3
	Southeast (1)	20	38	7.0	.505(.020)	.082	.47(.006)	115.5
9.0-14.9	Northern (5)	10	36	11.4	.510(.012)	.079	.46(.005)	99.5
	N. Central (4)	52	105	11.0	.481(.006)	.051	.45(.003)	368.9
	Central (3)	140	324	11.4	.490(.004)	.067	.45(.002)	1059.3
	Southwest (2)	17	23	11.4	.512(.015)	.068	.46(.006)	82.1
	Southeast (1)	31	57	12.0	.542(.011)	.057	.48(.005)	243.2
15.0+	Northern (5)	4	5	20.2	.472(.015)	.034	.43(.015)	34.0
	N. Central (4)	7	10	17.7	.517(.025)	.075	.45(.011)	71.3
	Central (3)	53	87	17.0	.500(.004)	.076	.44(.005)	353.9
	Southwest (2)	8	19	20.4	.560(.005)	.038	.47(.010)	82.5
	Southeast (1)	17	27	18.0	.544(.012)	.060	.46(.008)	134.8
All Classes	Northern (5)	20	85	9.3	.475(.011)	.078	.45(.004)	237.1
	N. Central (4)	87	253	8.8	.468(.005)	.054	.45(.002)	728.7
	Central (3)	210	710	10.0	.478(.003)	.071	.45(.002)	2010.2
	Southwest (2)	30	71	12.0	.510(.012)	.058	.46(.004)	186.9
	Southeast (1)	49	128	11.4	.530(.009)	.066	.48(.003)	493.5
Sawtimber 9.0+	Northern (5)	11	41	12.5	.505(.011)	.076	.47(.005)	133.5
	N. Central (4)	56	115	11.6	.484(.006)	.055	.46(.003)	440.2
	Central (3)	158	411	12.6	.492(.003)	.063	.46(.002)	1413.2
	Southwest (2)	24	42	15.4	.534(.010)	.060	.47(.006)	164.6
	Southeast (1)	38	84	13.9	.542(.010)	.056	.48(.004)	378.0

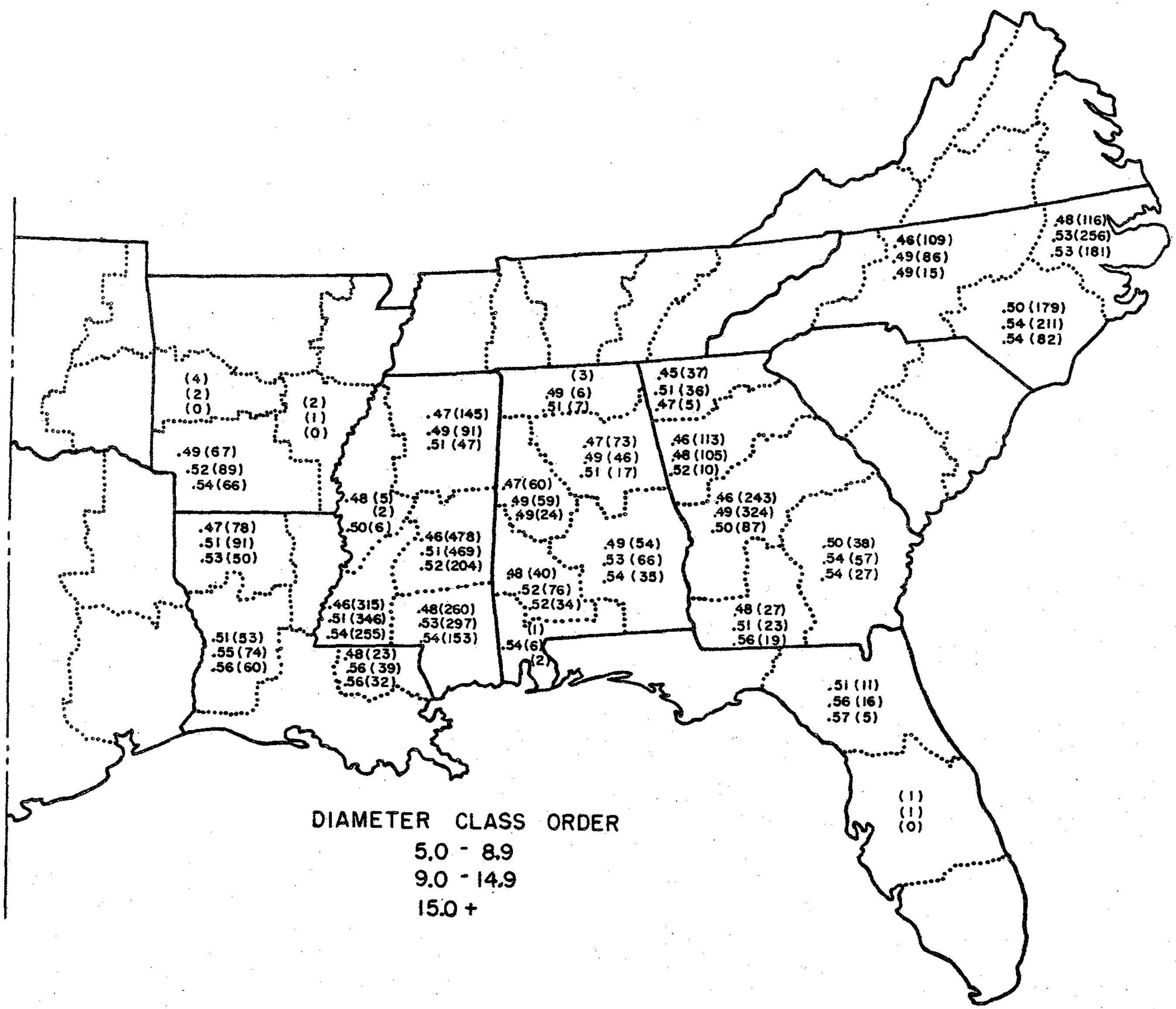

Figure 11.--Loblolly pine, Average increment core specific gravity and number of sample trees by survey units and diameter classes.

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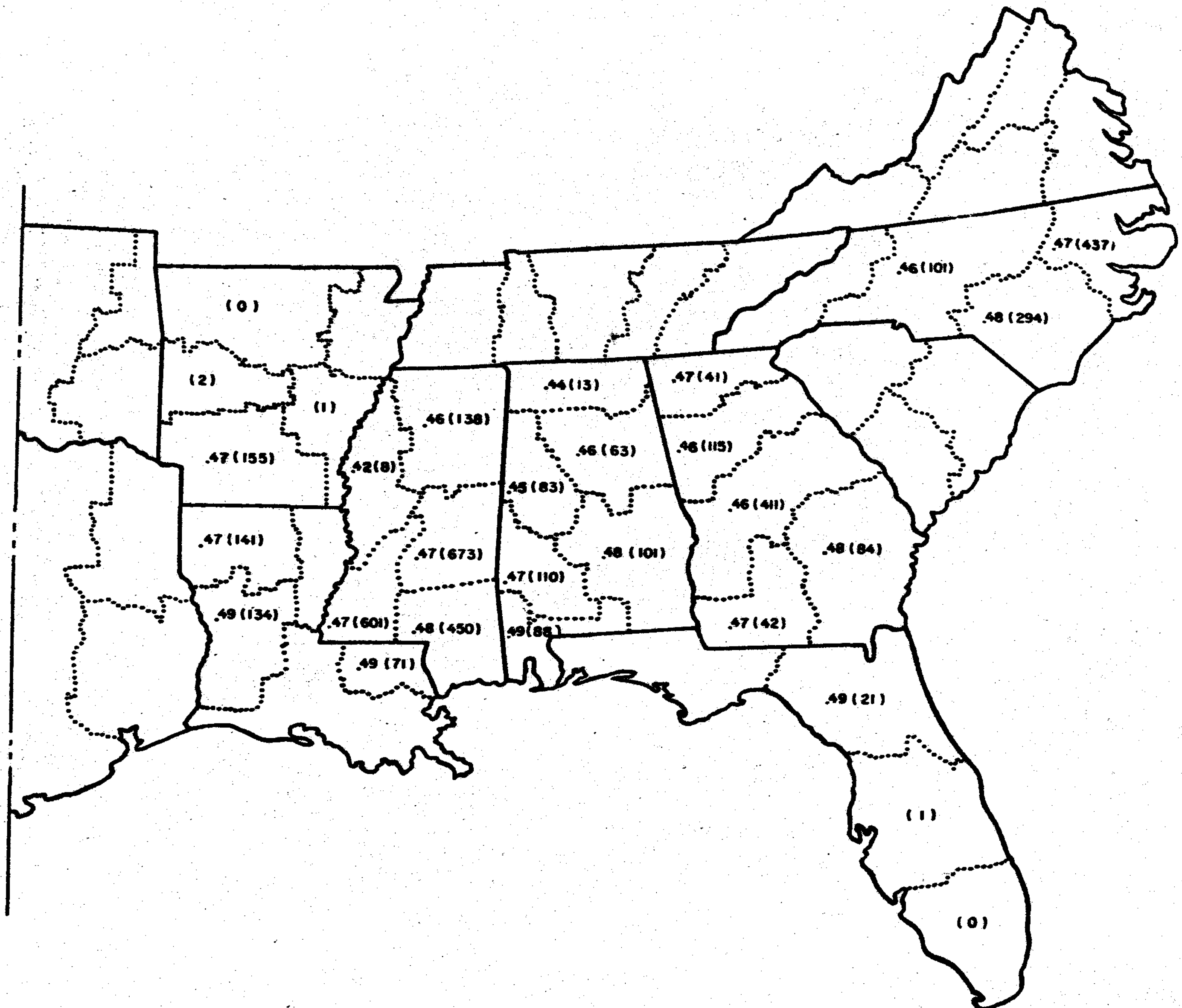

Figure 12.--Loblolly pine. Average sawtimber specific gravity and number of samples for trees 9.0 inches d.b.h. and larger.

M 124 738

Results of Preliminary Statistical Analysis

Data for the other southern states have not yet been subjected to the same rigorous statistical analysis as the Mississippi data. In some cases, such as Arkansas, the sampling was rather light in comparison to Mississippi. However, a start has been made on data for four additional states--Alabama, Arkansas, Georgia, and Florida. The results of preliminary regression analysis of core specific gravity data for loblolly pine in these states are summarized in figure 13. The results for the other major species of pine are essentially similar. As in Mississippi, age has the greatest effect on specific gravity. Of the eight independent variables tested, all (with the exception of longitude and rainfall in Alabama) have a statistically significant influence on specific gravity.

In view of all the conflicting evidence and opinions in the World's literature regarding the effect of growth rate on specific gravity, the data in figure 13 may be of special interest. Note the significant correlations between diameter/age and specific gravity for loblolly pine in these four States, as well as for loblolly, shortleaf, and longleaf in Mississippi (fig. 2), based on a systematic sample of a combined predominantly forested area one-fourth larger than France. The observed relationship is inverse; that is, rapid diameter growth is associated with low specific gravity. Most of the controversy on this subject is probably due to poorly designed experiments, too few observations, and inadequate statistical analysis. Moreover, much of the past discussion of this subject has been of little consequence since growth rate is only one of the many factors that influence specific gravity, and is definitely not a major one in southern pines.

The specific gravity isograms shown in figure 14 for loblolly pine in Alabama, Georgia, and Florida were developed in essentially the same way as for Mississippi, with one exception. The chief difference is that age was included as an independent variable in the regressions for the Southeastern States, and the results are in terms of average core specific gravities for trees 30 years of age. This probably gives a truer picture of the pattern and magnitude of variation with geographic location, which would be otherwise distorted by the fact that the average age (and diameter) of loblolly pine in Alabama is significantly higher than for comparable areas of Georgia. Age does not vary significantly with geography in Mississippi, so this was not a confounding factor in developing the isograms for that State.

Note the trend toward increasing specific gravity from northwest to southeast for loblolly pine in the southeastern States, similar to that first observed in Mississippi. It is of interest that for loblolly pine, the four variables--latitude, longitude, latitude X longitude, and age--account for 97 percent of the total variability explained by the eight variables tested. The other major pines in the Southeast show the same general pattern of variation.

It is significant that the substantial amount of core specific gravity data independently collected by Zobel and Rhodes (17) in Texas, Larson (4) in Louisiana, Alabama, Georgia, and Florida, and by Zobel and his associates (15) throughout the southeastern States, show the same pattern of variation as observed in the southern wood density survey. Although these independent studies had other objectives, and employed different sampling designs that do not permit the pooling of all data, their results nevertheless tend to substantiate and confirm the trends observed in the density survey. No inconsistencies were noted among the various studies.

Converting the Density Survey Data to Forms Most Useful to the Various Wood Using Industries

As indicated in the foregoing discussion, core specific gravity data may be used to advantage to study the within and between species variation of this wood quality characteristic, to investigate patterns of geographic variation, and to evaluate the relative effects of site, climate, tree, and other

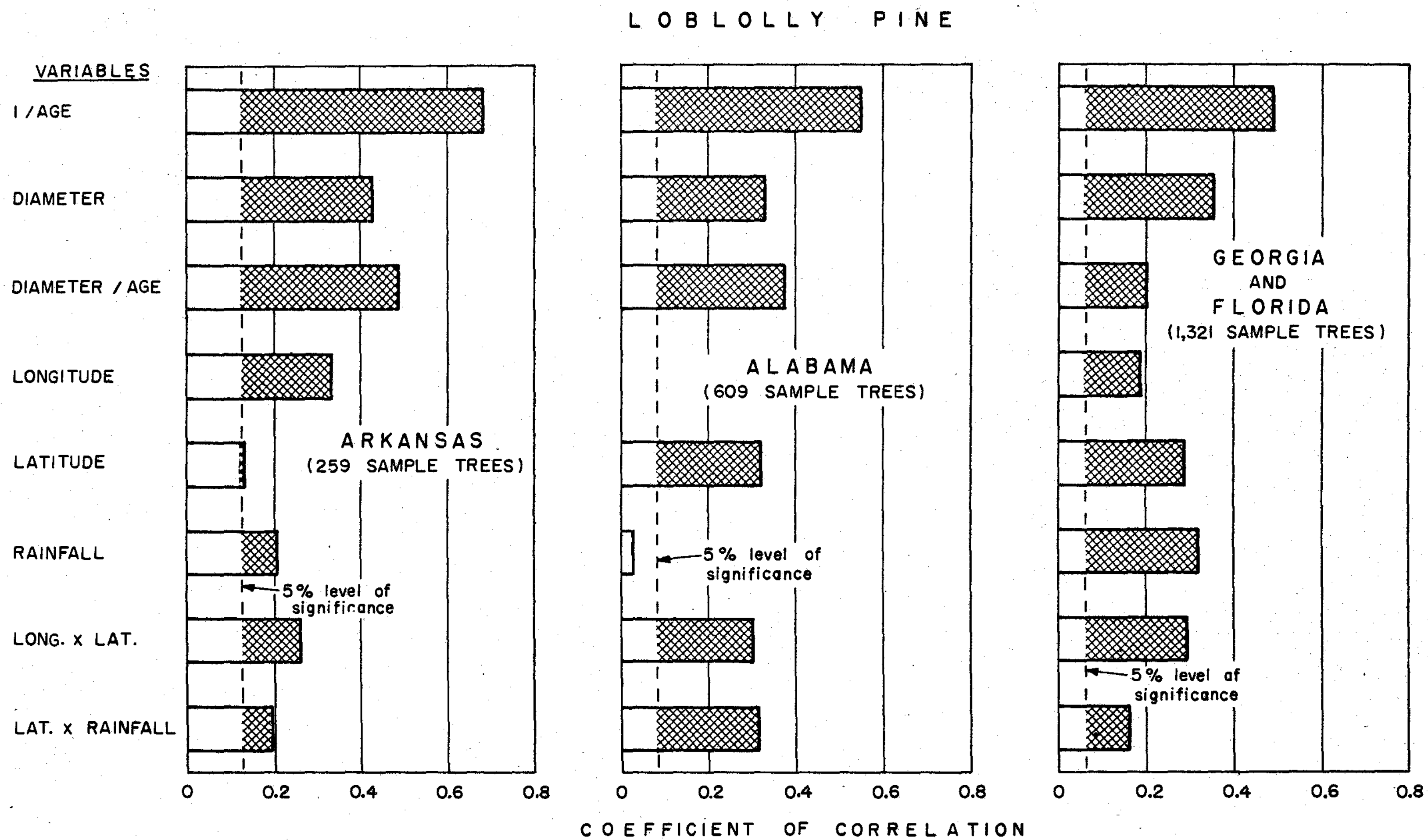

Figure 13.--Relationship between core specific gravity and each of the variables tested for loblolly pine in Arkansas, Alabama, and Georgia-Florida.

M 124 308

Figure 14.--Isograms of average core specific gravity for loblolly pine 30 years of age in Alabama, Georgia, and Florida.

factors on wood density. In addition, to make the density survey data more useful to industrial consumers of a wide variety of primary wood products, regressions have been developed for converting increment core specific gravities to tree gravities that represent averages for the total merchantable volume of the tree or for various portions thereof.

The procedure followed is essentially similar to that used in the Mississippi study to develop the simple core-to-tree gravity relationships shown in figure 7. In all, 1,015 trees of the four major species were destructively sampled at various locations throughout the south (fig. 15). The regressions developed from the pooled data are shown in table 2. Applicable regressions in this table were used to convert the increment core specific gravities (col. 6) to the tree gravities (col. 8) summarized in table 1.

Table 2.--Southern pine tree gravity estimating equations, all sampling areas combined

Diameter class	Regression equations	Number of trees	Correlation coefficient	Standard deviation from regression
In.				
	LOBLOLLY PINE			
3.0- 4.9	Y=0.17430+0.63615(Core sp.gr.)	27	0.6992	0.025
5.0- 8.9	Y=0.20775+0.52568(Core sp.gr.)	138	.7174	.022
9.0-14.9	Y=0.18529+0.54585(Core sp.gr.)	142	.7740	.020
15.0+	Y=0.20269+0.47459(Core sp.gr.)	35	.6509	.025
All diam.	Y=0.22447-0.0033442(DBH)+0.54385(Core sp.gr.)	342	.7471	.021
Sawtimber:				
9.0+	Y=0.22040-0.0035688(DBH)+0.57364(Core sp.gr.)	176	.7827	.020
	SHORTLEAF PINE			
3.0- 4.9	Y=0.09621+0.79595(Core sp.gr.)	25	.7505	.026
5.0- 8.9	Y=0.28935+0.35800(Core sp.gr.)	133	.5316	.029
9.0-14.9	Y=0.17229+0.55541(Core sp.gr.)	120	.7914	.020
15.0+	Y=0.16767+0.52278(Core sp.gr.)	22	.7698	.019
All diam.	Y=0.26033-0.0039465(DBH)+0.47243(Core sp.gr.)	300	.7051	.025
Sawtimber:				
9.0+	Y=0.20394-0.0043035(DBH)+0.60574(Core sp.gr.)	142	.8266	.020
	LONGLEAF PINE			
3.0- 8.9	Y=0.30254-0.0075103(DBH)+0.52723(Core sp.gr.)	86	.7860	.021
9.0+	Y=0.21272-0.0037375(DBH)+0.63441(Core sp.gr.)	99	.7749	.027
All diam.	Y=0.25236-0.0047277(DBH)+0.58468(Core sp.gr.)	185	.7707	.025
Sawtimber:				
9.0+	Y=0.26982-0.0039395(DBH)+0.55631(Core sp.gr.)	99	.7655	.025
	SLASH PINE			
3.0- 8.9	Y=0.22893-0.0004820(DBH)+0.57700(Core sp.gr.)	104	.6584	.027
9.0+	Y=0.31060-0.0043370(DBH)+0.47563(Core sp.gr.)	84	.6737	.023
All diam.	Y=0.27322-0.0040380(DBH)+0.53806(Core sp.gr.)	188	.6664	.025
Sawtimber:				
9.0+	Y=0.31198-0.0058519(DBH)+0.52878(Core sp.gr.)	84	.7216	.024

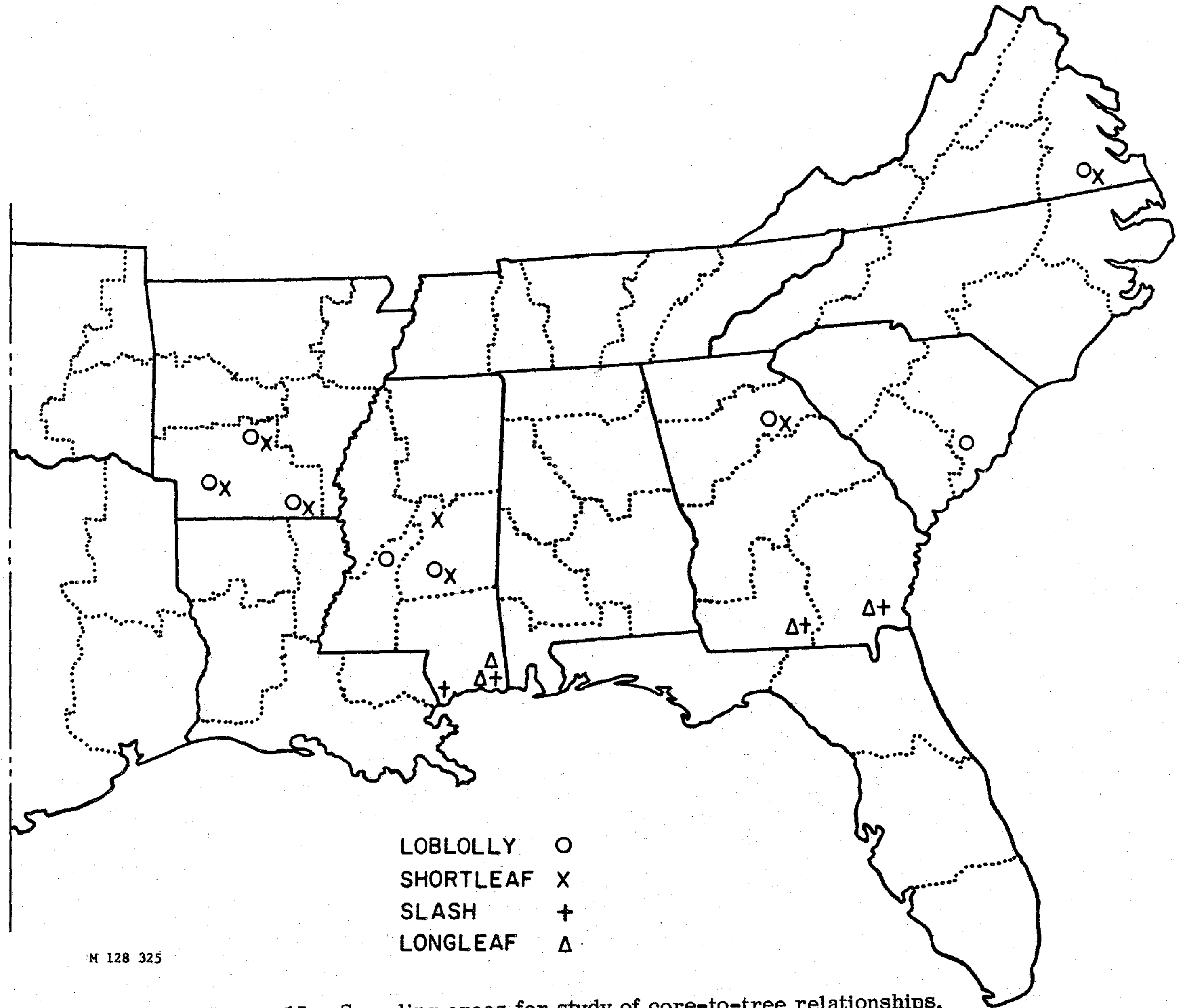

Figure 15.--Sampling areas for study of core-to-tree relationships.

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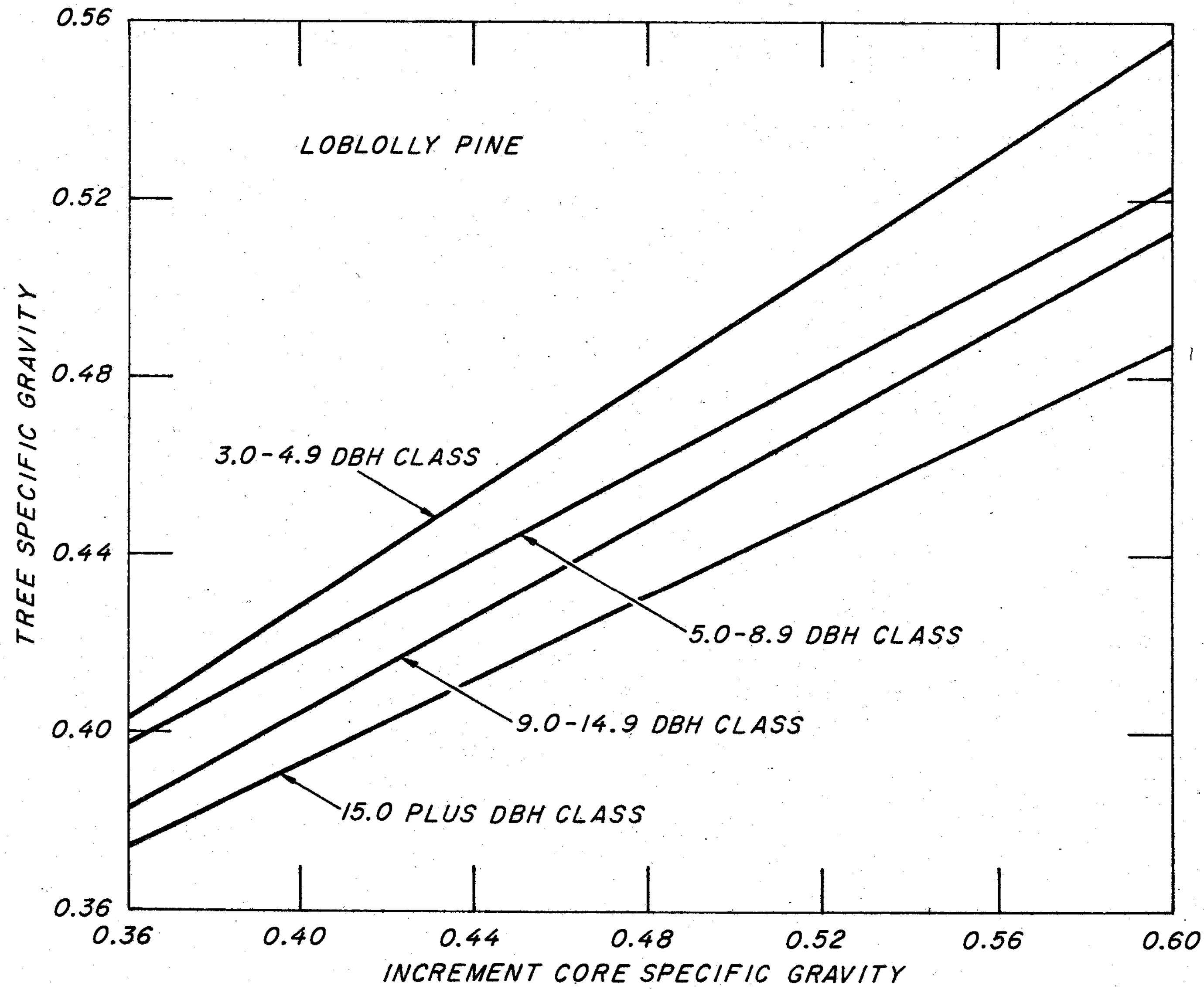

Figure 16.--Loblolly pine: Relationship between tree specific gravity and core specific gravity for four diameter classes.

M 128 309

Diameter has a significant effect on core gravity to tree gravity relationships (fig. 16). Thus, to the extent that sufficient data were available, and where applicable, the regressions were developed by diameter classes. Otherwise diameter was used as an independent variable in a multiple regression, as for the pooled "all diameter" tree gravity data in table 1 for loblolly pine. Similar data for other species are given in the full report (11).

The tree gravities given in table 1 by diameter classes, and for all diameters, are estimates of the average specific gravity of the total merchantable volume to a 3-inch (d.i.b.) top. These data are of primary interest to the pulp and paper industry.

Lumbermen, on the other hand, are chiefly concerned with the average specific gravity of only that portion of sawlog-size trees that can be economically converted to lumber, excluding small pulpwood bolts in the tops. Estimates of the average "lumber potential" specific gravity of trees 9 inches d.b.h. and larger are given for a special sawtimber category in table 1.

Studies are now in progress to develop conversions specifically tailored to the needs of the rapidly expanding southern pine plywood industry. The present commercial standard for southern pine plywood requires that the face plies of structural plywood made from loblolly and shortleaf pines must average 0.5 specific gravity, green volume-dry weight basis. This is to assure equality, in terms of modulus of elasticity, with Douglas-fir structural plywood. Accordingly, plywood mills are especially interested in the specific gravity of the peelable portion of suitable-sized trees, excluding both tops and a 4- or 5-inch unpeeled core. It is expected that regressions for estimating the average "plywood potential" specific gravity by species, size classes, and areas will be available in the relatively near future.

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PROGRESS IN WOOD DENSITY RESEARCH AT THE SCHOOLS

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A topic including only "Research at the Schools" is necessarily restricted. There are active and effective research programs going on at many other places beside the universities. To draw conclusions from only a part of the available knowledge of a subject is not without pitfalls--therefore any conclusions drawn here must be considered as tentative. Further, the following discussion is largely limited to material, published and unpublished, from about 1959 on.

For supplying reprints, references, and unpublished theses and papers, presenting progress at each school, sincere appreciation is due all of those to whom requests for such material were sent, whether or not this field of research appeared in their programs. Without their full cooperation much of what is included here would not have been available. The courtesy displayed in including comments on current programs is especially appreciated.

Consideration is limited to density variations in the bole of the tree and the influences acting to bring them about. Programs in genetics research are included insofar as they relate to density. However, cell and cell wall dimensions, the growth factors governing them, and their relation to specific gravity of the wood have been ignored--a large and productive area of research that needs a great deal more attention.

Specific Gravity Variation in Softwood Trees

Variation in Specific Gravity at a Given Height

There is a general and inherent pattern of variation in specific gravity of the wood formed in successive years from the pith of the tree outward at a given height in the bole of softwoods. This pattern appears to be based in the genetics of the species and of the individual trees, but is modified by the superimposed effects of the changing environment as the tree grows and matures.

Beginning with a low at the pith, specific gravity usually rises rapidly at first, then more gradually, later tending to level off. In so-called overmaturity, a maximum is passed and a gradually decreasing trend may then set in.

Environmental influences alter the amount and kind of material laid down in the ring each season. Springwood and summerwood may each be wider or narrower, varying in proportion to each other, and varying in the amount of wood substance present per unit volume in each. The extractive content of the final product may mask the genetic pattern or may even be a part of it.

Interest has been strong in effort leading to clarification of the outlines of the general pattern of variation at a given height level as well as to the magnitude of the influences that can be exerted by environment on each of the structural variables in the wood cell.

Numerous authors have reported that specific gravity of the annual rings increases from the pith outward. Taras (1965) reported an increase in slash pine trees to 8 to 12 years and then a leveling off. This was a result of springwood specific gravity in his trees decreasing for 8 to 12 years and then leveling off while summerwood specific gravity first increased rapidly, leveled off for a short period, then decreased steadily. While this occurred, percent summerwood, although fluctuating, increased for the same length of time and then leveled off. He reported that these patterns were true at all heights except the 1-foot level. There, springwood specific gravity did not show a sharp decline in the early rings and summerwood is lower in specific gravity and higher in percentage than at breast height.

Investigating mechanical properties of Monterey pine (Pinus radiata D.Don) grown in California, Cockrell (1959) noted that wood near the pith was usually less dense and weaker than wood farther out, even though in some trees growth rate had not decreased in the outer material. Wood adjacent to the pith had a specific gravity of 0.41 as compared to that farther out which was 0.47.

Wellwood and Smith (1962), summarizing a number of studies on wood quality of Douglas-fir and western hemlock, indicated that core wood is usually rapidly grown and of low specific gravity, and that rate of growth, number of rings from the pith and height within tree influences specific gravity of the wood.

In determining specific gravity of planted red pine grown at different spacings on two sites, Jayne (1958) supported the general view that wood nearer the pith is lower in specific gravity.

McElwee and Zobel (1962) reported observing a small but significant, positive correlation between mature specific gravity and age, as measured in rings from the pith in pond pine. They were examining trees from several geographic areas in the Coastal Plain of North Carolina.

Reporting on 444 trees of lodgepole pine from the range of this species in Colorado and Wyoming, Collett (1963) stated specific gravity of the wood increased with distance from the pith.

Zobel (1965), in examining 145 trees of 20 different species or subspecies of Mexican pines, found that most species showed the same trend with age from pith common in pines from other areas. In exceptional cases, he noted alcohol-benzene extracted specific gravity as high in the 0-10 year segment from the pith as at a greater distance.

Risi and Zeller (1960), however, in a study of five black spruce trees in Quebec, found that, in the lower part of the stem, specific gravity tended first to decrease and then to increase from the pith toward the bark.

Gilmore (1963), in calling attention to the fact that shortleaf pine trees in Southern Illinois were low in specific gravity, also stated that he found no relation of specific gravity to age or diameter in these trees, which ranged in age from 55 to 144 years. His finding is in contrast to others given here.

Variation in Specific Gravity at Different Heights in the Tree

The picture with respect to variation in specific gravity upwards in the tree is not clear. There are contradictions, the reasons for which have not been fully explained. It would appear that if the pattern of increase to a maximum with rings from pith at a given height level in the tree is correct, then as a given annual increment is followed upward in the tree and approaches nearer to the pith, its specific gravity should decrease. From this, the average specific gravity of entire cross-sections should decrease as one goes upward.

Growth conditions or some genetic factor characteristic of a species, such as proportion of summerwood in the ring or relative density of springwood vs. summerwood, may be the explanation for the variations that occur.

An additional variable, to which relatively little attention has been paid, is the actual linear distance of the point of measurement from the pith. Closely related to linear distance would be number of cells from the pith. It is not necessarily sound to assume that number of annual rings is the only basic variable. Perhaps number of cell divisions in the radial direction is a better measure of cambial age than number of growth periods. It would be interesting to know in a particular tree whether all the wood at the same linear distance or the same number of cells from the pith was of the same specific gravity from the ground upward to the point where such a vertical line intersected the cambium.

Wellwood (1960) found the expected pattern in 39 hemlock trees thinned from a 60-year-old stand of mixed Douglas-fir and western hemlock. He took discs at stump height, mid-length of the merchantable stem, and at a 5-inch top. Site index varied from 90 to 160. Two trees were sampled at 5-foot intervals. Dominant, codominant, and intermediate trees made up the group tested. He concluded that specific gravity of the cross section was maximum at the base of the tree and minimum at the top. Crown class in this study had no significant effect on specific gravity, although the data did suggest a general trend of decrease in specific gravity with improvement in crown class. Site index had a negative effect on specific gravity at the basal section but no significant effect at the middle or top sections.

Taras (1965) reported that, in three slash pine trees, within a given annual increment sheath, springwood specific gravity decreased upward to breast height or to the 10-foot level, then increased to the top. Summerwood specific gravity, on the other hand, increased to breast height, then decreased upward. Percent summerwood decreased with height. The net result was that whole ring specific gravity increased upward to breast height, then decreased toward the top.

Collett (1963), in his study of 444 trees of lodgepole pine from Colorado and Wyoming, reported the most important single factor in explaining specific gravity in cross sections was the height level. However he found a rapid decrease in the first 10 feet of the bole, after which specific gravity remained relatively constant to a height of approximately 50 feet where an increase began. Whole-tree specific gravity was best indicated by specimens taken at breast height.

Jayne (1958) determined the specific gravity of groups of annual rings formed in the same years at various heights in red pine trees. He showed that specific gravity of these rings decreased with height in tree. It was apparent that this occurred as the rings approached the pith, higher in the tree.

However, in five trees of black spruce grown on a Hylocomium-Cornus site, Risi and Zeller (1960) found the influence of height on specific gravity to be small and not uniform in all trees.

Pearce (1956) also found no variation in specific gravity attributable to vertical position in the tree in balsam fir. Crown class and height class also were without significant effect in his study.

Juvenile or "Core" Wood

The juvenile wood includes the wood formed in the early years from the pith at all heights in the tree. Juvenile wood has also been called "core" wood--presumably to clearly locate it as a sort of cylinder around the pith. It is well-known that this wood varies from the wood formed in later years.

Of interest here (there are other differences) is its lower specific gravity--a fact of importance to foresters growing trees on a short rotation for such crops as pulpwood. The fact that it appears to be formed within or close to the crown has also caused it to be termed "crown-formed" wood while the wood formed below the crown to the outside of the core has been called "stem-formed" wood.

Brunden (1964) compared specific gravity of wood formed within the living crown during the life of four red pine, natural-grown trees with wood formed only below the living crown. To avoid effect of resins, extracted wood was used. He found strong support for the hypothesis that stem and crown-formed wood represent different populations and should be treated as such in quality analyses. Stem-formed wood has significantly higher mean specific gravity than crown-formed wood, by 10 percent. Cooper (1960), in earlier work on four plantation-grown, red pine trees, came to the same general conclusion as Brunden (1964).

Zobel and McElwee (1958a), in a study of loblolly pine, found that core wood at breast height averaged 0.45 as compared to mature wood from the same trees which averaged 0.54. Juvenile wood production extended over the first 8 years from the pith, plus another 2-year transition period.

Sukotjo (1964) determined variation of specific gravity of benzene-extracted wood of Pinus merkusii trees from three different sites near Lembang, West Java, Indonesia. Dividing the entire bole into crown-formed and stem-formed wood gave specific gravity averages of 0.348 and 0.393, respectively.

Zobel, Webb, and Henson (1959) reported extensively on core or juvenile wood of loblolly and slash pine trees. They reviewed the literature, pointing out references to the poor quality of the core wood, its proportion and extent, instability in seasoning, low mechanical strength, shorter tracheid length, effects on paper properties, large fibril angle, wide rings, and low specific gravity. At the same time, they mentioned disagreement regarding the specific gravity characteristics of core wood--some authors reporting that core wood was equal or even higher in specific gravity than later formed wood. They call attention, however, to the fact that it was not known to them whether these latter reports made allowance for resins and other materials deposited in the core wood by the tree.

Zobel, Webb, and Henson (1959) pointed out the importance of extractives in the wood and presented data showing quantitatively the effects on specific gravity values. They found that, for practical purposes, core wood could be considered to have a uniform specific gravity within a tree, although there was a tendency for it to vary inversely with height up to 10 feet, thereafter becoming relatively constant. Core wood was considerably lower in specific gravity than mature wood from the same tree at any position up the tree.

Influence of Radial Growth Rate on Specific Gravity

Earlier writers were often of the opinion that rate of growth in diameter and specific gravity were closely correlated.

If one considers only growth rate and specific gravity along a radial line, close correlation does exist between these two variables.

The lighter core wood is usually faster grown than the later formed, but heavier outer wood of the bole. However, if the position of origin of the wood along the radius is considered the correlation may become weak and may even disappear.

Age from pith, however, has been shown to be an important factor in this picture, even though environment cannot be ignored.

For 31 trees of eastern white pine, Thor (1965) reported on the relation between specific gravity and amount of radial growth in the 10-20-year rings and in the 20-30-year rings. For the younger wood the correlation coefficient was significant at the 1-percent level but for the 20-30 year wood the significance of this coefficient was at the 5-percent level. These correlations were for alcohol-benzene extracted wood.

Jackson (1962b) reported on ray count and moisture content of increment cores taken at breast height from 30-year-old, planted loblolly and slash pine trees in the dominant crown class. Sampling 15 trees in each species, he found a high inverse correlation of specific gravity with both ray count and moisture content. Taking the outermost 18 annual rings from 25 loblolly and 25 slash pines in a 28-year-old planting, he found a highly significant positive relationship between basal area increments and specific gravity. This last is somewhat unexpected since relation of radial growth to specific gravity has frequently been considered to be negatively correlated with growth rate, even though this correlation has usually been weak in mature wood.

In 15 trees from each of 13 stands of Virginia pine, Thor (1964) found no significant relationship existing between radial growth and specific gravity before extraction. After extraction, however, he found that radial growth accounted for almost 7 percent of the among-tree variation in specific gravity. Rapid growth rate was associated with larger amounts of extractives.

Thor and Brown (1962) found only a limited relation between growth rate and wood specific gravity in the first 5 years of growth of loblolly pine seedlings. This relationship accounted for only 4 percent of the total variation in specific gravity.

In 444 trees of lodgepole pine from Colorado and Wyoming, Collett (1963) reported that growth rate had no consistent effect on specific gravity.

No significant relation between ring width and specific gravity was detected by Risi and Zeller (1960) in five trees of black spruce in Quebec.

Zobel and McElwee (1958a), in several hundred loblolly pine trees in southeastern United States, found little effect of growth rate on specific gravity of mature wood.

Hall (1964) examined the relation between rate of growth and specific gravity for wood of 57 black spruce trees. He found a definite relationship for young upland trees but an indefinite relationship in the older upland trees and for trees from a lowland stand. The trees ranged from 81 to 160 years in age and variation along the radii due to age from pith was not considered.

McKimmy (1959) studied factors affecting specific gravity of wood of 36 Douglas-fir trees under 160 years of age. He included dominant, codominant, intermediate, and low intermediate trees from sites II, III, and IV at several locations in Oregon and Washington. Site, crown class, and geographical location appeared to have little effect on specific gravity. Age of the tree at the time the wood was formed was an important factor. Specific gravity tended to be more dependent upon combined effect of percentage of summerwood and growth rate as the height level increased. He showed, in an analysis of covariance, a significant relation between growth rate and specific gravity and also percentage summerwood and specific gravity. Percentage summerwood, in general, tended to influence specific gravity more than did growth rate. However, he pointed out that, although the combined effect of percentage of summerwood and growth rate was highly significant in certain decades, this effect was not sufficient to permit a reliable prediction of specific gravity on the basis of the two factors.

Wellwood and Smith (1962), in summarizing several studies on wood quality of young Douglas-fir and western hemlock trees, stated that in most of the regressions, specific gravity decreased moderately but at a statistically significant rate with increased growth rate. However, they point out that this influence is less at advanced ages.

Wellwood (1960) plotted average specific gravity of cross sections of 39 hemlock trees, taken at several heights in the tree, against average rings per inch of the sections. The plot showed a well-defined, statistically significant, positive relationship. However, this relation does not account for the age from pith factor which seems to be confounded with rings per inch.

In view of the fact that stand density in terms of trees per acre has an effect on diameter growth rate, the following studies related to specific gravity of some plantation-grown trees are of interest.

Jayne (1958) reported that spacing in 35-year-old plantations of red pine had no more than a minor effect on specific gravity. Spacing varied from 4 x 4 to 8 x 8 feet.

Hamilton and Matthews (1965) examined the relationships between stand density and specific gravity, and also percentage of latewood, in 15-year-old, planted shortleaf and loblolly pine. Five spacings of each species ranging from 4 to 8 feet were studied. Both specific gravity and percent latewood were significantly influenced by spacing, maxima for both occurring in the 5-foot spacing.

In a study of spacing effects on specific gravity of 21-year-old planted Virginia pine, Chang (1962) found that average specific gravity was not significantly different among 4 x 4, 6 x 6, and 8 x 8-foot spacings. On 2 x 2-foot spacing it was slightly lower but he stated that this might have been due to location more than spacing.

Extractive Content of the Wood

References have been made to the confounding effects of extractives in some of the work on wood quality just mentioned. Several other investigators have been concerned with this problem, which may be at the root of at least some of the contradictions reported in the literature on wood specific gravity. Perhaps all wood analyzed for quality variations related to amount of wood substance present should be extracted for removal of all water or alcohol-benzene soluble infiltrates before specific gravity is considered.

Sampling 15 Virginia pine trees in each of 13 stands, Thor (1964) found that differences in specific gravity among stands were largely due to differences in amounts of extractives, and there were no significant differences among stands when extracted specific gravity of the wood was under consideration. Trees with high specific gravity and a high extractive content were found to have extracted specific gravities close to the normal for the species. A large proportion, 68 percent, of the total variation in specific gravity was accounted for by the among-tree variance component in his data.

Resch and Ecklund (1964) analyzed the variability in the drying rate of redwood. They were interested in any association between drying rate and density, content of hot-water-soluble extractives, and other pertinent factors. They did not relate their analyses to position or origin in the tree. They found a relation between density and rings per inch such that a piece with 10 rings per inch had an average density of 0.401 gram per cubic centimeter while one with 25 rings per inch had a density of 0.383 grams per cubic centimeter. They also found a statistically significant positive relation between hot water extractives and density. Rate of drying was slowed down by high extractive content or by high specific gravity.

Thor (1965), in eastern white pine, found extractives varied from 3 to 17 percent of the weight of the extracted wood in the 10 to 30-year growth period of trees varying in total age from 34 to 75 years.

Effect of Environment on Specific Gravity

Environmental factors, for the purposes of this section, include geographic location as well as the immediate factors affecting growth of the tree. Some of these factors have already been referred to.

Although there appears to be an almost universal agreement that contemporary environment affects the specific gravity of the wood formed in the tree, it is becoming more apparent that the effects are relative. The rainfall at a given site may be such that the fluctuations over a period of years, although quite obvious in amount, may not be of sufficient magnitude or timing as to be strongly reflected in specific gravity. The fact that two locations are on opposite sides of a ridge may be more important than that they are separated by a great many miles.

Although the forester is restricted in his control of environment on a given piece of ground, knowledge of environmental effects may decide a choice of species or degree of thinning or aid him in application of some other silvicultural device.

With a change in silvicultural practice may go a change not only in growth rate but also in wood quality. For this reason numerous investigators have been concerned with environmental effects on specific gravity of wood in the tree.

Goddard and Strickland (1962) found that slash pine exhibited its highest specific gravity in the southeastern part of its range, decreasing to the north and west. They pointed out that early seasonal rainfall was closely correlated with this trend, spring rainfall being higher in the western part of the range and decreasing as one moves eastward. Average specific gravities in 11 areas ranged from 0.560 to 0.623.

McElwee and Zobel (1962) examined the variation of wood properties of pond pine growing in several geographic areas and on different soil types in the Coastal Plain of North Carolina. No significant differences in specific gravity between geographic areas were found although there were large statistically significant stand-to-stand and tree-to-tree variations.

Gilmore, Metcalf, and Boggess (1961) pointed out that 17-year-old shortleaf and 14-year-old planted loblolly pines growing in Illinois were lower in specific gravity than the same species in Mississippi. This was re-emphasized by Gilmore and Boggess (1962) when they reported shortleaf in Illinois weighed 2.3 pounds per cubic foot less and loblolly weighed 2.4 pounds per cubic foot less than in Mississippi.

Gilmore (1963) again called attention to the fact that the specific gravity of shortleaf pine trees (in this case, natural-grown) in Southern Illinois some distance east of their natural range in the Mississippi Valley, was low--ranging from 0.438 to 0.588, as compared to figures given for the species in Mississippi. The trees were from 55 to 144 years in age. He attributes this difference to physiographic or climatic factors or to both.

Balsam fir, a species little referred to in the literature concerned with effect of growth factors on specific gravity, was studied by Pearce (1956). In an attempt to determine the effect of site, crown class, height class, and vertical position in the tree on density, he found that only the variation attributable to differences in site was significant. A dry site produced dense wood and a wet site relatively lighter wood. There was a great deal of variation in density between trees not accountable for by a consideration of site, crown or height together.

The effect of two site qualities on specific gravity of three clones each of 7-year-old loblolly and slash pine was investigated by Harris (1962). He found that the wood of loblolly averaged slightly higher on the poorer site, this difference being highly significant. Slash pine showed no effect of site on specific gravity. He used extracted sections of the first order branches of the current year's growth for determination of specific gravity, eliminating the first inch of the branch nearest the stem. He did not report whether he attempted to correlate specific gravity of the branch with that of the stem.

Lotan (1961), integrating initiation of small diameter, latewood-type cells with terminal and cambial activity, controlled available water in the soil for 20-year-old red pine trees by irrigation and trenching. High moisture stress curtailed both magnitude and seasonal periodicity of all growth processes measured, including growth activity in the crown. This reduction of the metabolism in the crown was accompanied by an early changeover to small diameter, latewood-type cells which he thought to be a result of a lessening of the production of a supply of auxin in the crown.

Zahner, Lotan, and Baughman (1964), reporting on controlled soil moisture for 20-year-old red pine, state that approximately 100 percent more xylem was formed in the irrigated trees, both in wood volume and in number of tracheids. In the upper bole about 50 percent more xylem was formed in the irrigated trees. By Mork's definition latewood was greater in size of cells and in number of cells at all stem positions in irrigated trees but percentage of latewood was equal in both treatments at comparable stem positions.

Zahner (1963), in a review of internal moisture and wood formation in conifers, discussed the effects of environmental conditions, such as soil moisture and drought, silvicultural thinning, and stand density, season of year, and site quality in terms of moisture stresses within the tree and subsequent influences on wood formation. He considered variations in dimensions of tracheids and degree of secondary wall thickening to be related physiologically to moisture stress.

Zahner (1962) grew loblolly pine from seed in large containers for 5 years. He maintained two contrasting soil moisture regimes for the final years--a wet soil near field capacity throughout the growing season, and a dry soil which simulated summer drought. He found that gross radial growth was more than twice as great in the wet trees, but the net latewood band was equal in both treatments, making percent latewood greater in the dry trees, and so higher in specific gravity, particularly in the basal half of the stem. No difference in specific gravities of the earlywood portions of the rings was noted. Dry treatment produced somewhat denser latewood.

Taras (1965) checked rainfall with summerwood specific gravity and with springwood specific gravity of three slash pine trees and found no relationship. He found only a barely apparent positive relationship between whole ring specific gravity and rainfall.

Zobel (1965) measured extracted specific gravity of 145 trees of approximately 20 species or subspecies of Mexican pines. Differences in specific gravity as large as 0.10 among five trees from a single plot were not unusual. There were considerable plot-to-plot differences but no pattern was found. In some instances plots of the same species from distant areas were similar. The Mexican pines showed a remarkable variation in wood properties among trees, among stands, among sites within species and among species. Wood with nearly any desired qualities for softwoods could be found among them.

Specimens from 444 trees of lodgepole pine collected throughout the range of the species in Colorado and Wyoming were analyzed by Collett (1963). Specific gravity of cross sections varied with age and diameter of the specimens, and with the height class of the tree itself. There was an increase with distance from the pith but the response to growth-rate changes was not consistent. Tree diameter was the most important single variable in explaining whole-tree specific gravity. His results indicated stand density and site index as important considerations in production of trees of consistently high wood density.

Zobel, Thorbjornsen, and Henson (1960) studied 308 loblolly pine trees in southeastern United States from Alabama to Delaware, including eastern Tennessee. Essentially even-aged stands with average age of plots varying from 32 to 41 years were selected. Average diameters varied from 11.7 to 15.7 inches d.b.h. Trees were dominants and codominants. Increment cores were taken at breast height and core wood removed. Highly significant differences in specific gravity between sites were found. Specific gravity followed a geographic pattern, the low-specific gravity being in the north and northwest extremes, the Piedmont having intermediate values and the Coastal Plain of the Carolinas and Georgia having the highest specific gravity. Variation among trees within each plot was highly significant.

Zobel and McElwee (1958a) examined 2000 loblolly pine trees in the Southeastern United States from Virginia to Alabama and Tennesee to determine the natural variation in wood specific gravity.

They found a tendency toward lower specific gravity as one moves westward in the geographic area sampled. They emphasized, however, that the tree-to-tree variation in mature wood specific gravity is always much greater than the variation between regions or sites. They found a variation throughout their study of mature wood of from 0.40 to 0.68. The spread on one company's holdings in the coastal plain ranged from 0.44 to 0.64.

Strickland (1960) and Jackson and Strickland (1962a) noted a significant correlation between specific gravity of loblolly pine and both longitude and latitude in trees representing provenances grown in a plantation in Clarke County, Ga. These provenances represented 10 of the 11 states in which loblolly is a commercial species. The exception was Arkansas. From South Carolina to Maryland, the specific gravity increased from 0.510 to 0.550. From South Carolina to Texas specific gravity increased from 0.510 to 0.540. There are some contradictory geographic trends in specific gravity for loblolly pine in these three studies. However, it should be noted that Zobel and McElwee were working with natural stands while Strickland dealt with trees grown in Georgia from seeds representing the various provenances. Furthermore, Zobel and McElwee's statement related to only as far west as Alabama. Strickland shows specific gravities as follows: North Carolina, 0.519; South Carolina, 0.510; Georgia, 0.514; Alabama, 0.517; Mississippi, 0.524; Texas, 0.536.

Influence of Fertilizers on Specific Gravity of Wood

Several studies of the effect of fertilizers on growth rate and specific gravity have been reported. Results obtained appear to be related to quantity of the various components used as well as to composition of the soil to which the fertilizer is applied.

The effects of nitrogen, phosphorus, and potassium on specific gravity were investigated by Underwood (1963) for a 3-year-old loblolly pine plantation in Rapides Parish, La. Fertilizers were applied at 0, 100, and 200 pounds per acre in the possible combinations. Seven to 10 trees from each of 81 plots were analyzed. Specific gravity was increased significantly by a 100-pound rate of nitrogen and 200-pound rate of phosphorus combination. The increase was somewhat less pronounced with a 200-pound rate of nitrogen. In the case of nitrogen applied alone at a 200-pound rate, specific gravity was decreased below that of the controls. It seems that maximum specific gravity may be obtained under the conditions prevailing in the study by the combination of 100 pounds of nitrogen and 200 pounds of phosphorus per acre.

Youngsberg et al. (1963) fertilized 9-year-old, planted slash pine with 200 pounds per acre of nitrogen, with 44 pounds per acre of phosphorus, and also with both elements. Phosphorus treatments created no response but nitrogen increased diameter and basal area growth. Accompanying this increase was a 3 to 7 percent reduction in both percent latewood and specific gravity.

An investigation was conducted by Posey (1964) to determine the effects of various combinations of NPK ranging from 0-0-0 to 160-80-80, on several wood properties of loblolly pine. Potassium in his experiments had no detectable effect on growth rate or on specific gravity. Nitrogen caused the greater difference in wood properties and growth rate, although nitrogen with phosphorus gave slightly greater response than nitrogen without it. In the average tree, fertilization resulted in an increase in growth rate and a decrease in specific gravity. It is important to note that trees with high initial specific gravity showed more reduction than did trees with initially low specific gravity.

Posey stated that a tree with initial specific gravity of 0.52 dropped 0.103 whereas a tree with an initial value of 0.42 dropped only 0.045. He pointed out that this difference in response to fertilizer has implications for progeny from high density orchards as compared to those from low density orchards when fertilizing is being contemplated.

Zobel et al. (1961), analyzed the effect of fertilizer on wood properties of loblolly pine. Fertilizer was applied three successive years beginning when the trees were 16 years old. Rates of 160-80-80 pounds per acre and 80-40-40 pounds per acre of N, P, and K were applied. Seven years later the effects were examined and compared with 7 years' growth just prior to treating, as well as with check trees. Specific gravity was significantly decreased by the higher level of fertilization (up to 16 percent) but less so by the lower level. They point out that there may be some differential effect of fertilizer depending on the initial wood properties of the tree. This "individual response" they say, may become important in development of improved strains of trees.

Heredity and Specific Gravity Variation

There has been an upsurge of interest in the possibility of selecting trees exhibiting a property desirable for particular purposes. Such a property might be high specific gravity, low specific gravity, or long tracheids. Reproduction of such trees with establishment of seed orchards could then supply quantities of planting stock for use wherever desirable.

The studies noted here have an optimistic note regarding the value of this selection procedure--which would seem to be justified. There are still numerous problems to be overcome such as the actual selection of high specific gravity trees that are truly genotypes and not just the result of some local environmental factor. How to sample the progeny at an early age so that it will be known whether they have actually inherited the desired character is another problem. These problems are well-recognized, however.

Wellwood and Smith (1962), in summarizing investigations made between 1950 and 1962 on wood quality of Douglas-fir and western hemlock, noted that trees with high specific gravity near the pith usually were also above average specific gravity at advanced ages. For one study of four, 7-year-old trees from each of five provenances of Douglas-fir, it was concluded that provenances exerted the dominating influence on specific gravity. One provenance had the tallest seedlings, yet had the highest specific gravity. They felt that in selecting trees for quality it should be possible, by concentrating sampling on the fastest growing dominants, to find individuals that possess the "desirable ability of combining acceptable form, spiral angle, and tracheid length with outstanding ability to produce dry matter or cellulose". Because of the "extremely low probability of finding all desirable characteristics in selected trees it may be necessary to rely on hybridization rather than selection".

Mergen, Burley, and Yeatman (1964) studied two stands of Norway spruce. They stated that flushing (opening of buds) is under fairly rigid genetic control and that selection for fairly early or late flushing is feasible. Trees that flushed early had a greater ring width, lower percentage of latewood, and also a lower average specific gravity. Differences in specific gravity were also influenced by other factors. In a 20-year stand they obtained low correlations between fiber length, specific gravity, percentage latewood and ring width. In a 44-year-old stand, they found highly significant relationships between percentage latewood and ring width, and specific gravity and percentage latewood. They felt that their studies indicated that external phenological characteristics might assist in prediction of internal wood structure, thus reducing the work entailed in a search for trees of specific wood characteristics when selection is in a uniform stand.

For 31 eastern white pines ranging in age from 34 to 75 years, Thor (1965) noted that specific gravity of the younger wood was fairly closely related to that of the older wood, a helpful factor in selection for breeding purposes. These trees were part of a study whose object was to develop a fume resistant strain.

In a seed source test of variation of loblolly pine from six provenances of southeastern United States, Thor and Brown (1962) sampled wood of the first five growing seasons from seed of 96 trees. Of the three sources of seed which were located fairly close to each other, two had the heaviest wood and one the lightest. Their data did not follow a clinal pattern.

Harris (1962) found a difference in specific gravity of the resultant wood between three clones each of 7-year-old loblolly and slash pines. He used extracted sections of the first order branches of the current year's growth for specific gravity determinations, eliminating the first inch of the branch nearest the stem.

Saylor and McElwee (1963) reported on a collection trip to Mexico to bring back pine material of 17 species for provenance trials and wood studies. Information will be sought regarding survival, tolerance to drought, frost, etc., as well as growth rate, wood structure and other variables. It will be interesting to see how these pines succeed, especially since, as the authors point out, several have been planted previously in New Zealand, South Africa, South America, and Australia with quite promising results.

In Virginia pine Thor (1964) found rapid growth rate in diameter to be associated with larger amounts of extractives. He found that differences in specific gravity among stands were largely due to differences in amounts of extractives and there were no significant differences among stands for extracted specific gravity of the wood. Trees with high specific gravity and a high extractive content were found to have extracted specific gravities close to the normal for the species. He suggested that extractives be incorporated as a factor in a selection program for Virginia pine.

Goggans (1961) reviewed selected literature regarding the effects of environment and heredity on specific gravity, proportion of summerwood, extractives, and certain anatomical characters of the xylem. He concluded that both environment and heredity play an important part in controlling the mentioned characteristics and justify inclusion of specific gravity in genetic improvement programs in conifers. He also concluded that those environmental factors that the forester can control within a given stand become much less in effect when considered in relation to their total possible effect. Growth rate, which to some extent is controlled by heredity, can be controlled by the forester but has only a minor effect on specific gravity. He felt that since little of the between-tree variation in specific gravity had been correlated with environmental factors, this in itself was evidence of heritability of this characteristic.

Jones (1958) found that seed source influenced wood specific gravity of white spruce on two sites, but that the effect was not the same in all cases. When adjusted for rate of growth, the effect was more marked. Site affected both rate of growth and specific gravity. He stated that longitude of seed source also appeared to have an effect on specific gravity.

Risi and Zeller (1960), after studying specific gravity variation in five trees of black spruce growing on a Hylocomium-Cornus site in Quebec, suggested that hereditary factors in the individual trees might have a decisive effect on frequency distribution of specific gravity and on the type and degree of influence of certain factors on specific gravity.

Zobel, Cole, and Stonecypher (1962) studied wood properties of clones of slash pine to determine heritability of specific gravity, effect of root stock on characteristics of the clone, and relation between specific gravity and tracheid length of given clones. Grafts from 39 separate parents with a total of 258 grafts were sampled. The gross (broad sense) heritabilities obtained for specific gravity were from 0.54 to 0.63. No effect of stock on graft was detectable. Grafts in most cases had put on three growth rings.

Cech, Stonecypher, and Zobel (1962) describe a study of loblolly pine designed to evaluate quantitatively, the heritability results which can be obtained in open and control-pollinated progeny tests. The characters to be examined include, among others, specific gravity of the wood. The study was initiated in 1959. Some results in 2- and 3-year-old seedlings are given by Stonecypher, Cech, and Zobel (1964) for progeny of randomly selected parents from 35- to 45-year-old stands. Narrow sense heritability values of 0.56 and 0.72 were obtained for specific gravity of open-pollinated 2- and 3-year-old seedlings respectively. Values for diameter growth were 0.35 and 0.14 respectively. They point out that genetic correlations calculated from their data indicate that selection for increased specific gravity alone would result in lowered diameter growth, but simultaneous selection may be accomplished by choosing parents with both high specific gravity and high diameter growth. This would require more careful selection of parents and, in practice, would seem to result in some compromise in degree for each character. Their paper also illustrates the organizational pattern and analytical approach required in a study of inheritance of specific gravity by observation of phenotypes.

Zobel, Henson, and Webb (1960) checked breast height sampling as a means of predicting whole tree specific gravity. They examined 59 slash and loblolly pine trees ranging in age from 17 to 50 years and concluded that it was possible to get a good estimate of specific gravity in the whole tree by this method. They caution regarding the effect of defects, heartwood, and pitch as upsetting factors, however. In older trees, they felt the most practical measurement to use is outer wood at breast height to total outer wood in the bole.

Rodrique (1962) and Belanger (1961) investigated the density of branch wood in several species. They found that the density decreased rapidly near the trunk and then tended to level off in white spruce, balsam fir, black spruce, and eastern hemlock. They found that density in branches of hop-hornbeam, American beech, white ash, and sugar maple diminished quite gradually away from the trunk. Density did not vary with height in the tree for any of the species studied. In general, though not always, branch wood was heavier than trunk wood.

Jackson and Warren (1962c) found high correlation in specific gravity of the first two rings of branch and stem wood of 50 trees of 35-year-old slash and 38 trees of 25-year-old loblolly pine. They found the same true of 4-year-old loblolly trees and then went on to study correlations in specific gravity between parents and progeny of slash and loblolly trees. They concluded that sampling of the first two annual rings of branch wood adjacent to the stem was a feasible method of testing variation in specific gravity among parents and progeny of these two species. In open-pollinated series, they found highly significant correlations between parents and progeny. In control-pollinated series, the progeny were closely related to the average of both parents and to the female parents, but not so closely related to the male parents.

Specific Gravity and Properties of Coniferous Wood

Permeability.--Benvenuti (1963) determined the longitudinal pressure permeability coefficient of loblolly pine, using nitrogen as the permeating gas, while he investigated methods of increasing permeability in the species. He found no relationship between extractive content and permeability prior to extraction, but did get some indications of a relationship between specific gravity and permeability prior to extraction.

Erickson and Estep (1962) measured permeability to water of Douglas-fir heartwood from Oregon and Washington. In their measurements, specific gravity of the wood and percent summerwood were not directly related to longitudinal permeability. There was evidence, however, that higher percentages of summerwood were associated with higher rate of radial flow, a fact they suggested should be explored further.

Craig (1963), in a study of permeability of 47 Douglas-fir trees from six areas in Washington, noted no apparent relation of permeability to specific gravity.

Strength.--Kellogg and Ifju (1962), after testing 2 softwoods and 19 hardwoods, concluded that the single factor of greatest importance--specific gravity--is linearly related to both tensile strength and modulus of elasticity. Of several quality factors evaluated--conductivity ratio, portion of wood specific gravity attributable to extractives, fibril angle, and fiber wall expressed as a percent of total wall area--only thermal conductivity ratio was significantly related to specific strength and specific stiffness.

Van Vliet (1959) selected second-growth Douglas-fir lumber from five mills in western Oregon and southwestern Washington. He concluded that in tensile strength parallel to the grain, second-growth wood appeared to be comparable to old-growth wood of Douglas-fir. He noted that specific gravity averages between sawmills (essentially geographic areas) were significantly different.

Barefoot, Hitchings, and Ellwood (1964), preselected four loblolly pines for a wide range and particular combinations of specific gravity and fiber length determined from increment cores. Pulping fractions were made separately for each tree from the core (juvenile) wood, from the outer wood, and from a reconstructed combination of the two. Of the fiber dimensions, summerwood cell wall thickness was the best single predictor of paper properties, accounting for 74 percent of the variation of any of the properties examined. The Runkel ratio $(\frac{2CW}{CL})$[1] accounted for at least 58 percent of any of these properties. In general, those fiber characteristics which were associated with wood density were predominant in determining paper properties.

Van Buijtenen, Zobel, and Joranson (1961) related some wood and kraft pulp properties of samples from 24 loblolly pine trees from South Carolina. The trees were dominants and codominants from a natural, even-aged, old-field stand. They found a large tree-to-tree variation with respect to many properties that they felt might be useful for genetic improvement. They found that percent lignin, percent alcohol-benzene extractives, and specific gravity could account for the major part of the predictable yield of pulp. Of the factors influencing the zero-span tensile strength, fiber length, specific gravity, alpha-cellulose content, and water-resistant carbohydrates appeared to have the strongest influence.

Microtensile strength of summerwood and springwood microtome sections from annual increments of Douglas-fir was determined by Ifju and Kennedy (1962). They found a very high correlation between density and tensile strength of summerwood and springwood section data treated together, but found summerwood to be stronger than expected in comparison to springwood. They felt that this superiority of summerwood could be ascribed to differential molecular architecture of the cell wall, morphological features of the cell walls, and increased proportion of middle lamella in the springwood. Tensile strength was found to be correlated significantly with cellulose content in both spring- and summerwood. Wellwood (1962) also reported a disproportionate increase in strength of summerwood over that of springwood, based on specific gravity.

Ifju, Wellwood, and Wilson (1965) in a paper currently submitted for publication, report ultimate tensile strength, modulus of elasticity, and earlywood and latewood specific gravity as determined from serial microtome sections of annual rings of Douglas-fir. They observed two anomalies: constant earlywood specific gravity in contrast to progressive increase in strength properties across this zone, and maximum specific strength (tensile or elasticity/specific gravity) at point of latewood initiation.

Tracheid length and specific gravity.--Thor (1964), working with Virginia pine, found no significant correlation between specific gravity and tracheid length.

Zobel, Cole, and Stonecypher (1962), using grafts from 39 separate parents, found no relation between specific gravity and tracheid length of given clones. Grafts in most cases had put on 3 growth rings.

In 31 eastern white pine trees ranging in age from 34 to 75 years, Thor (1965) reported the relation between specific gravity and tracheid length as very weak.

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[1] CW Summerwood cell wall thickness.
CL Summerwood cell lumen diameter.

Specific Gravity Variation in the Bole of Hardwoods

There has been less emphasis by the colleges on research in variations in hardwood specific gravity and the factors influencing it, during the period of this review. Apparently the more urgent need for this kind of knowledge has been in pulpwood and construction material where, in the past, softwoods have been paramount. Perhaps the future, with the hardwoods being much more commonly in demand for pulpwood than some few years ago, will tell a different story.

The hardwoods, with their more complex and diverse anatomical structure, probably have more complex and diverse responses to changes in environment than do the softwoods. Under some circumstances, ring-porous woods develop higher specific gravity as the diameter growth rate increases, under other circumstances, the reverse is true. Only spotty information is available on what happens in diffuse-porous species. Obviously there is much to be done with hardwoods.

In a study of sprout growth of black cottonwood, Kennedy and Smith (1959) concluded that in 1-year-old material, specific gravity of fast-growth wood was lower than that of slow-growth.

Cech, Kennedy, and Smith (1960) then took 1-year-old shoots grown from cuttings or seeds of individual black cottonwoods, removed the pith and determined specific gravity of the wood. They reported that as diameter growth rate increased, specific gravity decreased, but found sufficient variation in individuals to encourage the recommendation that one particular clone "should be propagated for its apparent ability to produce wood of high specific gravity and long fibers when fast grown".

Barefoot (1963a), studied the wood characteristics of young yellow-poplar, correlating toughness and specific gravity with age from pith and height in tree. The density and toughness of his material decreased with increase in site index. He stated that wood of this species "within a span of from 30 to 90 rings from the pith becomes progressively denser and tougher for a period, after which the trends are reversed. This is not to say that there is not an absolute maximizing age or that no leveling out period develops thereafter". Within a given growth increment, density and toughness were lower at the 17-foot level than at the base of the tree.

In a second article on yellow-poplar, Barefoot (1963b) reported that tangential and radial shrinkage of the wood of this species was positively correlated with density, as expected. Longitudinal shrinkage, however, could not be correlated with density.

Examining further (1965) the properties of yellow-poplar normal and tension wood, he found that toughness was proportional to specific gravity without respect to the presence or absence of tension wood. He used 24 wood samples from 11 different trees in his study.

In a study designed to determine if variation in wood properties among yellow-poplars in east Tennessee and southeast Kentucky was large enough to encourage a breeding program, Thorbjornsen (1961) collected cores for specific gravity from 10 stands and 63 trees. Density increased from 0.42 gram per cubic centimeter at 5 years to 0.46 gram per cubic centimeter at 25 years of age. Extractives averaged 2.5 percent and varied little with radius. The component of the total variation in density which the individuals account for was large, about 70 percent. There was a good relationship between core wood and mature wood. This looks good for a breeding selection program.

Variation in wood properties of southern red oak (*Quercus falcata* Michx.) was reported by Hamilton (1961). He examined six trees from two mixed hardwood-pine stands in Durham County, Ga. These were at least 12 inches, d.b.h., dominant or codominant trees, free of defects and representation of extremes of local site conditions. Wood at the center of the tree was denser (reaching 0.896), harder and tougher than later formed wood. There was generally a decrease in specific gravity with age from the pith at all heights.

Wood with the highest density was found in a central core extending the length of the tree, this core being widest at the bottom, pinching in with increase in height and finally widening out again somewhat at the top, like an hour-glass. He concluded that density of the wood was closely correlated with percent of latewood in the ring. Although he found variation in density between trees, he indicated that a larger amount of variation was observed in most instances within individual trees.

Collecting samples from red oak lumber grown in Illinois, without regard to species, Guiher, Peterson, and Walters (1959), in a marketing study of the use of this wood for farm construction determined a specific gravity range of from 0.54 to 0.90, with a mean of 0.68. In a similar study of cottonwood also grown in Illinois, Peterson, Guiher, and Walters (1959) report a range for cottonwood of 0.32 to 0.67, with a mean of 0.43.

In 40-year-old clones of bigtooth aspen, Albert (1960) found that specific gravity of the wood increased essentially linearly from the pith at all height levels investigated (up to 16 feet from ground level). Specific gravity decreased with increasing height, the greatest decrease occurring in the first 8 feet, but was slight thereafter.

In a study undertaken to determine the pattern of specific gravity variation in the trunk of black willow, Lisboa (1961) examined four trees cut along the Mississippi River near Baton Rouge, La. They were about 9 inches d.b.h., and 60 feet in height. The lowest specific gravity was at the 1-foot level, from there rising rapidly to the 9-foot level, afterwards increasing gradually to 41 feet and then decreasing slightly. In the lower portions, specific gravity at first increased with distance from the bark, later decreasing toward the pith. In the higher portions of the tree, there was a more or less consistent increase with distance from the bark all the way to the pith.

Average specific gravity in 10 dominant or codominant sweetgum trees from three sawtimber stands in the Mississippi Delta was 0.510 according to Carpenter (1965). Tree averages ran from 0.456 to 0.573. There was indication that one stand was heavier than the other two, possibly because of soil differences. Bole-wood from 2 to 18 feet above ground was lower in specific gravity than crown-wood by approximately 0.02. There was also indication that poorer site qualities produced heavier wood. Specific gravity varied more between trees than between sites, suggesting that the influence of hereditary factors and/or microenvironment are very important.

Weight of Trees and Pulpwood

Young, Hoar, and Ashley (1965) estimated the dry weights of fiber in each of the components of a tree of each one of several species (red spruce, balsam fir, white pine, hemlock, red maple, white birch, and aspen). They found that, on a dry weight basis, for every hundred tons of dry fiber removed from the forest by present standards, 55 tons of tree residue is left in the forest with at least two-thirds of this in the stump, large and medium roots. On a dry weight basis the present merchantable stem contains 71 percent of the fiber in all material larger than 1 inch in the tree.

Young, Strand, and Altenberger (1964) published preliminary tables presenting fresh and dry weights of the various tree components for white birch, red spruce, balsam fir, white pine, hemlock, aspen, and red maple. They defined the individual tree components in terms of roots less than 1 inch, medium roots, large roots, stump, merchantable stem, large branches, branches smaller than one inch, and unmerchantable stem. The last-named is the bole above the merchantable stem.

Bendtsen and Rees (1962) reported on the seasonal variation in water content of standing aspen trees in northern Minnesota. Seasonal changes in water content (highest in the winter) were much more conspicuous in the sapwood than in the heartwood. Within the sapwood the seasonal change increased with distance from the pith, becoming maximum in those rings adjacent to the cambium.

In contrast to the xylem, the bark underwent a marked increase in water content from winter to summer. They estimated that if it was assumed that a load of whole trees of pulpwood were composed of one-half water and one-half wood substance, by weight, the assumption would be valid for the month from June to July. In the winter season, however, because of the higher moisture content, there would be a 6 percent error introduced by this assumption.

Hardy (1961), in an investigation of weight as a basis for purchase of spruce and fir pulpwood (mixed) in Maine, concluded from measurements of 44 randomly selected truck loads that scaling by weight was less accurate than by volume when moisture or density is not considered. The average bone-dry specific gravity of his fir samples was 0.33 and that of his spruce samples was 0.37. However, the rough, green weight of the fir (because its moisture content was higher) was 55.6 pounds per cubic foot as compared to 49.4 pounds for the spruce. He calculated that 21 percent more was paid for an equal amount of bone-dry fir fiber with weight scaling under his conditions.

Special Reports

In late July and early August, 1960, A Special Field Institute in Forest Biology was held under the auspices of the School of Forestry at North Carolina State University, Raleigh, N.C. A Proceedings, edited by Maki, was published in 1963 by the School of Forestry. This Proceedings reports the topics on wood properties, physiology, entomology, and pathology. The discussions are pertinent and searching. "Part I: Tree-Growth--Wood Property Inter-Relationships" by H. E. Dadswell is of special interest.

The Eighth Annual Report (Anon.-1964), "N.C. State--Industry Cooperative Tree Improvement Program" describes the research at the School of Forestry, North Carolina State, Raleigh. It calls attention to many current projects, as well as problems, in the research program for tree improvement under way there.

Research in Wood Specific Gravity in Progress

It is evident from the following list of projects at the various universities with whom contact was made, that much research is currently under way and much is planned. There should be some interesting progress in the next 5 to 10 years. Many of the genetics studies should begin to bear fruit in that period.

Arizona State College, School of Forestry

Correspondent: Glenn Voorhies

Project: Wood quality of ponderosa pine in the southwest, including specific gravity, rate of growth, percent latewood and fiber length distribution in the tree. Also, fibril angles in the latewood and the amount of extractives present in the wood.

University of British Columbia, Faculty of Forestry

Correspondent: J. W. Wilson

Project: (1) Intra-increment profiles relating specific gravity and tensile strength to position in increment.
(2) Microphotometer scanning of annual increments.
(3) Douglas-fir wood density, tensile strength, and stiffness.
(4) Relation of wood density to compression perpendicular to grain.
(5) Relation of wood density to chemical properties.

University of California, Forest Products Laboratory

Correspondent: Fred E. Dickinson

Project: (1) Influence of growth rate and age on the tracheid length, specific gravity, and extractive contents in redwood.

(2) Variation in heart stains and specific gravity in tanoak.

(3) Influence of fine and gross wood characteristics on the machining of redwood and Douglas-fir, determined by surface measurements.

University of California, School of Forestry

Correspondent: Robert A. Cockrell

Project: Density and shrinkage of very rapidly grown ponderosa pine.

University of Florida, School of Forestry

Correspondent: Ray E. Goddard

Project: (1) Correlation studies with slash pine tracheid length.

(2) Inheritance of wood traits and their relationships with growth.

University of Illinois, Department of Forestry

Correspondent: C. S. Walters

Project: Effects of soil moisture stress and application of fertilizers on growth and wood characteristics of loblolly pine.

Louisiana State University, School of Forestry

Correspondent: William C. Hopkins

Project: (1) Natural variation in American sycamore. Objectives are:

(a) Assessment of natural variation in botanical features and certain characteristics, including specific gravity.

(b) Determination of any relationships between variation in the properties under study and the existence of geographic races, clines, or environmental influences.

(2) Development of a wood quality index for certain bottomland hardwood tree species. Objectives are:

Development of a numerical expression of the intrinsic quality of the wood produced by certain species, including cottonwood and black willow, relating tree average specific gravity to various factors such as age of tree, live crown ratio, etc.

University of Maine, School of Forestry

Correspondent: Gregory Baker and Harold E. Young

Project: Maine Wood Density Survey. Objectives are to:

(a) Establish relationships between density at breast height and density of merchantable volume of the tree for Maine softwoods.

(b) Determine averages and ranges in specific gravity for these species.

(c) Determine if there are significant differences in specific gravity in various geographic locations.

(d) Dry weight of fiber-fresh weight relationships for components of tree species in Maine.

University of Massachusetts, Department of Forestry and Wildlife Management

Correspondent: R. Bruce Hoadley

Project: A preliminary study of drying characteristics and strength properties of plantation-grown red pine dimension lumber. Objectives:

(a) To develop a graduate research program.

(b) To obtain pilot information on:

(1) Variation of properties of red pine lumber within a single stand.

(2) Drying characteristics and strength properties of plantation-grown red pine as compared to eastern hemlock and eastern white pine.
(3) Critical growth characteristics as related to drying and strength properties of red pine.
(4) Sample size necessary for a stand of red pine.

University of Michigan, School of Natural Resources
Correspondent: Everett L. Ellis
Project: (1) Specific gravity variation in ponderosa pine.
(2) Specific gravity variation in Douglas-fir.
(3) Specific gravity variation in forest trees.

Michigan State University, Department of Forest Products
Correspondent: A. J. Panshin
Project: Evaluation of strength and related properties of forest-grown and plantation-grown red pine in determining its suitability for poles.

Michigan Technological University, Department of Forestry
Correspondent: Hereford Garland
Project: Genetics of sugar maple. Objectives include intensive study of the specific gravity of the species.

Mississippi State University, Forest Products Utilization Laboratory
Correspondent: Warren S. Thompson
Project: Shrinkage of southern pine wood with specific gravity as one parameter.

University of Missouri, School of Forestry
Correspondent: R. H. Westveld
Project: Growth-quality evaluation of the wood of Missouri's commercial tree species. Includes normal and abnormal wood in Quercus, Pinus, and Juniperus. Includes within-tree variation and patterns of xylem tissue for these genera.

Montana State University, School of Forestry
Correspondent: John P. Krier
Project: (1) Density as a quality factor in release growth of long suppressed ponderosa pine trees.
(2) Density and extractive content in western larch.
(3) Density as a factor in relative strength properties of western larch and sub-alpine larch.

State University of New York, College of Forestry
Source: C. de Zeeuw and G. Stairs
Project: (1) Relation of fertilizer additives to wood properties of 35-year-old coniferous plantations on potash-deficient soils.
(2) Tensile strength of Douglas-fir wood as affected by moisture content and specific gravity.
(3) Comparison of methods for determining specific gravity of wood.
(4) Wood quality variations among selected trees for breeding purposes. Norway spruce, eastern white pine, European larch, Japanese larch, Dahurican larch, and a hybrid (Dunkeld) of Japanese and European larches.

North Carolina State at Raleigh, School of Forestry
Correspondent: Eric Ellwood and Bruce Zobel
Project: (1) Age at which harvesting of loblolly pine can yield profit. Objectives are:
(a) To determine dry wood weight yields on a per acre basis, of stands of different ages and stockings growing on different sites.

(b) To pick out trees with non-juvenile wood and see how this is inherited.

(2) Pulp and paper properties as related to wood characteristics, limb volume, knot wood, and including compression wood in several species.

(3) Factors of growth, site and form affecting specific gravity of wood, pulp qualities, and yield.

(4) Determine variance components and heritability of wood properties.

(5) Seed orchards to produce stock of high, low, or intermediate specific gravity wood as required.

(6) Checking specific gravity values for wood substances.

(7) Specific gravity variation within and among trees.

(8) Relation of wood density to end use requirements.

(9) Moisture movement, ultra-structure, and reaction wood formation including wood density as a parameter.

(10) Other projects are also under way.

Oklahoma State University, Department of Forestry

Correspondent: Edwin Y. Wheeler

Project: Wood properties of shortleaf pine in eastern Oklahoma. Objectives:

(a) To determine density, tracheid sizes, and cellulose contents of wood of shortleaf pine in Oklahoma.

(b) To determine the change in these properties due to clinal and environmental factors.

Oregon State University, School of Forestry

Correspondent: M. D. McKimmy

Project: (1) Variation and heritability of wood specific gravity in 44-year-old Douglas-fir from known seed sources.

(2) Relation between branch and stem wood specific gravity in young Douglas-fir trees.

(3) Specific gravity variation in a young Douglas-fir clone.

University of Tennessee, Department of Forestry

Correspondent: E. Thor

Project: (1) Relationship of 12 site characteristics to wood properties of yellow-poplar and shortleaf pine.

(2) Variation in wood properties of eastern white pine in the southern part of the species range.

(3) Inheritance of wood properties in Virginia pine in an open-pollinated test.

(4) Influence of irrigation and fertilization on wood density.

University of Toronto, Faculty of Forestry

Correspondent: R. W. Kennedy

Project: (1) Basic characteristics of tracheids, fibers, and vessels in seedlings grown under strict environmental and/or genetic control.

(2) Intra-increment variation in specific gravity, stiffness, and parallel-to-grain tensile strength in clonal Norway spruce.

University of Washington, College of Forestry

Correspondent: Harvey D. Erickson

Project: (1) Specific gravity and chemical changes in 30-year-old trees after thinning and fertilizing.

(2) Permeability of western red cedar.

Yale University, School of Forestry

Correspondent: F. Wangaard

Project: (1) Variation in wood properties and pulp sheet properties of slash pine.

(2) Radial patterns of specific gravity variation in red pine trees.

(3) Influence of wood density, other wood characteristics and fiber characteristics on hardwood pulp sheet properties.

(4) Approaches to cell wall density.

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RESEARCH PROGRESS ON THE RELATIONSHIPS BETWEEN DENSITY AND STRENGTH

By

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It is intuitively apparent that mechanical properties of wood should be related to density or specific gravity for, other things being equal, the higher the specific gravity value, the more wood substance there will be available to resist stress. Newlin and Wilson published the results of investigations of these relationships in 1919. Their work has provided the basis for most of the published accounts of strength-gravity relations to date. The data used by Newlin and Wilson were taken from more than 200,000 tests of small clear specimens in the green and air-dry condition. These data were averaged by what they called "species-localities," now more commonly called shipments. Using shipment averages, and graphical methods of analysis, the authors of that work fit power functions of the form

$$\text{Property} = a\ (\text{specific gravity})^{b} \qquad (1)$$

to the data, where a and b are suitable constants. For each property of interest, the function was fit to all available shipment averages to give a general relationship for wood. Values for the constants a and b for each property of interest are given in the Wood Handbook, and figure 1 is an often copied plot of modulus of rupture in bending versus specific gravity from the study cited. It is also noted in the Wood Handbook that the power function seemed to have a slightly higher power for individual species than when all species were combined, and an increase in the value of the exponent of 0.25 is suggested.

Since the original publication of these data in 1919, the Forest Products Laboratory has increased its storehouse of basic data by an estimated 50 percent. In addition, methods of data collection and analysis have been greatly improved during the intervening years. Interest has increased in the application of property-gravity relations as a means for up-dating estimates of species average properties using the techniques of double sampling. All of these factors have provided stimulation for a reevaluation of our knowledge of the strength-density relationships. Furthermore we are fortunate to have available computing facilities many times faster and more flexible than the earlier researchers, which has made exploration with available data relatively easy. This presentation gives an account of recent developments.

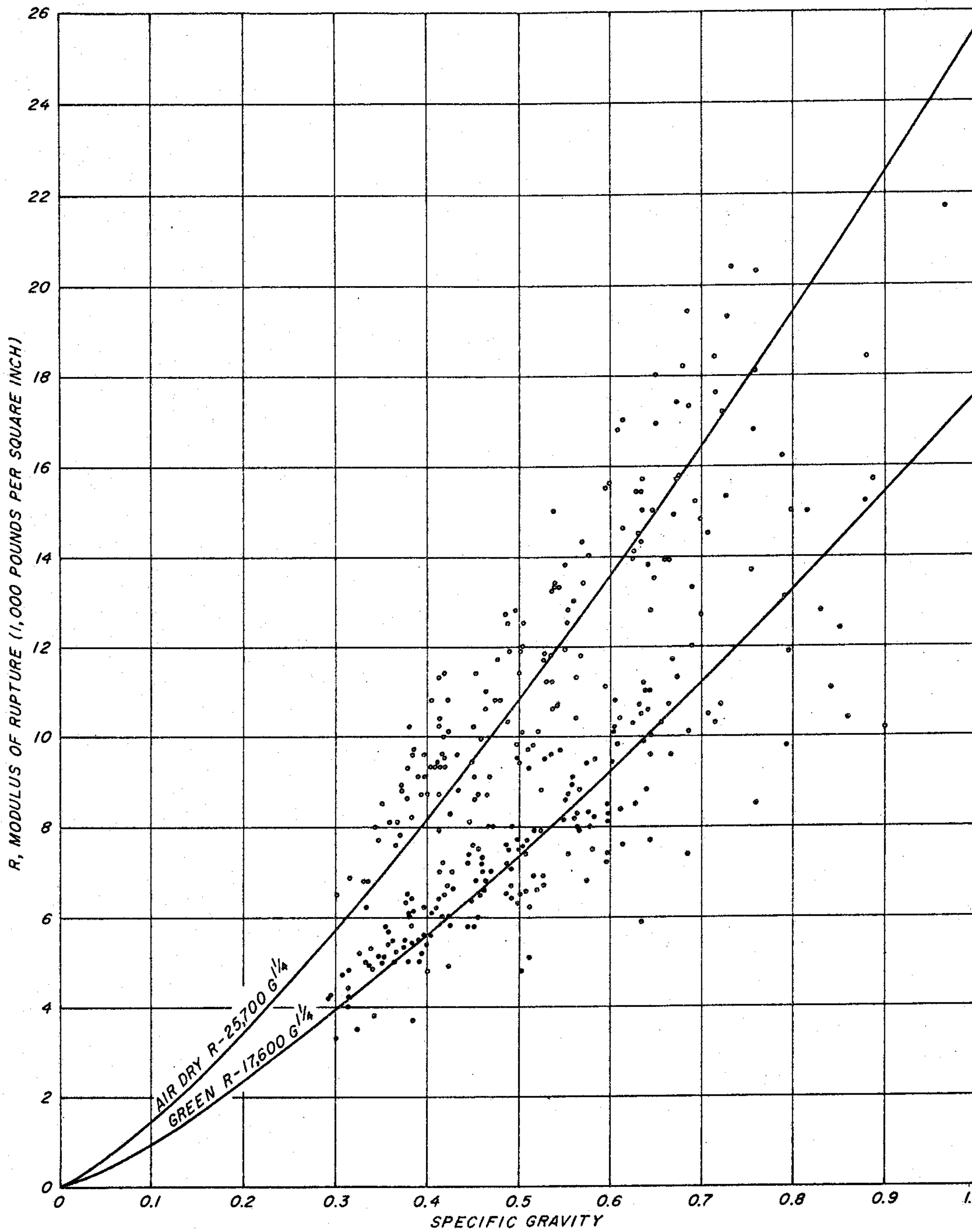

Figure 1.--Relation of modulus of rupture to specific gravity for green and air-dry material of various species (from U.S. Dept. Agr. Tech. Bull. 479).

The Strength-Gravity Relation for Individual Species

In our recent work in conjunction with the Western Woods Density Survey, where correlations between four mechanical properties and specific gravity were needed, some plots of rather substantial amounts of available data seemed to indicate that, within the range of specific gravities encountered, a straight-line relationship was justified. In these plots, results of tests on individual specimens were employed, rather than shipment averages. These straight lines obviously did not pass through the origin. Apparently Newlin and Wilson selected the functional form given by equation (1) above in part because they felt that the function must pass through the origin; that is, that a piece of wood with zero specific gravity should have zero strength. Although quite logical, this argument is somewhat academic. While the power function does pass through the origin, few species produce normal woody tissue with a specific gravity approaching zero.

An exploratory evaluation was made of the linearity of the function, using the large numbers of green Douglas-fir data that were available. This was done by obtaining least squares correlations of each property with successively higher integral powers of specific gravity. Specific gravity was represented by polynomials up to and including the sixth power. In such a method, it is possible to test statistically if the addition of each successive term makes a significant reduction in residual sums of squares; i.e., to test if the data show significant curvature.

Table 1 summarizes the results of this investigation.

Table 1.--Significant[a,b] results from correlations of properties with all combinations of six integral powers of specific gravity

Property	Source[c]	Integral power	Number of specimens	Correlation coefficient
Modulus of rupture	West Coast	1	1,374	0.902
	Interior north	1	555	.840
	Interior south	1	376	.773
Modulus of elasticity	West Coast	1	1,373	.736
		2		.744
	Interior north	1	55	.651
	Interior south	1	377	.531
Maximum crushing strength	West Coast	1	2,638	.867
	Interior north	1	763	.794
	Interior south	1	404	.654
Shear strength	West Coast	1	526	.639
	Interior north	1	194	.603
	Interior south	1	203	.773

[a]In each case, successive integral powers of specific gravity were added to the correlation until two consecutive terms made no significant reduction in residual sums of squares.

[b]Significance measured at the 1 percent level.

[c]There is ample evidence to indicate geographical differences in Douglas-fir over its producing range. The broad regional subdivisions used here are defined in the Western Wood Density Survey report No. 1 with the exception that west coast is a combination of the coast and interior west discussed in that work.

In one instance, a higher order term than the first power of specific gravity made a significant contribution. It must be noted that the statistical tests performed were exceedingly sensitive, considering the unusually large number of specimens contributing information. It may be observed that the significant higher order terms made no practical increase in the multiple correlation coefficient. It was concluded that no curvilinearity may be justified on the basis of these data. Then the form of the suggested function is

$$\text{Property} = a_1 + b_1 \text{ (specific gravity)} \qquad (2)$$

Although this function does not, in general, pass through the origin, it is the simplest functional form which may be used to adequately fit the data at hand, according to a least-squares criterion. In this sense it is somewhat easier to work with than expression (1).

The Strength-Gravity Relation for All Wood

As mentioned earlier, the range of specific gravities encountered within a single species is relatively small and does not approach zero gravity except for a few very light woods. However, if we consider many species combined, then it is possible to treat a wide range of specific gravities, including those that are comparatively low. We are led to the inescapable premise that this particular strength-gravity correlation should pass through the origin, and that the function is of more than academic importance in the vicinity of the origin if species exist with average specific gravity in that vicinity.

Modulus of rupture was correlated with specific gravity, using average values for 173 species in the green condition and 171 species in the dry condition. All species used are native to the United States. Species averages were used, rather than the shipment averages as in figure 1. It was hoped that the average of all available data would somewhat more reliably represent the species. The various species are represented by from one to many shipments, so that each species average is not estimated with the same precision. The number of green specimens is usually two to three times the number of dry specimens for any species. The correlations were also made using the logarithmics of species averages, in order to compare the functional form (1) with (2). Table 2 summarizes the results of these correlations.

Table 2.--Several correlations of modulus of rupture with specific gravity for many species

Form of function	Moisture content	Correlation coefficient	Constants[1]		
			a	b	c[2]
Linear	Green	0.889	-340	15,648	15,006
	12 percent	.766	2,192	17,560	21,348
Power	Green	.888	15,226	1.04	
	12 percent	.785	19,631	.86	

[1] In the linear function, the constants are from the expression $y = a + bx$. In the power function, the constants are from the expression $y = ax^b$.

[2] Slope constants for linear function when straight line passes through origin.

Quite clearly, differences in correlation between the two functional forms are not great enough to give a strong indication that either type is preferable over the other on the basis of excellence of fit.

Figure 2 shows the species averages plotted, along with the linear correlation lines. It can be seen that the line representing the green data very nearly passes through the origin. It is also apparent that the dry data are more scattered, and that a line through the origin may represent a fit almost as good as the least-squares line. It is possible to find a best line according to a least-squares criterion, but with the added restriction that the line must pass through the origin. These computations were made, and the hypothesis tested that there is no difference between the slope given in table 2, and the slope given by the line through the origin. No difference was found at the 95 percent level of significance in either case; a significant difference at the 99 percent level was found for the line representing the dry averages. The dry averages are based on fewer data, and are known to be less precise. It does not seem unreasonable that the line through the origin be used in each case.

Figure 3 shows the straight lines, the power functions, and the power functions proposed by Newlin and Wilson. Their power function was given a power of $b = 1.25$ for both green and dry. Neither of the values given in table 2 is close to this value.

In figure 2 no data provided species average gravities below about 0.3, and few occurred above 0.8. In an effort to evaluate the effectiveness of the functions, average properties were taken from some of the literature on foreign species and placed on the plot given in figure 4, where a wider range of specific gravities could be found. These data do not appear to be best represented by the straight lines superimposed on them. Although they have not been treated by a least-squares analysis, as were the data of figure 2, it appears that the dry data would probably best be represented by a somewhat steeper straight line other than that shown, not through the origin; and that the green data might best be represented by a curve. It was observed, while plotting, that data from the Australian source were much closer to the lines shown in figure 4 than were data from the other two sources. Strangely enough, the green data are much like the line shown, for specific gravities of about 0.85 or less; they show disproportionately high modulus of rupture for greater specific gravities. The accumulated foreign information was obtained at a number of different laboratories, which may account for some of the scatter in results.

Discussion

It can be concluded from the work this far that, according to our existing data on American species, and for at least four properties, the data do not indicate a significant curvature in the property-gravity relation. Furthermore, for all species combined, the relation appears to be a straight line through the origin, although this is not supported by data from foreign sources. It seems unlikely that "best fits" can be obtained using the same power for green and dry wood, as reported by Newlin and Wilson, even if a power function is used. It also seems unlikely that the same power can be used for each individual species.

There are several assets that the straight line enjoys over the power function. It is slightly easier to obtain the least-squares fit. It is considerably easier to use the straight-line function in predicting properties. For individual species, it is somewhat academic how the function behaves outside the range in which the variable exists in practice.

The following additional work will probably be done on this study:

1. We have some semitheoretical methods by which we suppose we can predict specific gravity on one moisture content basis if we know it at another. We might explore how this predictor works in predicting one of these curves from another.

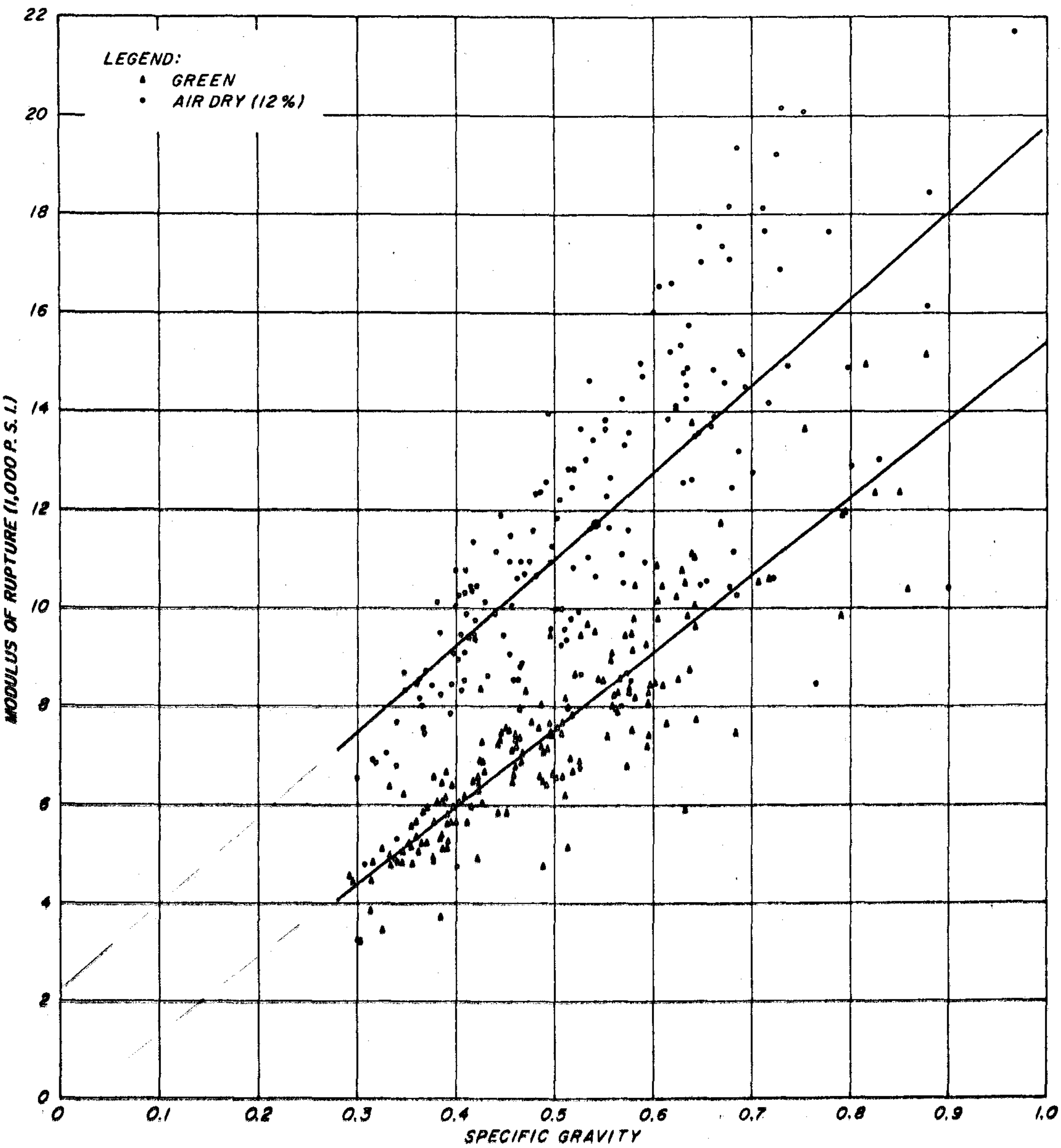

Figure 2.--Relationship of modulus of rupture of specific gravity based on species average values.

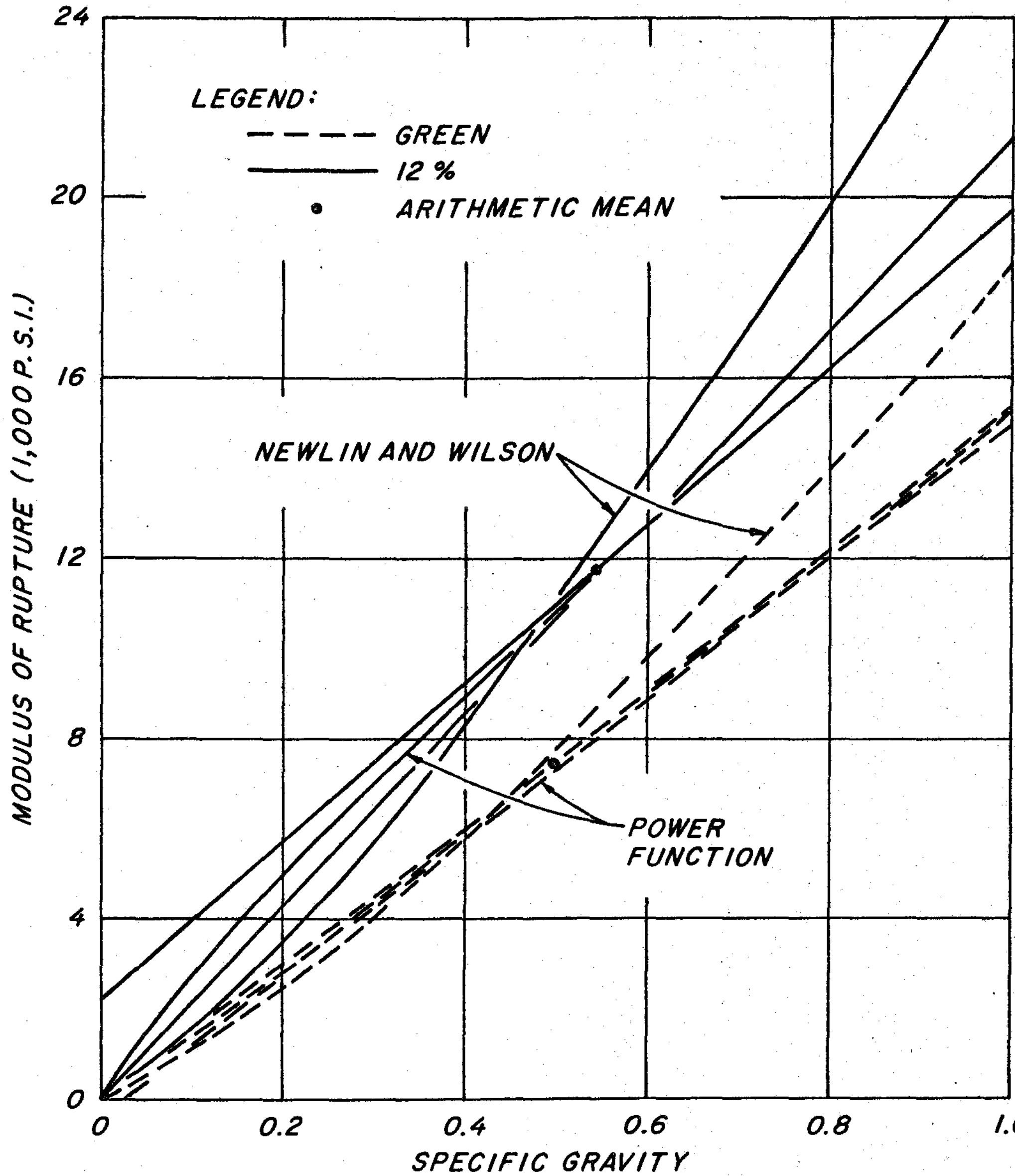

Figure 3.--Summary curves of various modulus of rupture-specific gravity relationships.

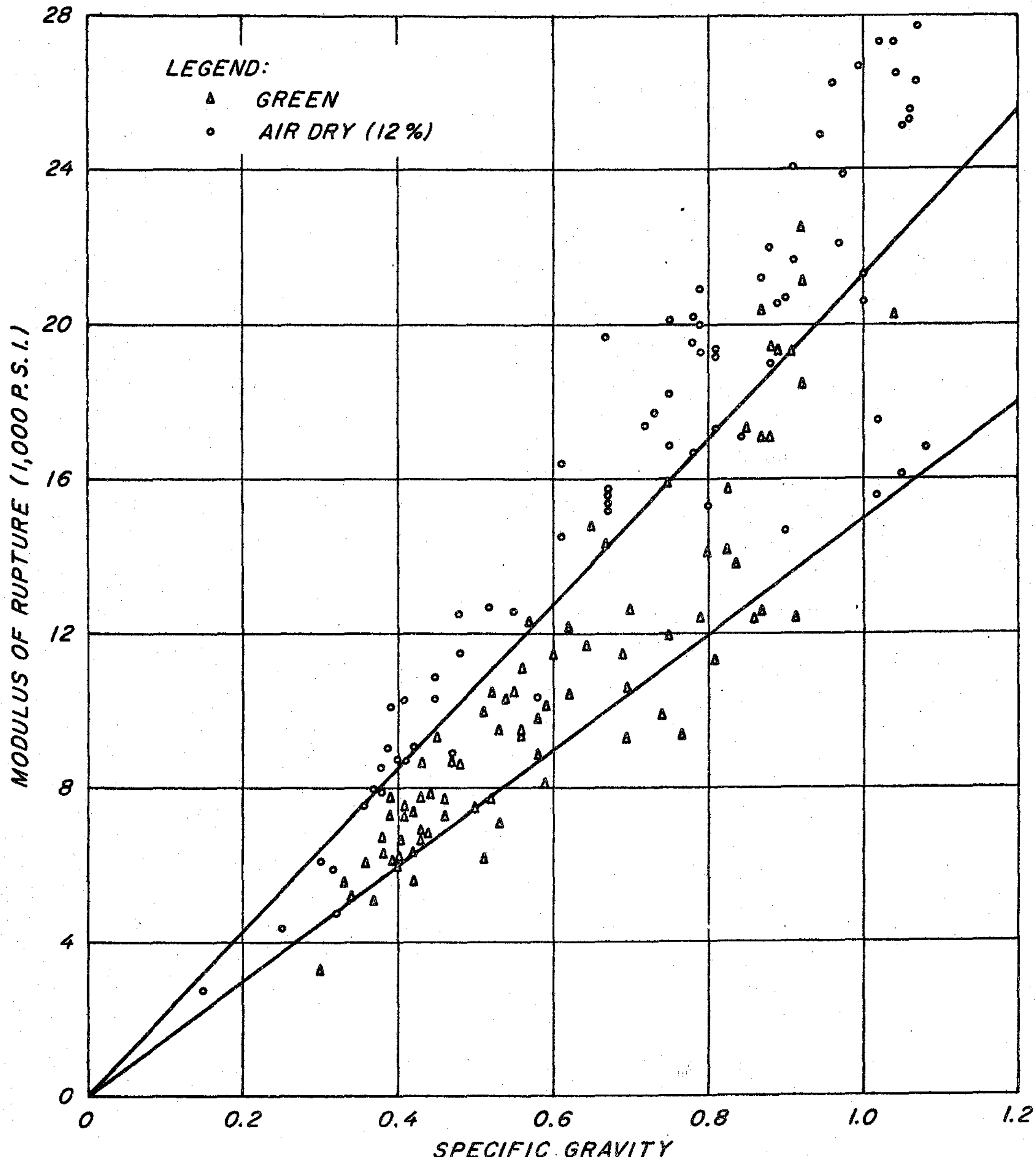

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Figure 4.--Relationship of modulus of rupture to specific gravity for United States and some foreign species.

2. It is known that presence of extractives affects the apparent specific gravity of wood, but should not affect the strength. For American woods, it would be of interest to pick out the averages for those woods known to be high in extractive content, and then obtain new correlations on the remainder, to see if the correlation is improved.

3. It would be of interest to sort by hardwoods and softwoods, and determine if this improves the correlations.

4. The Wood Handbook indicates that, using the power function, the power is independent of species, and is 0.25 greater than for all species combined. Our work on western softwoods would not substantiate this, and there seems to be room for additional investigation.

5. We should extend this analysis to other mechanical properties. It is particularly of interest to know whether this technique is more suitable for some properties than others. For instance, of the four properties considered in the Western Wood Density Survey, modulus of elasticity seemed to present poorer correlations than the other properties, for equal amounts of data.

(Summary of Presentation)

USE OF DENSITY DATA BY THE PULP AND PAPER INDUSTRY

By

J. C. WOLLWAGE, Vice President

Kimberly Clark Corporation

The Pulp and Paper Industry feels the systematic service to determine specific gravity and related quality characteristics of various forest species is both of immediate and long-term use to this industry. Emphasis on laboratories such as the Forest Products Laboratory should be on fundamental research. Companies within our industry can most efficiently conduct their own developmental research. The work being discussed in this symposium, and done by the Division of Wood Quality Research at the Forest Products Laboratory, is of a more fundamental nature and best done by this type of agency.

Of short-range interest, the economical factors involved in the study of wood density are readily calculable. In a southern kraft operation, wood costs represent about 40 percent of total mill door-cost per ton of pulp ($40 out of $100). Since pulp yield and specific gravity are directly related, a 10 percent variation in average wood density would yield a 4 percent change in pulp costs. Even for a small $150 ton per day operation, this is close to $300,000 per year savings or loss, dependent on the variation of wood density.

All of the story, of course, is not told by density. In some cases the paper end products require low density wood because of the fiber characteristics obtained therefrom. In this case, higher pulp costs will have to be incurred in order to satisfy the quality needs. In both cases, however, economical and quality-wise, the pulp and paper industry can do better if it has available to it the knowledge of the density variations occurring in the forests.

USE OF WESTERN WOOD DENSITY DATA

BY THE LUMBER AND PLYWOOD INDUSTRY

By

R. G. KIMBELL, Jr., Assistant Technical Director

Western Wood Products Association

Introduction

Development of safe and proper working stresses for lumber, laminated timber, plywood, and other whole wood products depends on the availability of refined information on clear wood strength properties for each species. However, factors such as species preference, species groupings, marketing practices, design, and safety factors are a separate consideration for the end use of each product. Therefore, it is necessary that information on clear wood strength properties be available in a form that will permit all these factors to be taken into account in deriving design stresses for different wood products and their primary uses.

The U.S. Forest Service and Forest Products Laboratory, together with the western plywood and lumber industry, have taken the necessary steps to provide the needed information on clear wood strength properties. Committee D-7 Wood of the American Society for Testing and Materials is taking the next step to provide the means for translating these data into usable product values.

The Role of the U.S. Forest Products Laboratory in Developing Strength Data

Historically, assignments of strength values for wood have been made by the U.S. Forest Products Laboratory, using the best procedure available. This procedure is given in the Standard Method of Testing Small Clear Specimens of Timber, ASTM D-143. It consists of determining average strength values from destructive tests of small clear specimens that are cut from sample trees. Sample trees, of limited number, are selected by characteristics and geographical location that are deemed to make them as nearly representative of a species as possible. As few as five trees have been used to establish average strength values for a species. The assumption has also been made that the average value of the strength of clear wood does not vary significantly within an area nor from area to area of a species growing range.

Because of such limited data and insufficient information on the range of strength properties available through this procedure, much personal judgment has been interjected. The U.S. Forest Products Laboratory development of the Wood Density Survey procedure and its correlation to clear wood strength properties, literally new inventions, have opened the way to a far more accurate evaluation of basic clear wood strength values and to a complete flexibility in their use.

The U.S. Forest Service, to obtain more comprehensive information on the physical, mechanical, and silvicultural properties of the forest stands in the United States, developed a density survey procedure to be carried out region-by-region over periods of 10 to 15 years. The western portion of the density survey was initiated by the U.S. Forest Service in the spring of 1960. In recognition of the immediate need to obtain this more reliable and complete information on the strength properties of the Western species, the then Western Pine Association, West Coast Lumbermen's Association, and Douglas Fir Plywood Association, in early 1961, entered into a cooperative agreement with the U.S. Forest Service to assure the availability of data for Douglas-fir and certain associated high-priority species within a period of three years. The nine important softwood species for which data were to be completed in this time are Douglas-fir, white fir, California red fir, Pacific silver fir, grand fir, noble fir, western hemlock, western larch, and black cottonwood.

These data are now available. Information contained in the FPL Report, Western Wood Density Survey, represents the most complete and comprehensive collection of density data ever assembled for the most important western softwood species.

The data shown in tables 1 and 2 indicate the great volume of information accumulated. Table 1 lists the number of sample locations in each western state and the total number of increment core density samples per state. Only one increment core is taken from a tree. Table 2 shows the total number of core samples collected for each species and the number of trees per species that were felled to provide disks in order to establish a relation between increment core and tree density. Disks were cut from these felled trees at specified intervals of height from the butt to the crown. The average density of all disks from a tree was considered to represent, with good accuracy, the average tree density. Correlation of the increment core density values to the average tree density measurement expanded the information on tree densities materially.

Similar data are continuing to be accumulated for all of the remaining western softwood and hardwood species and will be available when completed.

TABLE 1.--Location of Sample Plots and Number of Increment Core Density Samples Accumulated.

STATE	NUMBER OF SAMPLE LOCATIONS	NUMBER OF INCREMENT CORE DENSITY SAMPLES
Arizona	184	1254
California	539	4960
Colorado	25	211
Idaho	711	5114
Montana	463	4284
New Mexico	109	672
Oregon	849	5622
South Dakota	88	397
Utah	172	1152
Washington	787	4774
Wyoming	298	1886
TOTAL	4225	30326

TABLE 2.--Total Increment Core Density Samples and Number of Trees Sampled to Determine Tree Density by Species.

SPECIES	NUMBER OF INCREMENT CORE DENSITY SAMPLES	NUMBER OF TREES SAMPLED TO DETERMINE TREE DENSITY
Douglas-fir	9133	412
White fir	2150	280
California red fir	840	157
Grand fir	862	106
Pacific silver fir	330	90
Noble fir	158	75
Western hemlock	1040	142
Western larch	678	162
Black cottonwood	120	78

ASTM Procedure for Determining Design Values

Presently, basic clear wood working stresses for lumber are derived by applying a series of adjustment factors to the average strength values obtained from the small clear specimen tests. These include adjustments for the effect of seasoning, effect of depth of beams, variability, and duration of load. For fiber stress in bending, these reductions result in a clear wood working stress value for lumber that is nearly one-fourth of the average clear wood breaking strength value. Figure 1 illustrates a hypothetical series of test specimens arranged in accordance with their strength values. It also shows the progression of reductions from an average breaking strength to a safe working stress level for clear wood.

The present ASTM D-245, "Tentative Methods for Establishing Structural Grades of Lumber" lists basic clear wood working stresses that have been determined by ASTM test methods and adjusted as described. Though these values have been developed for lumber, they are necessarily used in developing working stress values for other product lines as no others more applicable are available.

The listed basic clear wood stresses are given for some species individually and for a number of fixed groupings of species. However, the species included in the fixed groupings are not now the same as the species mixture being marketed.

Modernization is needed, such as a listing of clear wood strength values for each species that are unadjusted for end use and a standard method for determining similar clear wood strength values for any grouping of species. This method needs to be flexible so that groupings can be arranged or rearranged to meet marketing changes.

Also needed is a method for translating clear wood unadjusted strength values for individual species, or for a grouping of species, into design values applicable to specific end uses.

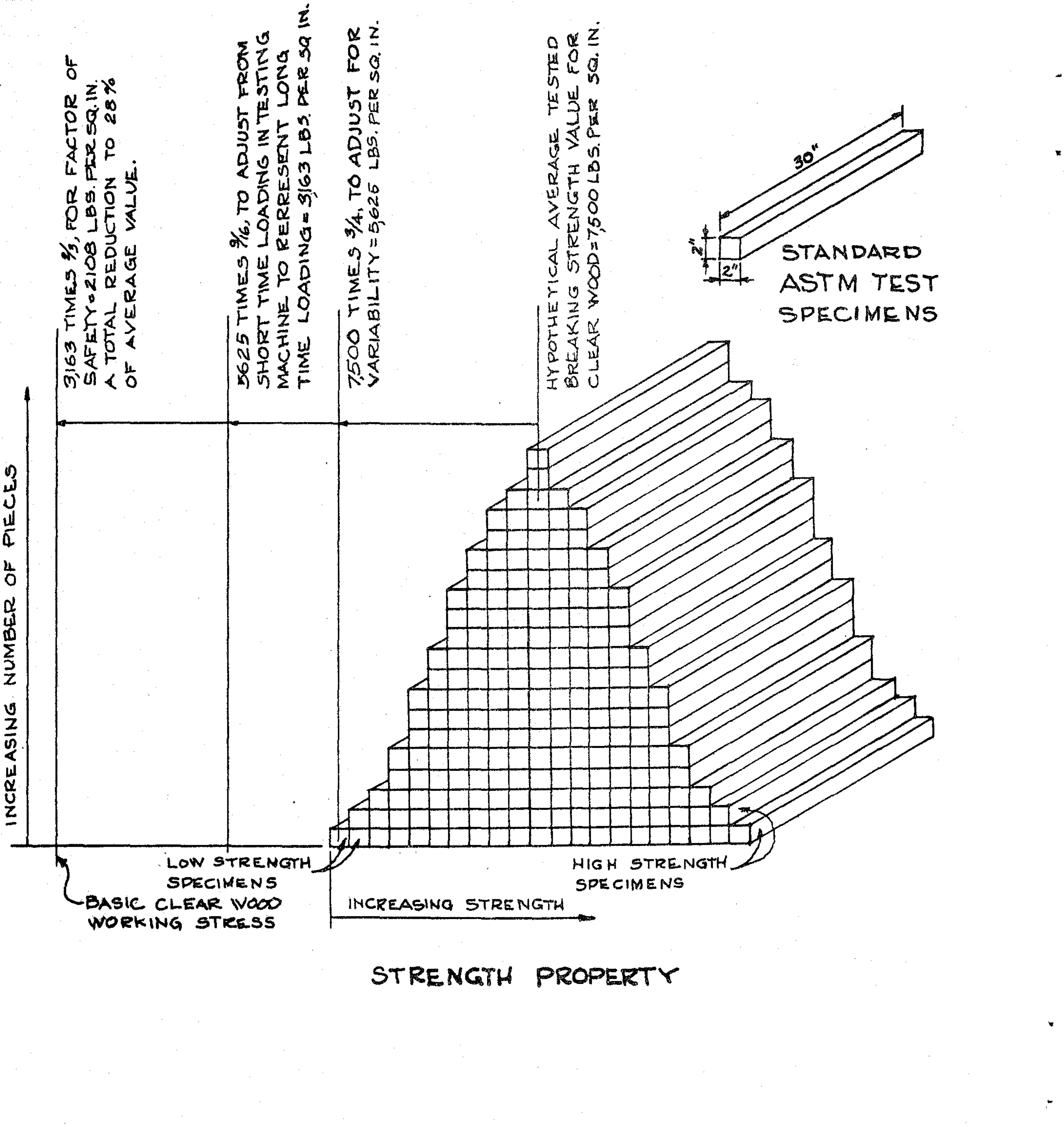


Figure 1.--Typical strength reduction factors from the average of clear wood breaking strengths to a clear wood working stress.

Western Woods Technical Committee Function

In keeping with the desire to expedite the Western Wood Density Survey, the lumber and plywood industry paved the way for early implementation of the Survey data by establishing jointly a "Western Woods Technical Committee." This Committee was charged with the development of an approach to the utilization of the Wood Density Survey data and its correlated strength properties information, as these data became available. Since the Committee had available an industry-conducted study on the variability in the density of a western species, and all of the published data on the strength properties of the species, they were able to proceed with the development of a technically sound statistical procedure for assessing the Western Wood Density Survey data, when available, into usable design values.

ASTM Committee D-7 Subcommittee XVII

ASTM Committee D-7 Wood has appointed a new subcommittee XVII on Clear Wood. This subcommittee has as its scope:

> "To develop standards for clear wood strength values unadjusted for end use for commercial species of wood, principles for grouping of species or subdivisions thereof, and general relationships for use in conversion of clear wood strength values to working stresses."

The Wood Density Survey data and the technical procedure developed by the Western Woods Technical Committee are being studied by the new ASTM Subcommittee. Proposed is a standard that will serve a common need for all whole wood products. It would provide basic information on average clear wood strength properties that are unadjusted for end use. The values would be for individual species or for areas within a species growth range. It would also set forth criteria for combining species into groups where such groupings are common marketing practice. In addition, the standard would include information on adjustments to the strengths of wood fibers that are related to conditions created by manufacture or use. Typical or variable adjusting factors are those for moisture content, temperature, and duration of load. Typical of fixed adjustments are those for wood treating chemicals.

Other separate ASTM subcommittees have been appointed and charged with establishing standard methods for converting the basic clear wood values to working stresses for the separate whole wood products that are appropriate to their method of manufacture and end uses.

Problem Revealed by Wood Density Survey

The Western Wood Density Survey data show that significant differences in density, and consequently in strength properties, exist from area to area within a species growth range; differences that were previously masked by using the average regional or species strength data based on "representative" trees. Obviously, it is necessary to account for these differences in determining clear wood strength properties for a species.

Proposed ASTM Clear Wood Standard

The problem is to establish a standard procedure for assessing strength properties and establishing values that are reliable and acceptable to the consumer of wood products in such a way that the area-to-area differences are properly considered. With the extent of the species density variability revealed for small units, geographically defined by the survey, an accumulative method of assembling these units with imposed limits, called the "unit area" method, has been developed. It is believed to be the most reliable approach.

From samples obtained in the West on the pre-established grid system followed by the Western Wood Density Survey, refined information is obtained in small increments on the variation in the density of a species across its growth range. However, these increments do not include a measure of the timber volume they contain and volume is very important to the overall consideration of strength properties.

To obtain values that are reliably representative, it is necessary to compare species variations on an area-volume basis that is as small as practical to consider.

In the West, U.S. Forest Service has standing timber volume data available by counties. However, some counties have such a small timber volume of some species that it is not worthy of consideration as a single unit. In order to build up a sufficient species volume to use statistically, county volumes can be combined, in a fixed and unbiased manner, until some basic minimum of the total standing timber volume of the species is accumulated. For this, 1 percent of the total volume is considered an adequate minimum. This is the system proposed for establishing "unit areas." It is interesting to note that the species volume in some counties is so small that it takes in the whole of a state before a basic minimum is reached.

Figure 2 illustrates the "unit areas" for Douglas-fir, which encompasses the largest growing range of all of the western species.

Wood density values from the grid sampling are readily correlated to appropriate "unit area" volumes from the geographical description of the sampling grids and the density survey.

From this information, the average density of trees of a species growing in each "unit area" can be determined.

By utilizing the relationships between density and strength properties that have been established from standard clear wood strength tests, each "unit area" average density is translated into average strength property values. The relationship between density and modulus of rupture (maximum fiber strength) is graphically illustrated in figure 3.

As determined from the density survey, some "unit areas" will have higher and some will have lower strength values than others. By weighting the average strength property of a species in each "unit area" in proportion to its ratio of timber volume to total volume, or total subdivision volume, the high-to-low variation between "unit areas" is accounted for in accumulating an average strength value for a species or a species subdivision.

With the exception of the value for modulus of elasticity, the measure of stiffness, it is necessary to know how extensive is the variability of strength properties below the determined species average, as it is necessary to set working stress values for design purposes from the lower limits. Basic information from existing standard strength test data, combined with similar information from the Wood Density Survey, provides a reliable measure of this variability. The total amount of variability of a species can be considerable as it is made up of the variation that exists between trees and that which occurs even within a tree. Some species will have greater variability than others. Figure 4 shows how hypothetical test specimens for two different species, arranged according to their strength, end up with different variabilities. The narrower spread of species A means that it has less variability than species B.

Variability is not considered in the case of modulus of elasticity. In design, stiffness is a separate consideration from strength and it is more important to know the average than either the low or high ends of the variability in modulus of elasticity values. For example: The joists in a floor system will have stiffness values that are within the variability range and a deflection limitation based on the lowest stiffness value in the assortment could result in a floor with overly stiff characteristics. Similarly, if deflection limits were based on the highest value in the assortment, the resultant floor would deflect undesirably.

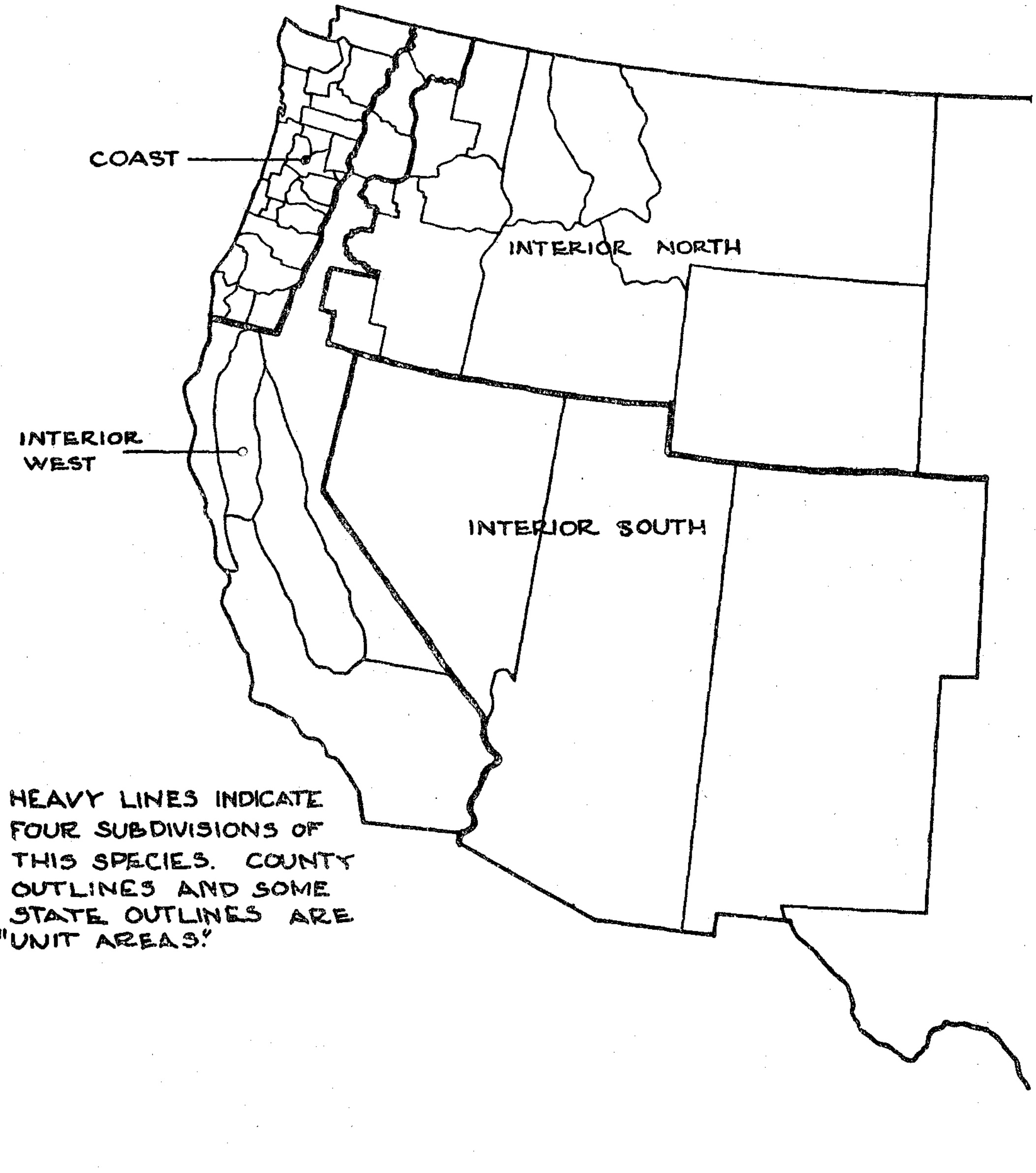


Figure 2.--Example of "unit areas" for Douglas-fir.

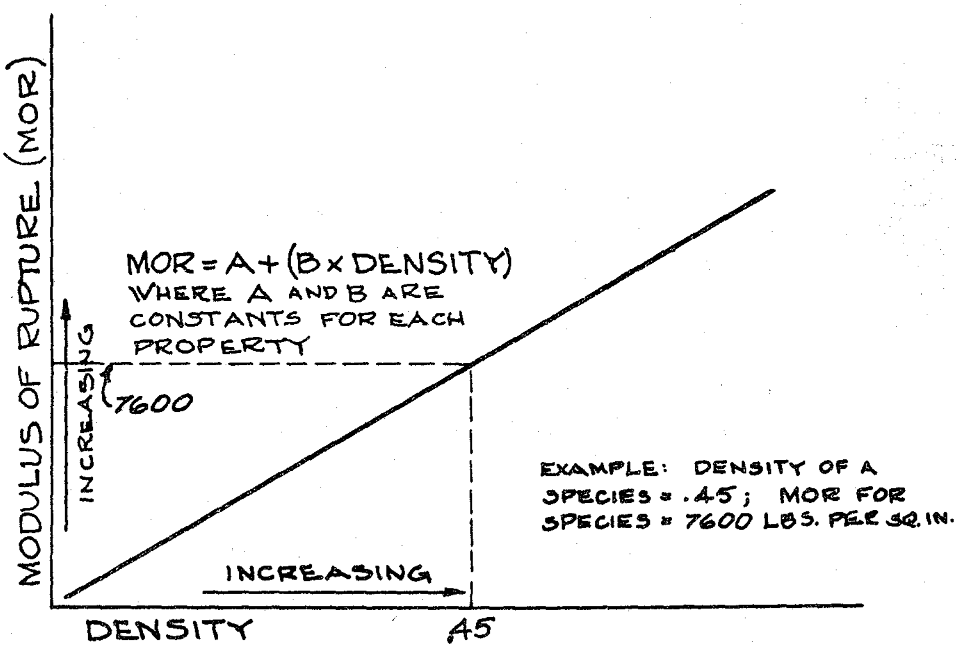
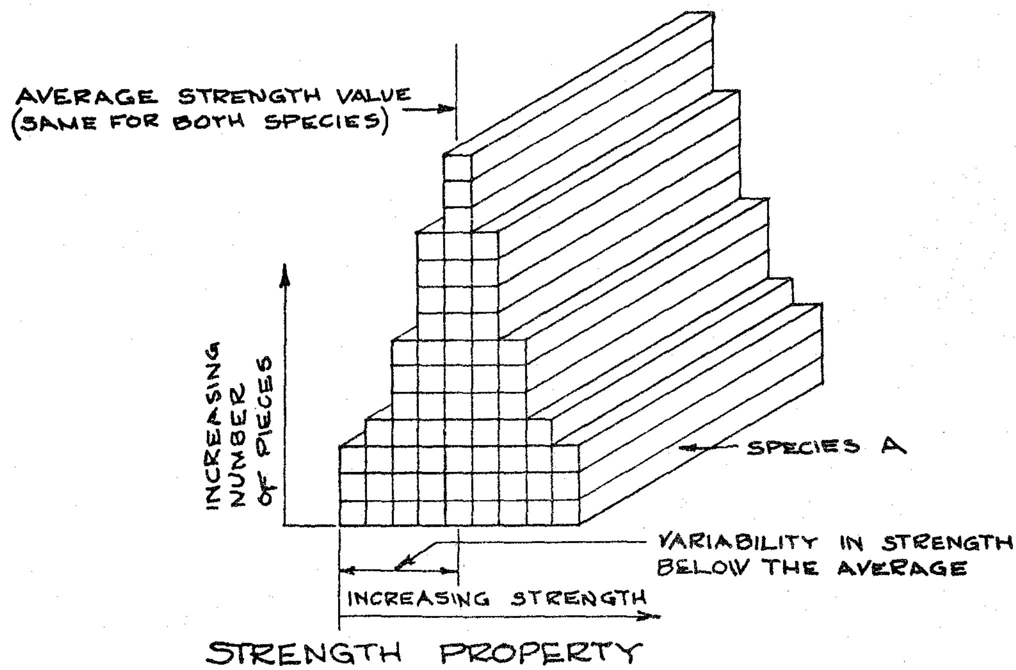


Figure 3.--Graphic representation of typical modulus of rupture-density relationship for a species.



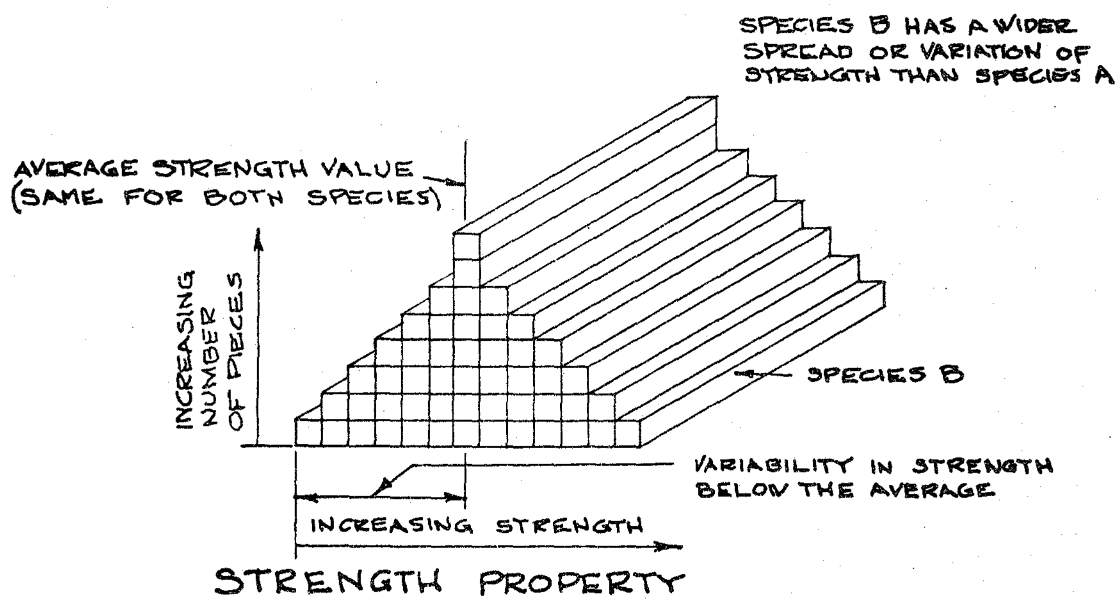


Figure 4.--Example of two species having comparable average strength but different variations.

Since there is considerable variability between "unit areas" across the whole growth range of a species, some limitation must be used in establishing a practical and realistic average modulus of elasticity value for a species.

For modulus of elasticity, the "unit areas" having the lowest average stiffness, in the group of "unit areas" comprising a species or a subdivision, can be a critical factor in determining the value applicable to the species. Because the "unit area" with the lowest value could also have the minimum standing timber volume requirement, it would have little effect on the species average. However, since shipments from this low value area would have much lower stiffness than the species average, it must be considered in setting the stiffness value for the species. Setting logical limits between the average stiffness of the species and the average stiffness of the "unit area" with the lowest value will assure that an average modulus of elasticity for all of a species will not be unrealistically high for shipments originating in the low value "unit area." The proposed limits provide that the average modulus of elasticity assigned to a species must not be more than 16 percent greater than the average stiffness value for the "unit area" with the lowest stiffness value. Figure 5 illustrates how these limits are applied to a hypothetical species.

Some logical limits must also be set between the lower limit of strength value obtained from the array of values for a species and the lower limit obtained in a "unit area" in order to stay within safe design levels. Limits have been proposed for the several strength properties--modulus of rupture, compression parallel to grain, and horizontal shear. These limits follow the same principle as those for modulus of elasticity except that they are related to the lower end of the variation in strength properties, rather than to an average value for safety reasons.

In engineering jargon, this low value limit is called an "exclusion limit." For lumber, the exclusion limit has long been set at 5 percent, which means that the value used as a base is limited so that no more than 5 percent of all of the values in the array of test values can be below the base value. Conversely it also means that 95 percent of all the values will be higher than the base value. Previously the exclusion limit has been applied to the total array of test values for a species, but with the advent of the Density Survey data, it is evident that strength values within unit areas or subdivisions of a species can be diverse and not unlike the differences to be expected between different species. This has therefore led to a criteria for the combining of values by unit areas whereby the strength value associated with a 12 percent exclusion limit for the unit area having the lowest strength values or the 5 percent exclusion limit on the total array of values for the species, whichever is the least, is the governing value for the species.

These same limits apply when species are combined into groups because of production or marketing practices. Since data from a wood density survey are not available for all species, slightly different limits have been proposed for these species so that it will be possible to combine any mixture of species into groups regardless of whether or not density survey data are available for the species.

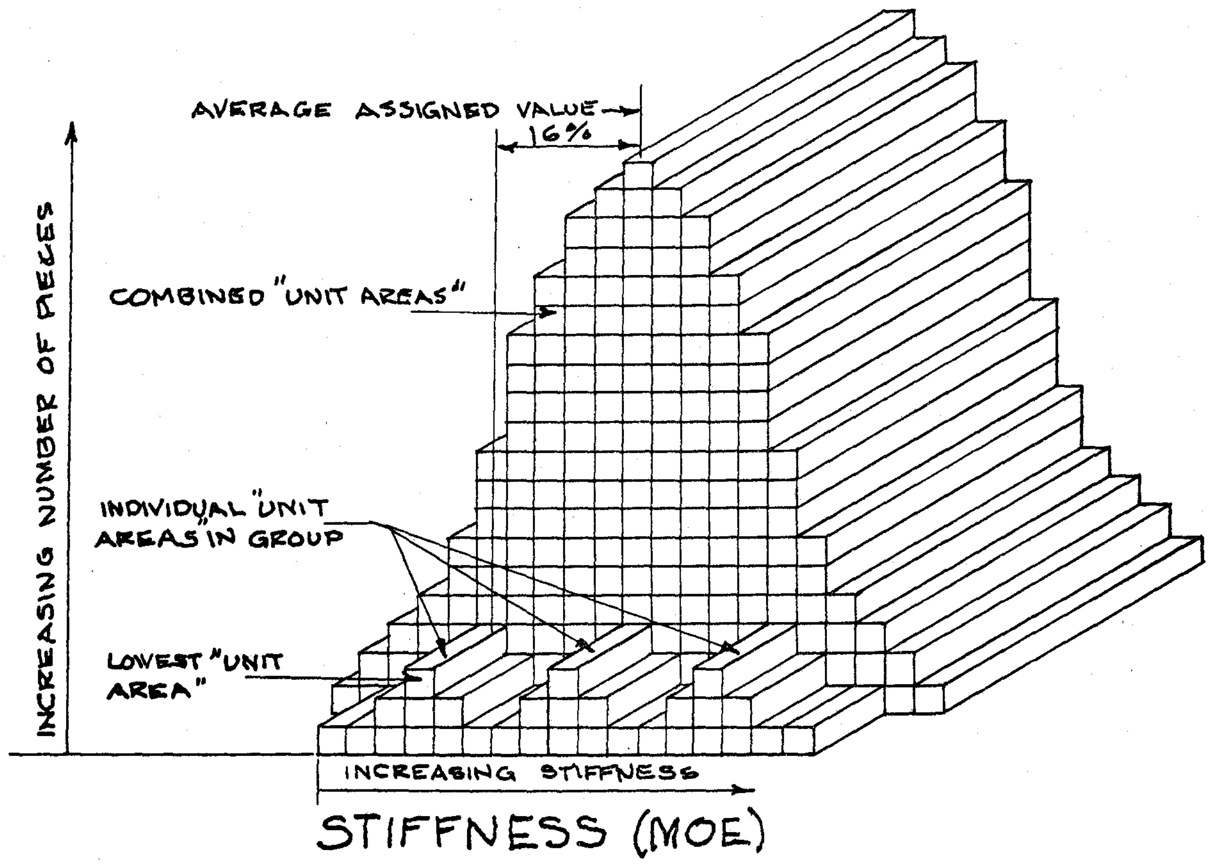


Figure 5.--Illustration of limits for modulus of elasticity.

INTEREST BY THE LUMBER-LAMINATING INDUSTRY IN WOOD DENSITY AND RELATED STRENGTH DATA

By

MAURICE J. RHUDE, Chief Engineer
Unit Structures Department

Koppers Company, Inc.

The lumber-laminating industry is interested in wood density-strength relationships because it is the structural glued laminated timber industry.

Specific gravity is an index of the amount of wood substance present and is an index of wood strength properties. Density, as an indicator of fiber content, is a quality factor of prime importance to the pulp and paper manufacturer. Density, as an indicator of mechanical strength properties, is of prime importance to the structural timber laminator.

We are interested in research on wood density for the simple reason that wood density influences our profits and the performance of the end product we manufacture.

The slides which you are about to view describe better than words this product of our industry. If you feel they are also a sales pitch for wood to you as a potential customer, you are right.

"He who whispers down a well
About the goods he has to sell
Will never reap the golden dollars
Like he who climbs a tree and hollers."

Over the wide range of lengths, cross sections and shapes shown in these slides, it is apparent the wood density plays a prominent role.

To focus your attention upon this wood density-strength relationship as it applies to our industry, I refer you to figure 1. I will, in turn, discuss the raw materials, the production and quality control procedures, the structural design criteria, and the field performance. It is for our structural product, in particular, that consideration for density must exist from selection of raw materials to the final inspection of the finished product.

Wood and Density

Specific gravity is, by definition, the relationship between the weight of the wood substance and an equal volume of water.

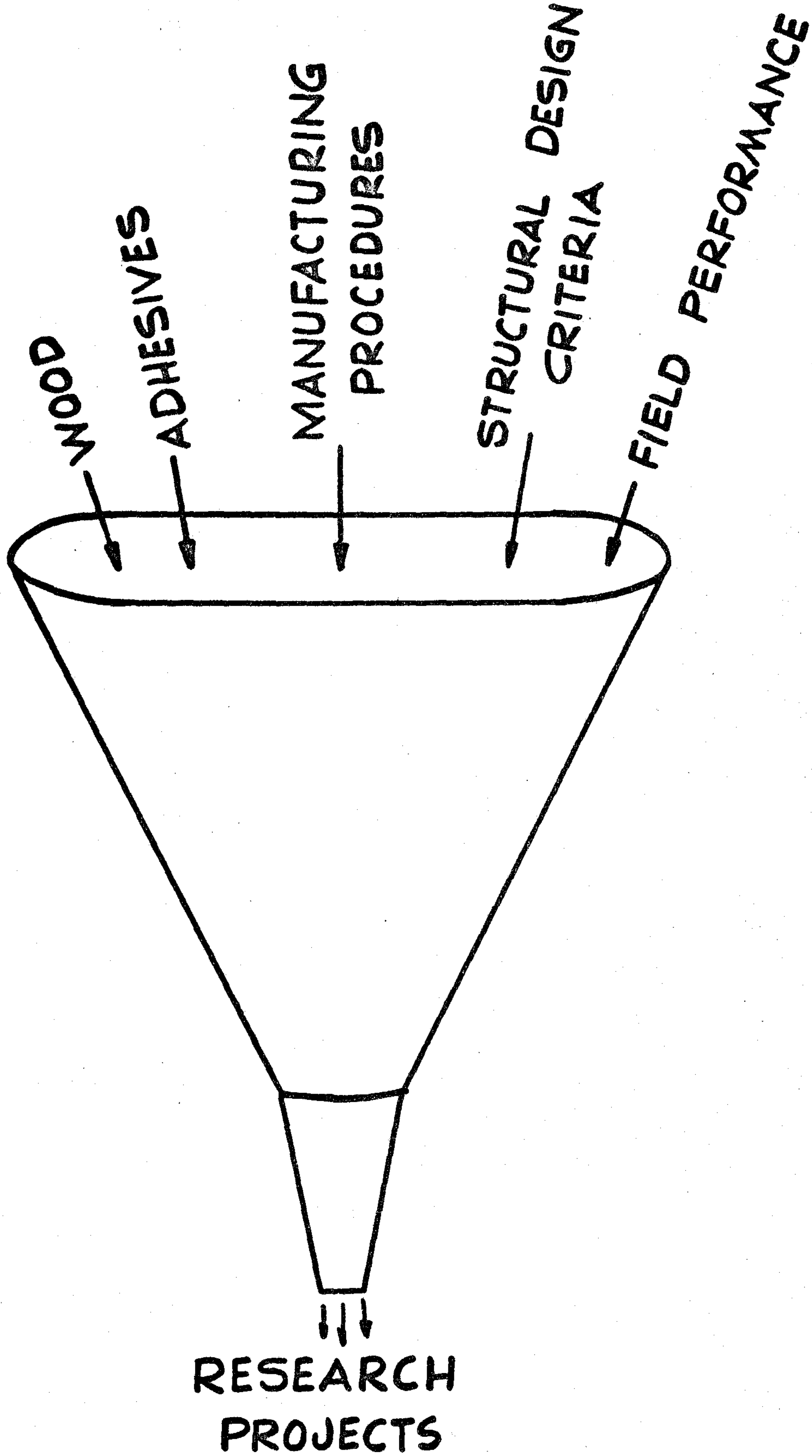

WOOD
ADHESIVES
MANUFACTURING PROCEDURES
STRUCTURAL DESIGN CRITERIA
FIELD PERFORMANCE
RESEARCH PROJECTS

Figure 1

It is readily apparent that a considerable portion of a piece of wood is occupied by voids of air space.

Different species of wood vary in weight, despite the fact that the density of wood substance is practically constant, about 1.5 for all species. Variations in the size of voids and in the thickness of the cell walls causes one species to have a higher specific gravity than another. It is my understanding the lightweight woods have thin-walled cells with large air spaces and dense woods have thick-walled cells with relatively small voids.

A general relationship of specific gravity to strength is that the higher the specific gravity, the stronger the wood. The strength in one property may vary as the 1-1/4 power of specific gravity. Other properties are related to specific gravity by equations of still higher powers.

Allowable unit stresses for structural laminating have been developed in accordance with principles in 1069. However, we are operating under U.S. Commercial Standard CS 253-63 still containing a provision which reads as follows:

> 4.2.6.2 As an interim action, pending modification of basic stress values as contained in Bulletin No. 1069, Douglas Fir from Eastern Oregon, Eastern Washington, Montana and that portion of Idaho north of the Snake River, shall have basic stress values for use in establishing glued laminated stresses as follows:

BASIC STRESSES FOR NORMAL LOADING

(Coast Region Douglas Fir)

	Dry Use	Wet Use
f & t	3,050 psi	2,400 psi
H	165 psi	145 psi
$C \perp$	385 psi	260 psi
$C \parallel$	2,200 psi	1,600 psi
E	1,800,000 psi	1,600,000 psi

You will remember the question yesterday concerning the length of time before the ASTM Sub-Committee D-17 of D-7 is expected to complete their work on basic clear wood strength values. This was directed primarily at settling their interim decision.

Wood nondestructive testing, in the form of mechanical stress grading, uses the relationship between modulus of elasticity and several strength properties.

Much of the future research in machine-rating of lumber will deal with the relationship between deflection and allowable tensile strength. This correlation is considerably more complex than relationships between deflection and bending strength. Wood density is involved in these studies.

It is expected that when these answers are available that nondestructive test methods will influence our product specifications, methods of use and markets, manufacturing processes and controls, utilization of raw material, and techniques for still further research on wood density and strength.

Yesterday I learned that should I decide to build a laminating plant in the Pacific Northwest that nearby there should be trees at least 90 years in age and the elevation of growth should be less than 4,000 feet. If building in the South, I should remember Mitchell's Law and go to the Southeast corner of any particular State. If I wanted to build in the Midwest or the Northeast I have no specific gravity studies to guide in plant location. The task is, therefore, far from complete; I wish to encourage those in the Lake States area in particular, who are in a position to move ahead wood density studies for the area, to do it without further delay.

Adhesive and Wood Density

A species is considered to be glued satisfactorily when the strength of the glued joint is approximately equal to the strength of the wood. Whether it will be easy or difficult to obtain a satisfactory glued joint depends primarily upon the density of the wood, even though it also depends upon the wood structure, the presence of extractives in the wood, and the kind of adhesive.

As a second interim action in U.S. Commercial Standard CS 253-63, we have:

> 5.2.2.3 As an interim action pending completion of current studies, melamine-urea combinations in which the melamine is 60% or more by weight of solid resin content shall be considered as meeting the chemical requirements of Paragraph 3.3 of MIL-A-397B or Paragraph 3.1 of MIL-A-5534A provided all other requirements of the specifications are met. However, these melamine-urea combinations shall not be used for hardwoods or woods chemically treated before or after gluing.

Since wood is such a good insulator and wood can be damaged by elevated temperatures, it follows that room temperature is the preferred method for adhesive curing in gluelines. Various kinds of equipment, to bring elevated temperatures to the glueline, is then not required.

It is agreed, however, that curing of the adhesive, under certain conditions, can be accelerated by the application of elevated temperatures to the gluelines. In marine laminating of oak, elevated temperature cures are needed to resist delamination under extreme service conditions in sea water, but Douglas fir and southern pine, and similar woods of lesser density, are successfully glued at room temperature with phenol-resorcinol resins.

Production and Quality Control Procedures and Wood Density

In 1963, the U.S. Department of Commerce published CS 253-63, the commercial standard "Structural Glued Laminated Timber," establishing quality criteria for glued laminated structural members, standard test methods, and certification criteria.

The individual wood species, largely due to density differences, are to the timber industry what alloys are to the metal industry. Different assembly times and curing conditions are needed dependent upon the species being glued. In the use of preservatively-treated lumber for certain service conditions and products, a whole new set of species-treatment-adhesive combinations exist to consider. Higher temperature, longer curing times, or modifications in adhesive formulations may then be required.

Physical tests on samples from daily production required by CS 253-63 are as follows:

1. Shear tests of gluelines at 12% M.C. must exceed certain minimum strength values and minimum average wood failure requirements. The sheared or broken surfaces must show at least 70% wood failure for Wet-Use adhesives with all species, and for Dry-Use adhesives with softwoods and non-dense hardwoods. Wood failures may be as low as 35% for Dry-Use adhesives with dense hardwoods. Shear strength values must exceed, for

Coast Region Douglas fir	1030 psi
Western hemlock	1050 psi
Southern pine	1180 psi
Western larch	1270 psi
White oak	1700 psi
Sugar maple	2100 psi

2. Cyclic delamination glueline tests must show levels of separation not exceeding 10% of the total end-grain glueline lengths on the test sample. For evaluation of each batch of Wet-Use adhesive before use in production, the criteria for performance is--

   Softwoods - Not more than 5% Delamination
   Hardwoods - Not more than 8% Delamination

The qualification test for end joints, whether the configuration be a plane slope or a finger, is a necked-down tension test where the straight-grained and clear specimens must meet the average specific gravity for the species as published in the Wood Handbook. The qualifying tension strength level is as follows:

1. The average ultimate load value must be 3.15 times the highest allowable bending or tension stress value for normal conditions of loading to be used in design with that end joint.

2. 95% of the test values must exceed 2.3625 times the highest allowable bending or tension value for normal conditions of loading to be used in design.

3. All test values must exceed 1.8 times the highest allowable bending or tension value for normal conditions of loading to be used in design.

Whether it be during qualification testing or in day-to-day production testing, species of similar gluing and strength characteristics can be grouped together and tests on the most difficult to glue and strongest wood species apply to all species in the groups. The primary guide referenced is the specific gravity of the wood.

Clamp pressures during assembly gluing must be a minimum of 100 psi and a maximum of 250 psi, with the lower end of this range for softwoods and the higher end for dense hardwoods. In no case shall the pressure exceed the compression perpendicular to grain allowable working stress of the particular species being glued.

Structural Design Criteria and Wood Density

The long-awaited first edition of the American Institute of Timber Construction "Timber Construction Manual" will be in print in 1965. Five years of industry-sponsored research and writing will have been used in preparing this two part book: Part I giving design and construction data, and Part II giving recommended design standards or specifications.

Design with wood utilizes the usual engineering formulas with additional consideration for the fact that wood is not a homogeneous material. For the curved members possible with glued laminated material, several considerations exist that are not present for solid-sawn material, such as end joints, bending to curvature, form and height of member, effect of shrinkage and swelling on shape of curved member, fastening designs in large cross-sections, and elastic stability of deep sections.

Field Performance

A product's problems are pointed out in its field performance. Many of our industry research projects are the direct result of products falling short in performance from that expected by customers or from what we desire.

Several of our AITC Research Committee projects are closely connected with the density of the species involved:

1. Size effects of bending members.
2. Testing and evaluating the strength of end joints.
3. Effects of notching and tapering.
4. Radial tension.
5. Arch design.
6. Shear under dynamic loading.

In glued laminated timber construction, the laminations are to be assembled so that the better grades are in the area most highly stressed. This may mean the assembly of the better grades in tension and compression on the outside tension and compression faces of a bending member. It may mean the same grade throughout the cross section for a tension or compression member. For short and heavily-loaded bending members or at member support points, material of the higher specific gravities with best shear strength potential must be properly located at the spot where shear stresses are the greatest.

Laminations can be arranged in accordance with the stiffness, density, appearance, or some other growth characteristic. By whatever method chosen, the arrangement must consider the task which the finished member is to perform.

The three successive issues of the FPRS Forest Products Journal, for September, October, and November of 1964, are heavily devoted to articles on structural wood, particularly glued laminated timber. This is wonderful--structural wood is a fertile field for research. I would like to call your attention, however, to a couple of points which I do not feel are covered adequately in these articles. I hope the authors will take these comments only as constructive criticism.

Beams were fabricated of No. 4 Common boards but slope of grain was limited to 1 in 12. These laminations were now hardly No. 4 Common boards.

The stiff laminations were to be placed on the outside, the limber or the less stiff ones on the inside. For crane runway beams, bridge stringers, and pitched and curved beams, this method of placement would be in error. Density and slope of grain--they go hand in hand. The highest density material would be worthless structurally unless consideration is given to lumber slope of grain.

Just recently an architect, well acquainted with wood in design, called my attention to the medicine bottle, clearly labeled "poison," but which children cannot read. He was very emphatic that AITC should remove all reference to concealed-type pipe hanger connections from its Standards for Timber Construction. Purlins on one of his projects had been supported at a mid-depth position at their ends with concealed pipe hangers and with horizontal shear stresses and compression perpendicular-to-grain stresses far exceeding the allowables. These had been a costly failure. AITC was being criticized, and I believe rightly so, for telling some of the story but not everything.

Also published in the Journal, but earlier than last Fall, was research on laminated members where the conclusion was reached that in curved beams with a particular species that as the laminations increased in thickness, the members became stronger. A study of the test data shows that as the laminations were selected for the members they actually increased in specific gravity for the thicker laminations and a higher strength could be expected due to wood density and not the greater lamination thickness.

Density is a most important criteria for strength. Use it independent of slope of grain and it means almost nothing in structural design. Use slope of grain or lamination thickness without consideration for wood density and we are equally going to arrive at erroneous conclusions.

The five slides which I will now show to you are further illustrations of the role of wood density in structural timber. Here are the authors and the titles of their papers or reports from which these curves were lifted.

1. Bohannan and Selbo
   "Evaluation of commercially made end joints in lumber by three test methods."

2. AAR Research Center Reports ER 26 and ER 52
   "Static and repeated load strength of full size Douglas Fir and Southern Pine glued laminated stringers."

3. Fred Werren
   "Research needed on tensile strength of wood."

4. P.L. Northcott, FPR Branch, Dept. of Forestry, Ottawa, Canada
   "Specific gravity influences wood bond durability"

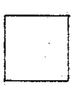
5. Pugent Sound Naval Shipyard - England & Stahl
   "Marine laminating properties of selected wood species."

No material combines in like degree the beauty, versatility, strength, durability, and workability of wood. It is a renewable resource unlike iron ore and oil, which, when gone, will be gone for good. More trees can always be grown; even today there is a favorable balance of growth to drain for many species.

Wood has a high strength-to-weight ratio, economy and flexibility, excellent appearance, low electrical and thermal conductance, resistance to the deteriorating action of many chemicals that are extremely corrosive to other materials, good performance at low temperatures and under short-time loading. It can be formed to almost any shape and size through laminating.

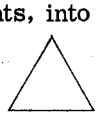
The versatility of glued laminated wood is such that the range of application brings all sorts of challenges and accompanying problems. In fact, these problems are primarily a result of the large sizes, variety of shapes, range of species, and our being without the ideal adhesive.

While searching to improve existing uses and to find new structural applications of wood, I found myself sketching the basic or elementary geometric shapes of figure 2. This meant the square, the triangle, and the circle.



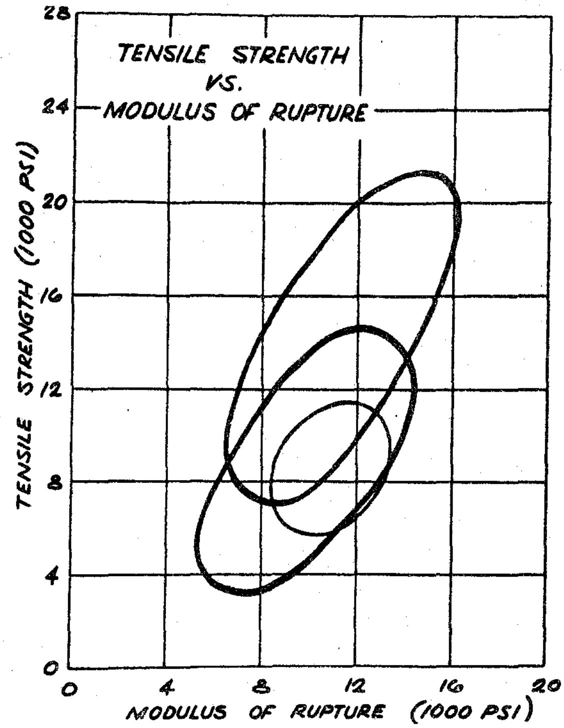
From the four corners of the square

From the four corners of this Country we funnel the several wood species, and the adhesives and the treatments, into our research problems.

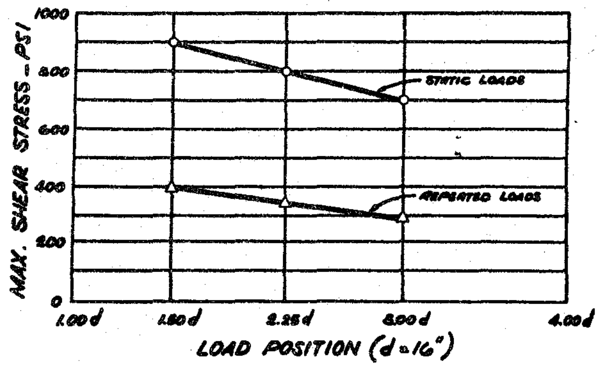


The perfect triangle

New product quality control is generally devised in close conjunction with actual development of the product itself. By the time a new product is ready for production, quality control procedures are well established by research personnel.

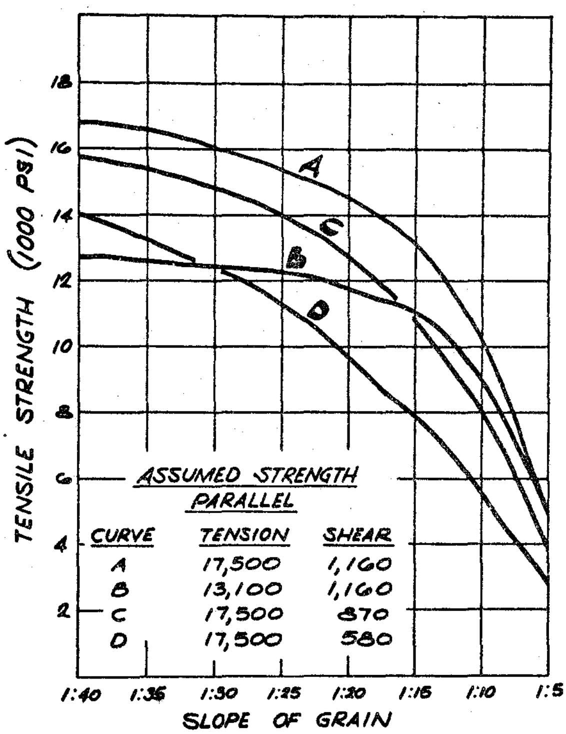


Slide 1

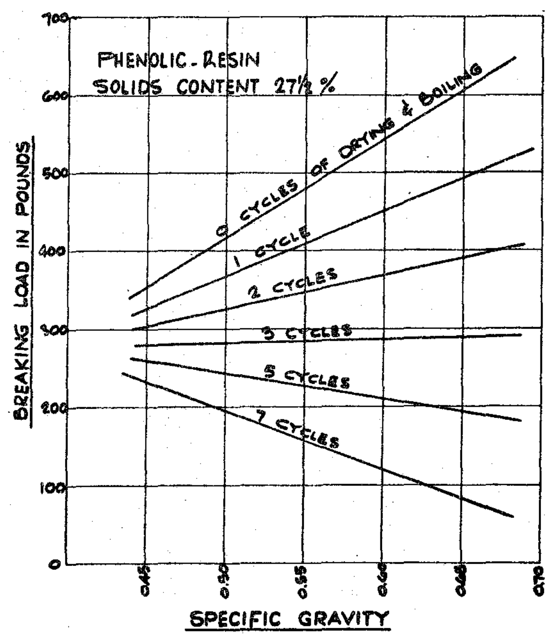


EFFECT OF LOAD POSITION ON STATIC & REPEATED LOAD SHEAR STRENGTH.

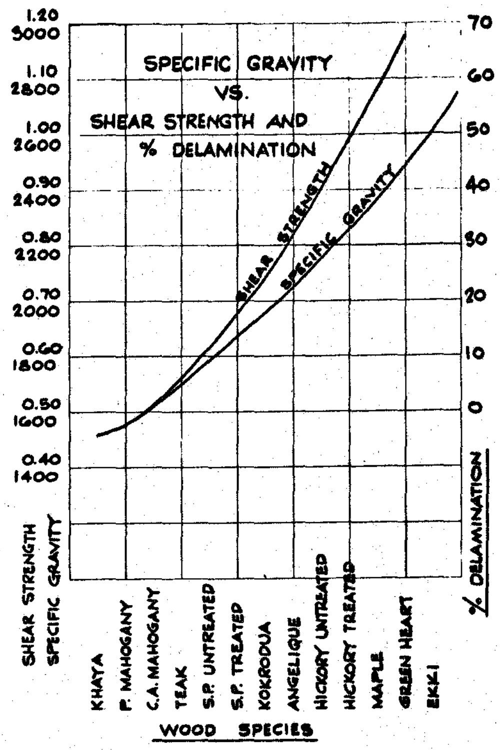
Slide 2



Slide 3



Slide 4



Slide 5

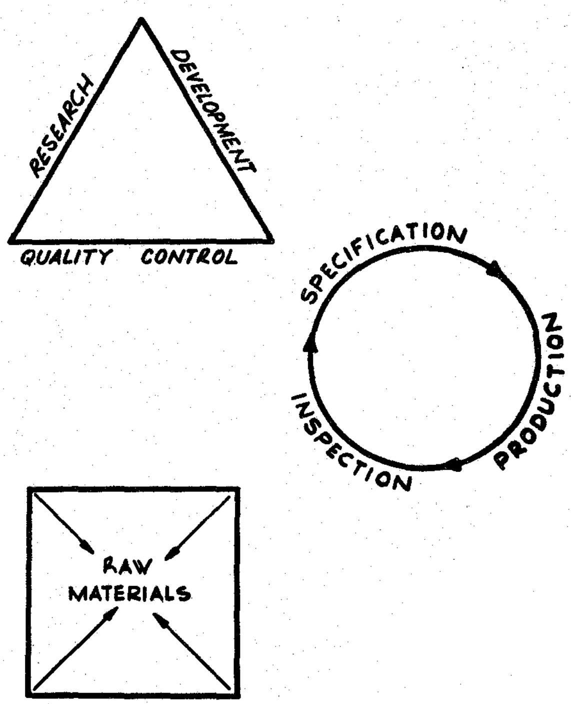
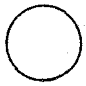


Figure 2

 Making ends meet, the circle

Samples of inspection data, when taken properly, yield valuable information about process and design. Specifications lead to production and it, in turn, leads us to inspection.

The several wood strength properties which determine its performance in use might be considered forces acting upon one of these elements or shapes. The density or specific gravity of the species is a reliable indicator of the resistance offered to the application of these forces shown in figure 3. We used R & D to counteract these forces, by test and experiment, to find new products of wood and to improve existing uses. As I sketched these shapes, I found myself looking upon them as both cross sections of wood members and as arrangements of wood members in structures.

The square or rectangle is not the cross section of the natural tree, but is by far the best cross section for a glued laminated member when we consider the raw material we must start with and our manufacturing equipment. On the other hand, the arrangement of four separate members into a square or rectangle is anything but a rigid structural system.

The triangular arrangement of members exists in truss construction or to provide rigidity in any building construction. As the cross-sectional shape of a wood member, the triangle leaves much to be desired.

The circle is the cross section of the natural tree. However, it is a cross section difficult to obtain in glued laminated timber. When used as an arrangement of members, the circle has many applications in structural framing. Glued laminated timber has a decided advantage over solid-sawn timber where shape is desire; gluing has therefore extended the use of wood.

Nature does not give us a hollow cross section in sound and growing trees. The tree-like grass, bamboo, comes the closest to providing a hollow cross section. The number of uses to which these plants are put is almost legend. It makes us wish we had the answer to growing hollow trees. Even with glued laminated timber, the tube or hollow cross section is not easily provided by the fabrication process.

Structural glued laminated timber is an opportunity to design structural elements that vary in cross section along their length in accordance with strength requirements. The product shown in figure 4, a Light Riser, came into being because of consideration for a shape and placing the material just where it is needed to do the job required.

The American Lutheran Church has a "Mission-Church-A-Month" program. Funds are solicited from the membership at large--this is beyond the building program of the local established congregation. Since such a high percentage of our structural glued laminated timber industry business involves church construction, I believe it appropriate to end my presentation by citing Isaiah 54:2 used by ALC to promote their church-a-month efforts:

> "Enlarge the place of your tent, and let the curtains of your habitation be stretched out; hold not back, lengthen your chords and strengthen your stakes."

If ropes are to be lengthened, stakes must be strengthened. Research on wood density--a key to wood quality--is one stake to a profitable growth in wood structures.

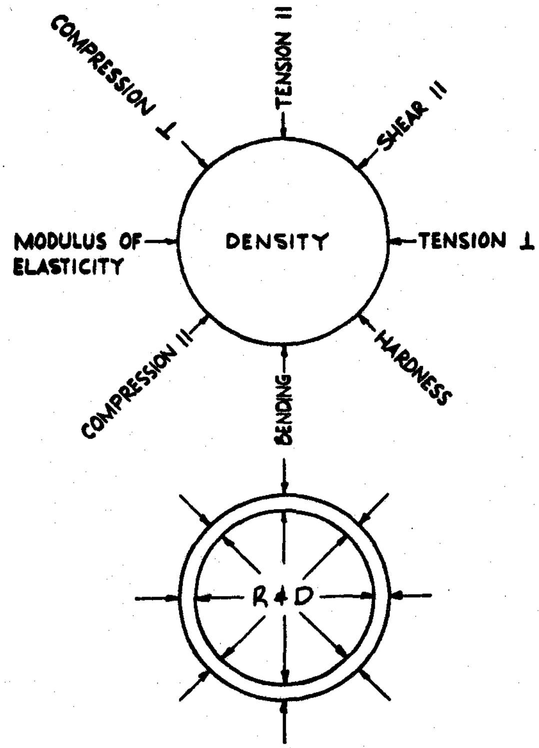


Figure 3

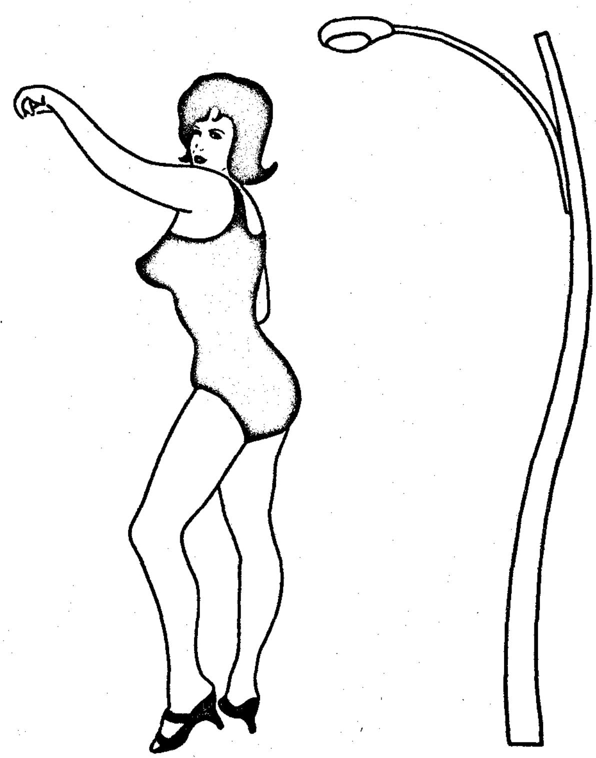


Figure 4

WOOD DENSITY DATA IN ASTM

By

LYMAN W. WOOD,[1] Project Leader
Structural Utilization
Division of Wood Engineering Research

Forest Products Laboratory, Forest Service
U.S. Department of Agriculture

Introduction

Previous speakers in this Symposium have referred to the American Society for Testing and Materials, and especially to its operations in connection with data from wood density surveys. I will deal with the Society in more general terms and will try to bring out the reasons for its interest in and need of the information that comes from density surveys and related data.

ASTM

The American Society for Testing and Materials is one of the older and larger standardizing groups, with a membership of nearly 15,000. It is international in scope, with members and officers from the United States and Canada, and members in Mexico and other countries. It operates mainly in the field of engineering standards. It provides a meeting place where a balanced group of producers and users of engineering materials can sit down together and arrive at mutually fair and acceptable standard test methods or specifications.

ASTM operates through some 100 technical committees, one of which is Committee D-7 on Wood, with about 150 members. The standards on wood under the jurisdiction of Committee D-7 include two that describe methods of arriving at working stresses for the engineering uses of lumber. One of these has been in existence for nearly 40 years and has complete acceptance by both producers and users of lumber.

Standards for stress-rated or engineered lumber have assumed new importance in the last decade or so with the increasing use of engineering design for light-frame construction. Joists and rafters, a major lumber use, are now specified as to allowable spans from strength and stiffness values that require stress ratings. Since the place of a grade or species of lumber in market competition with other grades or other materials is directly affected by the allowable spans, recent years have seen a sharp increase of interest in the ASTM standards for stress-rated lumber, especially on the part of the lumber producers.

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[1] Chairman, ASTM Committee D-7.

Why Density Information

Other speakers have brought out the relation of the strength and stiffness of clear wood to its density. A similar relation exists in structural lumber, though it may be obscured there by the presence of knots or other strength-reducing characteristics. However, clear-wood strength is an important consideration in developing working stresses for lumber because of the concept of basic stresses used in this and several other countries.

A basic stress is essentially a safe working stress for clear wood. It depends directly on clear-wood strength values, reduced to account for variability and other factors and to provide a suitable factor of safety. Details of these reduction factors need not be gone into here. The basic stress is a property of the species; it is unaffected by grade, and thus does not require reevaluation when grades are changed.

The strength ratio of a piece or a grade of lumber is the ratio of its strength to the strength of the clear wood of the species. It is determined from the size and location of knots or other strength-reducing characteristics that may be present. When the basic stress for a species is multiplied by the strength ratio for a grade, there is obtained a working stress for that grade of that species.

Basic stresses and strength ratios are established in ASTM D245-64T, "Tentative Methods for Establishing Structural Grades of Lumber." Since these enjoy wide acceptance, and have a direct effect on the marketing of stress-rated lumber such as joists and rafters, it is important that they be founded on the very best technical information available. Information on strength of clear wood comes from standard strength tests, now supplemented and refined by Phase IV analysis of wood density surveys in the West and the South. This, in brief, is why ASTM Committee D-7 is interested in the wood density surveys.

Operations in Committee D-7

Committee D-7 works through 17 subcommittees, of which the newest and one of the most important is Subcommittee XVII on Clear Wood. Subcommittees develop standards, which are then subject to approval by the main committee and by the Society. Subcommittee XVII has the responsibility to develop a standard on clear wood, to include (1) average or near-minimum clear-wood values for the commercial species or for regions within a species; (2) methods for arriving at combined values for groupings of species or of regions; and (3) factors to be considered in converting clear-wood values to basic stresses or working stresses.

Clear-wood values may be on the basis of the average for modulus of elasticity or of a near-minimum value such as the 5 percent exclusion level for other properties. The 5 percent exclusion level is a strength value such that 5 percent of the individual values, or 1 out of 20, fall below it. It may be necessary to have two tables, one for those species on which density surveys have been made, and the other for those species on which density surveys have not been made. The tables should include not only the woods grown in the United States, but also the woods grown in Canada and exported commercially to the United States.

Although the standard on clear wood will show how to arrive at strength values for combined species or regions, it is the responsibility of the industry to determine what combinations are appropriate for their producing and marketing conditions.

Committee D-7 has already several materials subcommittees including those on lumber, glued-laminated members, plywood, and round timbers. Each of these will develop the details of conversion of the strength values of clear wood from the Clear-Wood Subcommittee to basic stresses or working stresses for its particular product. In the instance of lumber, most of this work is done already, the results being shown in D245-64T.

This two-stage approach to working stresses for wood products recognizes that all such stresses depend upon the species clear-wood strength values, but that the application of those values will be different in the different products.

Committee operations to be effective must have the active support of a broad and balanced group of technically qualified persons. Committee D-7 is fortunate in this respect. The importance of stress ratings in the marketing of lumber has assured extensive support from producers. At the same time, general interest in lumber standards is high, and it has been possible to get consumer or general-interest members in numbers sufficient to maintain committee balance.

Present Status

A clear-wood standard as outlined above is now in draft in a task group of Subcommittee XVII. Work on the draft is continuing, and it is hoped to have something for consideration by the whole Subcommittee and the main committee at their next scheduled meeting in early November 1965.

Completion of a clear-wood standard will open the way for needed revisions in the basic stresses for lumber and for consideration by ASTM of working stresses for plywood or other wood products. Thus wood density surveys will have an early and important impact on the marketing of wood.

USE OF WOOD DENSITY DATA
BY THE SOUTHERN PINE PLYWOOD INDUSTRY

By

T. M. ORTH, Vice-President

The Kirby Lumber Corporation

I must confess that when my good friend, Harold Mitchell, commanded (and I use that word advisedly) that I participate in this Symposium, I accepted the assignment with something less than alacrity. I reminded him that, since I was neither a scientist nor a technical man, I was ill-equipped to address such an august group as this on any subject, much less the highly technical topic of density. Mitch, however, quickly swept that argument aside with the rejoinder that I was simply to tell the story, as I knew it, of how wood density data was used in the birth of the Southern Pine Plywood Industry. On that basis, I accepted, and you will note that my topic is, exactly, "Use of Wood Density Data by the Southern Pine Plywood Industry."

Now, I sincerely hope that I have made two points quite clear already. First, this is to be a narrative of actual events; and secondly, it is being told by an individual and not by a representative of any group, industry, or company. It is especially important that the latter point is understood, for there will be many, both in and out of this room, who will not agree with much of what I say today.

Now, as all of you well know, the birth of the Southern Pine Plywood Industry is a fait accompli. There are five plants in commercial production today, with two more to follow within a matter of weeks. Some of the experts are forecasting as many as 30 to 40 plants within the next few years! Indeed, this new industry came into being within the remarkably short period of less than 24 months, and its already fabulous history gives promise of growth in gigantic proportions. Without doubt, countless millions of dollars will be invested and literally thousands of new jobs will be created within the next few years. To those of us who were privileged to have been a part of this story from its very conception to fruition, it has been, upon retrospect, an exciting and enriching experience; but along the way there were a few of the painful pangs that frequently accompany the joys of birth.

For instance, there is a great deal of controversy now, as there has been from the very beginning, about the inclusion of a specific gravity, or density, requirement in CS 259-63, the U.S. Department of Commerce's Commercial Standard for Southern Pine Plywood. There are many, and I am one of that group, who feel that the requirement is arbitrary and unnecessary, and there are those who feel that it is necessary. In this highly controversial provision, then, lies the very heart of this story, so I propose to tell you how it came into being, and in so doing, I will automatically cover my assigned subject, "Use of Wood Density Data by the Southern Pine Plywood Industry."

Every story must have a beginning, and I hope you will forgive me if this one seems personal, but it must necessarily start with Kirby Lumber Corporation's actual plant production tests in a small hardwood veneer mill in Texas. By early 1962, the results of those mill tests, when coupled with our own feasibility studies, made the prospects appear so extremely encouraging that we obtained formal quotations from manufacturers of plywood equipment and made the final arrangements to send rail carloads of Southern Pine logs to a West Coast plywood plant where, for the first time, Southern Pine plywood could be made under the exacting conditions prevailing in a modern, high-speed, commercially successful Douglas Fir plywood plant.

Quite obviously, we had reached the point in time when matters of marketing the new product demanded primary attention. The most immediate facet of marketing, of course, was the need for a Commercial Standard. I am quite certain that Dr. Fleischer, who is sitting here today, can vividly recall our first phone conversation regarding the formal procedural guideline to be followed in the promulgation of Commercial Standards. While Commercial Standards CS 45-60 and CS 122-60 already existed for Douglas Fir and Western Softwoods, respectively, there was none, of course, applicable to Southern Pine.

Through Dr. Fleischer, arrangements were made for four interested firms to meet at the Forest Products Research Society's Mid-South Section Meeting in Hot Springs, Ark., in October of 1962. At that meeting, representatives from Olin-Mathieson, Potlatch Forests, Georgia Pacific, and Kirby Lumber Corporation met, in a "smoke-filled" motel room, and agreed to author, jointly, a new Commercial Standard specifically tailored for Southern Pine Plywood. At that very moment, I might add, Dr. Fleischer was delivering a paper at the FPRS meeting entitled "Southern Pine Plywood." This first organizational meeting was a fruitful one, indeed, and all four firms agreed to meet at the Forest Products Laboratory in Madison, Wis., on November 14 and 15, 1962, where we would review our first draft of the Standard with the Laboratory staff. In the interim, all of us were to exchange our thoughts, in order that the first draft would reflect the views of all to the maximum extent possible.

So, that was the beginning, but the wheels started to turn in earnest at the November 14-15 meeting in Madison. Although only one full-scale production test had been conducted at this point, the interest had reached a feverish pitch among the group that had now grown to five firms with the addition of a representative from Southern Pine Lumber Company.

We had decided, prior to the Madison meeting, to establish two overriding guidelines from the start. First and foremost, we wanted our new product produced under strict Commercial Standard provisions that would enable it to be marketed as an equal to Douglas Fir plywood in every respect. Secondly, we wanted our new Commercial Standard fast!

To those of us in the industry group, it was obvious that the Forest Products Laboratory represented the cornerstone of our program. Since the U.S. Department of Commerce, under whose auspices the Commercial Standard program is controlled, invariably looks to the Lab for technical approval in matters of this nature, we elected to secure the Lab's blessing before making our initial contact with Commerce. In this manner, we hoped to circumvent a considerable amount of the red tape and lost time normally encountered in "channels."

The Madison meeting convened on schedule the morning of November 14 and Dr. Locke had graciously assembled representatives from each and every division of his staff that would be involved in passing judgment upon our draft. It became readily apparent, from the outset, that everyone had done his homework; and the review progressed very smoothly, item by item, and section by section.

Then, immediately prior to the lunch break, the bomb exploded! Representatives of the Engineering Division calmly informed us that they could not, and would not, approve a Commercial Standard that would give us the same stiffness values that were assigned to Coastal Douglas Fir Plywood produced under CS 45-60. Their reasoning was based upon their assignment of lowered average modulus of elasticity values for the species of Shortleaf and Loblolly, two of the four Southern Pines.

Needless to say, this was a totally unexpected development, and, to say the very least, a very spirited discussion ensued. The five-man industry group argued mightily, cajoled and pleaded, but to no avail, as the Engineers stood fast.

I need not tell you that it was a blackly despondent group that headed for lunch that noon. Several of those assembled here today, including Ed Locke, Alan Freas, Herb Fleischer, John Lutz, Lyman Wood, and Ed Kuenzi were there, and I know they have a vivid recollection of that particular moment. There was good reason for our bleak outlook, for it appeared we were headed for a long drawn-out battle of the slide rules that could consume many precious months. We had already been informed, early in the game, that we could not hope to process a completely new Commercial Standard through federal channels in less than 2 years, and that 15 months had been the record time. We discussed our dilemma over lunch, and try as we might, we could only come up with two alternatives. First, we could accept the Lab's position and come out with a Commercial Standard similar to CS 122-60 for the Western Softwoods, which would require producing our plywood to a greater thickness than that of Coastal Douglas Fir; or secondly, we could fight the "slide rule battle," complete with tests, studies, analyses, etc., in the hope that we could eventually prove our conviction that our average stiffness values were the equal of Douglas Firs.

At this juncture, I remind you once again that everyone in our little industry group knew (as well as a few others it later developed) by now that the Kirby West Coast tests had been highly successful, and all of us were rushing ahead with our respective plant construction plans and feasibility studies. As for my own case, we had reached the stage in our planning that we only needed "reasonable assurance" of a Commercial Standard before asking our Board of Directors for the capital funds to proceed. In a word, we wanted to go, and go now--not later.

Under the circumstances, neither of the two alternatives were at all palatable. The first, a Standard similar to that for the Western Softwoods, would mean we would not have market equivalence to Douglas Fir; and the second, a long battle of the engineers, would consume precious "lead" time that could never be recovered from the competition that is certain to follow development of any new product.

I must confess, at this point, that there was even some discussion regarding the application of "political pressure" to force an "agonizing reappraisal" by the Lab. I am happy to say that the discussion was quite brief, and we have never followed, or for that matter, even seriously considered that always regrettable course of action. I mention it in passing, however, simply to reflect the depth of our desperation at that point.

Then, as we reconvened that afternoon at the Lab, a new approach occurred to me. Knowing of the Laboratory's work on the nationwide wood density studies, and particularly the work that had been conducted in Mississippi and Arkansas, I inquired if they had any final data compiled on the Southern Pines that would substantiate our contention for higher stiffness values. If such data were available, and if they reflected average specific gravity values higher than those historically assigned to the Southern Pines as a result of limited studies made years ago, perhaps our problem could be resolved.

The Engineers then pursued this tack and promised a quick determination of the average specific gravity figure that would be required to accomplish such an objective.

In the meantime, Dr. Locke called for Harold Mitchell, and that was the turning point. We asked Mitch if he had final statistics of this nature from the Mississippi and Arkansas studies, and he advised that while he did not, they were virtually complete and some answers could be obtained if he ran the computers around the clock.

Further discussions revealed that several interim analyses had been completed by Mr. Mitchell's staff, and it appeared that we were following the right track.

Then, before he could leave to start on his night-long task, I reminded Mitch that we were only interested in sawtimber sizes suitable for plywood production, and this would mean he could remove everything under 15" d.b.h. from his calculations. Furthermore, and of even greater importance, the center 5" of each log would be discarded as a core at the lathe and that portion should be excluded from his calculations. Quite obviously, we were asking for an almost impossible series of computer calculations, and not within a matter of months, but overnight. Nevertheless, Mitch accepted the challenge, and even promised an interim report the following day.

By then, the Engineers had completed their calculations, and advised that if face and back veneers of Loblolly and Shortleaf were obtained from logs having an average specific gravity of 0.50 or higher, our plywood would have stiffness characteristics comparable to Coastal Fir Plywood.

After the group had continued its review of the balance of the Standard with the Laboratory staff, Mr. Mitchell returned about 5:00 p.m. to advise us that his initial calculations led him to believe this specific gravity approach would satisfy our deficiencies and, as a matter of fact, it appeared that we might end up with even higher stiffness values than those assigned to Coastal Fir. With that interim report, the group adjourned for the night, leaving Mitch and his staff to their IBM companions. Needless to say, the mood of the group was somewhat different than that prevailing at noon.

The following day, just as he had promised, Mr. Mitchell delivered his report. He had developed results proving, conclusively, that we would average or exceed the 0.50 figure, and we would, therefore, be entitled to the same, or higher, modulus of elasticity value that was assigned to Coastal Fir.

Following a thorough review of Mr. Mitchell's analysis by the Engineers, they informed us that they would, if we so desired, give consideration to assigning higher stress values to our product than those assigned to Coastal Fir. We demurred, however, for we had, it was now clear, attained our goal of equivalence in the market place.

So, that is the full story of the 0.50 specific gravity limitation in CS 259-63, the present Commercial Standard for Southern Pine Plywood.

None of the original industry group felt that such a limitation was necessary, but we compromised. For that compromise, we have been criticized by many parties within the past few years.

Were we right, or were we wrong?

I think you can furnish the answer to that question from subsequent developments.

Within 3 weeks from the November 1962 meeting in Madison, we met in Washington, D.C., and presented the formal draft to the U.S. Department of Commerce. In January 1963, Commerce mailed it, designated as TS-5616, to the industry for comment. In March, 1963, the Industry Committee, still the original five members, met in Madison and made minor revisions to meet the few criticisms expressed by industry. On April 16, 1963, Commerce mailed the "Recommended" Standard, designated TS-5626, to the full "Acceptor" list throughout the nation. In late April, we met in Washington, D.C., with FHA and Commerce. In mid-June, we met in New Orleans and agreed to a few additional modifications which were submitted to Commerce. Then, on the glorious date of July 15, 1963, 9 months after the October 1962 meeting in Hot Springs, Ark., exactly 8 months after the November 1962 meeting in Madison, and only 7 months after our initial meeting with Commerce, it happened. On that date, we met in the halls of the U.S. Department of Commerce in Washington and listened to the Federal Government's announcement to the world that our Commercial Standard for Southern Pine Plywood had been approved and assigned the designation "CS 259-63," and it was to become effective November 15, 1963.

In 7 short months, we had accomplished the impossible, for we had more than shattered the earlier record of 15 months. We had a Standard that would put us in the market as the equal of Coastal Douglas Fir; we had a Standard our production people could live with; and, finally, we had a Standard that would be greeted with uniform acclaim in the market place because its nomenclature, grade names, specifications, and working stresses were virtually identical to those that were already in existence and in world-wide usage for western-produced softwood plywood.

How about today? Today there are five plants in commercial operation, producing millions of feet of Southern Pine Plywood that has been accepted and acclaimed in the market as few new products have ever been before. As a matter of fact, the first plant was in production within 2 years following our first contact with Commerce, and 2 years, we were told, was going to be required before we could even expect a Standard! Within 3 years from that initial contact, by December of 1965, there will be at least 10 plants in operation, and those 10 plants will be capable of producing almost one billion square feet of plywood. Within the next 2 years, there should be 30 plants in operation. Yes, it has been a fantastic explosion creating new sources of strength and wealth for the South and our entire nation.

I think, all things considered, that you will agree with me when I say that a wise choice was made in that compromise of 2-1/2 years ago, and I think you will agree with me that, with the gracious help of the Forest Products Laboratory, and Harold Mitchell especially, we put "Wood Density Data" to good use in the Southern Pine Plywood Industry.

Before closing, I want to say that our Standard has been revised from time to time since that original announcement of July 15, 1963, and still additional revisions will be made, for a Commercial Standard must be a living document. In the course of our short history, we are still learning, and we are asking a lot of questions that cannot be answered, for we are still breaking new ground. For example, we have recently discovered, in testing veneer for specific gravity, that the age-old and universally accepted volumetric shrinkage ratios for wood cannot be applied to veneer. We do not know why, but we know the slide rule figures and statistical equations simply do not work when you deal with veneer. This one discovery, alone, culminated from a very lengthy and costly study that was undertaken to avert an extremely dangerous rift that was forming within the entire plywood industry. Fortunately, the results conclusively proved that the textbooks were wrong, and the rift was averted.

So, if I have any message at all for you today, it is here somewhere. We do not know all the answers, and you scientists and technical people can reach some ill-founded conclusions that can result in long-lasting and damaging decisions within the industry if you do not maintain an open and questioning mind. Do not rely too heavily upon the increasingly popular and current rush to embrace statistical concepts and final conclusions that are necessarily fraught with interpolation and extrapolation. Let us not discard all historical concepts of the industry, simply for the sake of being statistically sophisticated or "modern." Let us take a long, hard look with an open and inquiring mind before accepting and espousing new values or new ideas. After all, we do live in a changing world, but a change is not always a good change just because it is a change.

WOOD QUALITY, PRESENT AND FUTURE, IN RELATION TO INDUSTRIAL USE

By

ROBERT J. SEIDL, Vice President

Simpson Timber Company

Just a few days ago I was reading a speech by William B. Reynolds, Vice President of Research for General Mills. He was concerned, as I am now, about what he called the "Monstrous Effrontery" of speaking to a learned group on a subject he was not sure he could handle. He described the situation as "somewhat akin to a novitiate addressing the National Association of Streetwalkers on the subject of sex."

Regardless of my qualifications, I am clearly delighted to be invited to share thoughts and experiences with people representing such a wide spectrum in this field.

Most people at this symposium are engaged in some phase of the intricate process of managing forest land, tending its crops, converting them to useful products, and dispensing the products through complex distribution, so this symposium should solicit our strong interest.

The topic assigned to me relates to needs and opportunities for industry in wood quality research. Trying to be analytical in my thinking for the program proved to be difficult, and I could not rationalize completely enough to provide peace of mind. I fell into a semantic jungle about wood "quality" and our objectives relating to the subject. If "density is the key to quality," (to repeat the conference theme) then quality can be viewed as the lock, which must be found before the key can be used. Frankly, I am not able to reconcile the generic use of "quality" with such things as density, surveys, log and tree grades. I was trapped in a tyranny of words. It is best that I expose my confusion and get on with the message.

There must be a better word than "quality" as a focal point for our thoughts, as the meaning of this word is much too elusive. I have read pages of definitions, and while the logic of most is reasonable, they certainly do not agree. I have a list of definitions which I will not repeat now, but if they are added to those already exposed here, we could provide about one definition per participant at this meeting. I will not attempt another, except to point out that, for my purpose, quality over a period of time is a changeable attribute that is characterized by a dynamic balance among intrinsic properties, economic value, and consumer satisfaction. This interpretation of quality colors my entire view and forces a distinction between an academic and a practical approach.

My interest in the subject of this meeting developed with my experience as a research scientist, and I have been consistently fascinated by the potential for tree improvement and growth increase through forest biology. I have also had a special interest in experiments that couple genetic improvement, fertilization, and systemic treatments with the micro testing of living trees. Under modern laboratory technics, these tests can be so highly revealing of the nature of a tree. Nothing that follows diminishes my view of the importance of this work. Yet, I have been asked to comment on the needs and potential for industry in wood quality, and these must reflect very strongly the effects of economic value and cost, now and in the future.

Because we have had so many good contributions on scientific research at this meeting, I hope you will forgive me if I assume a less scientific, but, hopefully, a practical approach to wood quality. I shall inject some flavor of crystal ball gazing, encouraged by a friend who said that "all we know about the future is that it won't be like the past, and it won't be like you think it is going to be, and change will occur at a faster and faster rate."

Let me begin with a few assumptions that might serve as planning premises as we move from the present to the future.

(1) The intrinsic quality of wood from mature forests as we have known them will not be available in any large volume.

(2) The mass regrowth of equivalent quality in a reasonable period of time and within tolerable economic limits will be very difficult or completely out of the question.

(3) The regrowth of a very large volume of wood substance of moderate quality is readily possible.

(4) The species and quality which can be developed will need to be utilized in a different manner.

(5) Raw materials, processes, and products will have much different relationship to each other.

(6) Maximum productivity from the land will become increasingly important, because of increasing costs of land, taxes, and operations.

(7) Any technological gain that can reduce cost, eliminate waste, or increase yield, is an absolute gain.

It is obviously important that we distinguish between the present and the future on the subject of wood quality. Broadly, the present deals with measurement of wood properties for products that exist today, while the future deals with growing wood for utilization and product patterns largely undetermined. What we cannot know of the future is more important than it used to be.

Considering the lexicon or vernacular of present basic forest products operations, we might hope for a sharper and more meaningful distinction between existing descriptions of logs and appraisal of the wood they contain. This need is emphasized by the increasing cost of wood. Obsolescence of the present system is implicit in the language of the trade. A "sawmill" log is bought by someone who wishes to make plywood. A "peeler" log is often bought for conversion to clear lumber. The increasingly important chip content is not named at all. We seem to ignore rather than classify that portion of a log not needed for one principal intended product. The so-called "wood log" is an orphan, but its common present use is for chips. A "shop" log crept into the language, apparently to accommodate one that can yield short but high quality pieces. Other logs are known as "pulp logs" or "peelable pulp logs" or "camp run logs." Other habits are equally quaint. We buy logs by units which, when cut, yield 1000 bd. ft. of lumber, and then look for something we call "overrun." We are completely accustomed to a 2x4 that is noticeably smaller than this dimension, and can sometimes reason that because it is "quality" wood it need not be carefully dried. Finally, since we do not know the strength of the piece, we generously sell all pieces large enough to permit designing structures for the weakest one in the pile. We can use the log measure to advantage if a high yield of chips is desired. We buy pulpwood by the cord or in volumetric units as chips for a pulp industry that operates on the basis of tons or weight. Certainly research on wood quality and technology is leading us to a more precise language, hopefully more independent of specific single products, or at least not so inflexible to changing conditions.

The above descriptions have served a useful purpose, but they are far from adequate. We can look to the future with a feeling of excitement that science and technology can be utilized more deeply to solve some of our oldest and most difficult problems.

We are now blessed with an enormous reservoir of standing timber, supporting a vast industry, which in general has gravitated toward concentrations of the raw material. We know something about the supply and expected demand, thanks to such work as the new report "Timber Trends in the United States." We also know considerable about properties of the wood species, thanks to years of patient research at the Forest Products Laboratory and elsewhere. We have at least rough agreement on future demand, although I believe that the habit of projection by extrapolation will have more pitfalls than it has had in the past.

There is no question that there has been decline in the traditional quality of timber in the form of larger trees and desired species. We have been cutting the best, most accessible trees, and "high grading" for many years has also reduced the quality of stock for reproduction. Parenthetically, the expression "high grading" has a poorer connotation than it deserves. It really describes the most economic utilization at a particular time. It was occurring when our forebears selected masts for ships from New England forests. It goes on now as we take what we need and leave minor species. It will continue until we are consuming everything we grow on an equilibrium basis. But there are compensating factors to this process. The high cost of old and large select logs has increased enough to stimulate utilization of much lower grade material, and to induce the public to accept and even like the products that result. Thus, the plywood industry continues spectacular growth predicated on what is now a broad base of acceptable trees. It was inevitable that small log plywood technology plus regrowth in the South should expand the plywood base even further. Under earlier standards for peeler logs, the plywood industry would long since have declined.

There is some validity to the thought that the pulp and paper industry was actually stimulated by a decline in tree quality as we have known it for the lumber industry, since it invited evolution to fiber processes. This can result in much higher additions to the value of wood before it is consumed, which in turn pays for forest management to improve volume and quality. With the new explosion in pulp capacity, the whole world looks to North America to be the dominant supplier of this valuable commodity.

It seems to me that even in dealing with present forests we are on the threshold of important and exciting developments for industry, and they stem from a combination of ingredients. One is organization that provides the mass of orderly data such as the cooperative density surveys. Another is the computer, which can digest data in prodigious volumes. This computer food includes data from tree and log grade studies, recovery, forest surveys, and the fine points of chemical and physical properties. When this knowledge is coupled with economics, we might unlock one of the brightest promises of all, which is to identify the best log for its intended product, and to provide the intelligence to direct it to the point of best advantage. For any given enterprise the determination of the technical fact in relation to economic fact by linear programming might well be a bigger advance in forestry than most foresters could ever achieve in the woods.

Experience along these lines invites interesting problems in more abstract analyses by means of the mathematical model. For example, the computer can be used to analyze the numerous factors that constitute intrinsic quality of wood, its location, and the quantity in which it exists. At any one time and place, the conversion processes are constant. Perhaps the problem can be "shaken down" by using the computer to describe conditions as they are, as a prelude to the more important problem of prediction. Following the linear programming approach, the mathematical model can be used to maximize values in selected conversion processes.

Control of masses of data therefore emerges as a first step toward determining the relationship between quality in a tree, present and future, and needs in conversion products. A pleasant aspect of this approach is that the sophisticated tools for such stimulating research are already here, inherited from research that had nothing much to do with wood.

Regarding the needs of industry, Alan Smith and others covered the benefits of the comprehensive wood density surveys. This is a fine example of what can be done to characterize a large geographical area, and point to practical use of the data in the present or near future. It provides orderly and useful limits on strength and density in relation to geography and species. I would like to acknowledge the splendid cooperation that took place between several units of the Forest Service and industry on this subject. This is a most important contribution to good use of the existing resource that must supply us for years to come. However, to answer the historic question "Exactly how strong is a piece of wood?" I expect the ultimate answer to come by means of a direct non-destructive test at low cost and not through density measurement. Regardless of tree quality, the penalty for non-uniformity of wood remains until eliminated by actual strength test. More important than finding the strongest boards is the ability to utilize both strong and weak boards in the most suitable places. When one considers shipping weights and product performance, for example, a direct benefit can sometimes be obtained by using lower density lumber in center plies of laminated beams, or as lumber for solid core panels, and for studs. Lower density, after all, can give lower shrinkages and lower stresses associated with moisture change. This question should be viewed in relation to the high strength-weight ratios obtained with plastic foams, aluminum, honeycomb, and other products aimed at the lumber markets.

Considering the present, then, we should exploit the improvement in raw material use and economics through the application of knowledge that was not available before the computer. Simultaneously, of course, we need the benefits of forestry research, coupled with comprehensive survey that provides a measure of the existing resource, which can meet quality standards of the moment. The studies of density are important because density is a good relative measure of biological response. There is an important and useful relationship between strength and density, and total mass of substance being grown is an absolute measure of material available for any use. Quite apart from what relationship density might have to quality, then, I hope I have made clear that I believe the comprehensive density and survey work to be very important to industry and science alike.

In terms of our daily projects the shades of change are gentle enough, but the future of which I speak is the time between tree planting and harvesting, which is a long measure in years. With the quickening pace of change, we will need a more sophisticated method for appraising, as they say, the futurity of present decisions.

Much of modern business management deals with planning and with any work as complicated as controlling quality of wood in future forests, proper planning certainly is critical. Two needs are controlling and deserve equal stature. They are economic intelligence and technical intelligence. We must avoid the trap of simple extrapolation to the future. I am reminded of a comment made by Ed Green, who is a very competent man on the subject of planning, and on the need for quality in planning. He says that poor planning is much worse than no planning, because "poor planning helps you make the wrong decision with a greater degree of assurance."

Foresters have an advantage over other professions since a long look ahead is second nature in forestry. If we can reconcile this historically patient view of the future to the modern crescendo of technological change, we have a good base for intelligent decision.

If we may view the existing forests as a reservoir for near-term uses, we might view the future forests as a supply that can be altered through forest biology or other technics. There could be easy agreement here, except that we must remember that future quality of wood has no safe meaning today. We must temper any large plans with the fact that we can know very little of future conversion processes and products against which quality might be balanced.

I am willing to base my plans on the concept of accelerated change of technology of wood use, and on what one can foresee in the use of wood in relation to non-wood products, which compete for the same markets. I ask you to consider the rate of change of technology in relation to the rate of tree growth, even if given genetic advance, free fertilizer, and the best sites. Think of what the computer alone has done in about 12 years of application! To challenge your thinking with this theme, I then offer the concept that technological change in the use of wood will outdistance in speed our ability to alter quality of wood as it grows. Stated another way, if we have wood in abundance, we can adapt technology to convert it to the needs of mankind. Wood in abundance at modest cost is more important to industry than the best wood in small quantity at high cost. I hope that in trying to understand the needs of industry you share my appreciation of the importance of economics.

A second theme which might be accepted (but could not be proven) is that economics will dominate the mass view of quality. The largest concentrations of raw material at the lowest cost and in the right location will create a standard of quality. For example, Douglas-fir and southern pine were anything but preferred quality wood for pulp when first used. Technical advances in pulping and bleaching made them only tolerable at the outset, but highly desirable later as the public became adjusted to the attributes of their economical products. The scientists may therefore now treat them as quality pulpwood and use their disciplines to improve quality further. Still another point is that the classification of logs and directing each to its optimum use via computer guidance, which I expect to be routine in the future, could overshadow costly efforts to grow exactly what we might like best.

These considerations all lead me to some seemingly paradoxical advice on what to grow in the future. It seems to me that, considering how much harvesting of nature's best trees has been done in history, and how much high-grading has occurred in most areas, the need for developing superior trees and wood will remain very strong. The need is indeed much too strong, considering the total effort likely to be put on the problem. Stated another way, the people who dedicate their lives to improved quality, stand improvement, genetic improvement or any of the tools that give us control over quality are far too few for the magnitude of the problem, and their efforts should be fully encouraged, supported, and expanded if possible.

Where quality falls short in trees, I expect technology to fill much of the vacuum. When the wood is not available in proper sizes, gluing will provide larger or more special sizes than we know today. When a young tree lacks durability, chemical treatment will give it this attribute. If it does not hold paint well, a plastic or an overlay surface will make up the deficiency. Wood will perform as well or better than before. When a special wood is very scarce, we will glue a paper-thin veneer to a surface to extend use, or use a printed paper which for practical purposes can eliminate need for that species as an appearance wood. In summary, we can use all of the top grade wood we can generate, and we will improvise to meet deficiencies, on the time schedule demanded by the raw material situation.

To put technological change in a proper time scope, you might reflect on the existing size of the pulp and paper industry and realize that there was no wood fiber at all used about 100 years ago. Who is to predict what kinds of wood we will need for what products in another 50 years, much less 100 years?

As I listened to others speak, I felt again that we might have more clear understanding by not fighting the word "quality." Why do we not use simpler relationships? For example:

(a) Density has a good relationship to strength for solid wood products, and

(b) Density has a good relationship to yield for fiber products.

Density is neither good nor bad, except in terms of use. Some woods are useful because of their low density. We should not like to ship high-density products where lower density is adequate. We should like high-density joists. For pulp, I agree with John Wollwage that the stiff cylindrical fibers in some high-density wood are not the quality we want for some papers, and a valid case can be made in favor of quality pulp that comes from low-density wood.

Low-density wood is not difficult to use if we have digester capacity, and dollars plus decision give digester capacity. Tons per acre, and not density, should dominate for pulp.

Density, therefore, is a key to strength in one case, and a key to yield in another. Its link to "quality" is a more obscure one to me.

I hope that I am not giving you an unpopular message or seeming to degrade the need for top grade trees and wood. However, products as we know them today, with random sizes, surface performance problems, and variability are destined to give way more and more to uniform products of the factory. In this transition, circumstance will force us to live with less favorable starting materials than are found in the old growth forests. However, I do not see how we can learn to live with less quantity.

I have been pressing the theme that wherever wood exists in quantity, in concentrated form, and at lowest cost, the force of technology will be applied to make useful products for the population. Again, this is not to say that what we plant is no longer critical. On the contrary, the nature of the industry that develops will depend very much on the wood species and its form. Since most changes in utilization come by evolution, and it is unlikely that lumber and plywood will become obsolete, it would seem logical enough to be growing material that will yield good form, as well as a large weight of material. To state a solid objective in one sentence, we should continually aspire to achieve the maximum volume and weight of wood in trees of good form on the minimum number of stems. This would favor the integration of solid lumber and fiber industries, which is much safer than to depend too heavily on fiber use alone in the future wood economy.

Another way to view the future would be in terms of total economic value contributed to mankind by the forest land, after all human effort has been totaled. One philosophy of this approach would be to apply the cost of any program, including interest charges for about 50 years, balanced against expected return. This might show the relative cost of growing the top grade presumed needed, as compared to the return from investment in technology to make equivalent products from lower grade wood.

If it were necessary to portray our whole objective in a single word, I would offer the word "balance." There are so many variables and uncertainties, not to mention that the efforts of all in our profession are rather feeble in relation to the staggering mass of land we would like to "mold to our hearts desires," as Omar Khayam said. We cannot afford to be either "volume-happy" or "quality-happy" to a point of extreme. We can nudge nature in a direction we believe to be helpful, but before committing too much resource to forced change, we should be certain that we need the end result.

I have suggested that astute planning is necessary, and I certainly believe that old guideposts for planning in the past are inadequate and even misleading. Accelerated technological change is given as a safe planning premise, and technology applied to use of wood substance will fill deficiencies in much less time then corrective action can occur in the forest.

Speaking for industry, it is essential that we have utmost respect for the relationships between quality needed and the cost of achieving it, which I describe as in dynamic balance. As an illustration, I suggest that we accept the view that high volumes of wood with modest cost and proper geography will actually create mass standards of quality.

While I recognize that quality of wood can be an intrinsic property, independent of cost in the academic view, it cannot be in the industrial view.

Finally, I would sincerely hope that my views on wood quality do not seem either harsh or impractical. They are intended only to help provide direction, and to cause us to be continually restless in probing exactly where we want to be in the time context needed to get there.

USE OF WOOD DENSITY DATA IN INDUSTRIAL FOREST MANAGEMENT

By

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For the past day and a half you have been discussing the progress made to date in the collection of wood density data, its implications, research, and use by specific segments of the wood using industry. Progress, we all agree, has been considerable. But like all other steps taken, each unknown which has been run down usually shows a collection of other variables, previously little recognized, which must in themselves be investigated.

However, as we move forward in the intensification of our efforts, so we must sophisticate our field procedures to meet the multiple needs of industry as well as those of an increasing population. To this must also be added the considerable pressures of competition for land use as we know it. The few remarks I have to make will be primarily focused on the South, for this is the basis of most of my professional experience. They will represent my thinking as well as excerpts from several of the publications now available. This is done for simplicity in presentation plus recognization of the broad approaches already in use in our region.

To present this matter I think it is important that first we evaluate the size of the area involved. The "Timber Trends in the United States," Resource Report 17, indicates 201,069,000 acres in commercial forest land in the South, 39.2 percent of the total land area in the region. Thirty-nine percent of this commercial forest land has a rated productivity of 85 cubic feet per acre per year or more and 85.6 percent, 50 cubic feet per acre per year or more. This is indicative of the growth potential.

But let us consider the ownership of these lands.

TABLE 1

	Acres	%Total
Total Federal	14,062,000	7.0%
State and Municipal	2,820,000	1.4%
Total Industry	37,422,000	18.6%
Farm	78,897,000	39.2%
Miscellaneous - Private	67,868,000	33.8%
TOTAL	201,069,000	100.0%

In our presentation we will be considering the 18.6 percent of the commercial forest land now owned by forest industries. This land has 22 percent of the South's growing stock and 25 percent of the South's sawtimber volume. It is one of the keys to answering the demands of today and the markets of tomorrow.

TABLE 2
COMMERCIAL FOREST LAND IN THE UNITED STATES BY PRODUCTIVITY CLASS JANUARY 1, 1963

Productivity Class	Total U.S.		South	
	Mil. Acres	%	Mil. Acres	%
120 Cu. Ft. or more	43	8.5%	16	8.0%
85 - 120 Cu. Ft.	117	22.9%	63	31.3%
50 - 85 Cu. Ft.	232	45.6%	93	46.3%
15 - 50 Cu. Ft.	117	23.0%	29	14.4%
All Classes	509	100.0%	201	100.0%

TABLE 3
COMMERCIAL FOREST LANDS IN THE SOUTH BY OWNERSHIP JAN. 1, 1965

	Thousands Acres	% South	National % Total
Federal			
National Forest	10,476	5.2%	19.%
Bureau Land Management	27	.0%	1.%
Bureau Indian Affairs	251	.1%	1.%
Other Federal	3,308	1.7%	1.%
	14,062	7.0%	22.%
State	2,164	1.1%	4.%
County & Municipal	656	0.3%	2.%
Forest Industries			
Pulp & Paper	21,614	10.8%	7.%
Lumber	12,551	6.2%	5.%
Other	3,257	1.6%	1.%
Total Industry	37,422	18.6%	13.%
Farm	78,897	39.2%	30.%
Miscellaneous Private	67,868	33.8%	29.%
All Ownership	201,069	100.0%	100.%

TABLE 4
OWNERSHIP OF GROWING STOCK AND SAWTIMBER
ON COMMERCIAL FOREST LANDS IN SOUTH

Type Owner	Growing Stock - January 1, 1963 Volume Mil. Cu. Ft.	South % Total	National % Total
National Forest	10,212	8%	37%
Other Public	4,046	3%	10%
Forest Industries	30,034	22%	15%
Farm & Miscellaneous	89,794	67%	38%
All Ownership	134,086	100%	100%

Type Owner	Sawtimber - January 1, 1963 Volume Mil. Bd. Ft.	South % Total	National % Total
National Forest	36,172	9%	46%
Other Public	12,958	3%	10%
Forest Industries	102,994	25%	16%
Farm & Miscellaneous	259,946	63%	28%
All Ownership	412,070	100%	100%

Much of the information we now have to work with is relatively recent and is being expanded and intensified daily as we proceed with our forest management decisions. The early work in Mississippi on the survey pointed out the extreme range of material we have available. It did much to awaken an already smoldering interest then springing up throughout the South. Many of you may recall the comparisons made on one of the longleaf pines located with a specific gravity of 0.748 at breast height, a net cubic volume of 16.2 cubic feet at age 34, and an estimated dry weight of 607 pounds. This tree was estimated at twice that of the average tree same age and about equal to average tree twice its age (5).

"Plus" trees such as the one mentioned above are being located by foresters in a whole range of projects throughout the South. This effort to preserve and perpetuate outstanding examples of the various southern yellow pines was best illustrated with sale this year by Georgia Forestry Commission of seedlings produced from seed from their seed orchard program. This is but an early milestone in a basic step of the program. Seed orchards made up of locally selected trees now stretch from Texas to Virginia. Each year finds a broader base of selected trees, larger acreage under intense development, and more trees coming into cone production.

In the above program density is one of the several items used on the check list for rating the individual tree. Its relative weight in rating depends on the objectives as determined by the company or agency. The other factors include height, diameter, form, crown shape, branch habit, and others, to name but a few.

To bridge the gap in time, seed production areas are being used. Here form, size, cone bearing capacity, and other factors are used. Density could well be included with field techniques now available. All this is aimed at better planting stock or seed by pre-selecting; a standard practice in agriculture for years.

Why this emphasis at this time? The answer lies in the large scale regeneration effort plus harvesting methods now in use or being considered. It reflects efforts now to grow for the future a crop suitable for maximum use in the primary products being considered. Above-average material has always given a better return in the open market place if all factors of size, time, volume, and value are considered. It offers one of the possibilities in meeting rising fixed costs.

The early geographic seed source study pointed to opportunities and pitfalls. Here the differences in loblolly pine from four sources, Louisiana, Texas, Arkansas, and Georgia were demonstrated for a part of Louisiana. Production figures ranged from a mean annual increment of 181.8 cubic feet (peeled wood) for the local stock to 35.7 cubic feet for Arkansas stock. This study also pinpointed the need for continued testing and re-evaluation of designed field tests as conclusions based on the first 10 or even 20 years of provenance tests may be premature.

Slash pine, which has been relatively uniform in geographic seed source tests, was reported by Larson (3) as having a strong correlation between the percentage of summerwood and specific gravity--accounting for about 60 percent of the total variation. Here also was reported "summer precipitation percent" as the best single variable for accounting for differences in summerwood percentages increased by plot location from north to south and from west to east. This trend also was noted and graphed on the Mississippi survey by species.

We have discussed but three of the commercially important yellow pines. To our consideration should be added shortleaf pine, spruce pine, Virginia pine, and others, depending on locality and site. Thus, if location is already determined (1st choice), then the second choice is that of what species to grow.

Work is rapidly intensifying in soils. Many organizations are mapping forest properties to determine their soil productive capacity as related to individual tree species. This may be by blocks, plots, or drainage areas, depending on use being made of the data. Report D1751 (2) states that "maintenance of forest soil conditions that will promote the retention of water, and thus make it continually available to the trees, will result not only in greater growth increment but also in the production of heavier and stronger wood than that which is obtained when soil moisture is lacking." This water-holding capacity is one of the factors along with topography, texture, fertility, and others being investigated.

After species and soil the next selection is one of spacing between trees. Spacings are determined by considerations of survival, thinnings, primary product, and rotation age for size of product grown, or based on a consideration of growth per acre and total volume yield. More recently consideration is being given methods of harvesting X years in the future.

These are all interlocking factors and are given proportionate weight depending on the primary products being grown by a particular company. We are all familar with the extremes which are found in natural stands. They range from too thick to too thin and from outstanding dominant trees to those dying from suppression.

This then becomes a problem of growing space for individual trees. When we adjust our thinking to a per tree-basis, and use it as a building block to per acre, per section, per-compartment, our job is somewhat easier. It would be even easier if our work on site carrying capacity, the requirements for optimum growth by species, and the physiology of tree processes were better known.

However with individual tree crown development as a visible indication of the relative use being made of sunlight, soil moisture, and nutrients, a base is available for decisions on cut or leave. This may be a decision made several times in the case of thinnings, made only 2 or 3 times as in shelter-wood, or perhaps once in harvest cut with seed trees. I believe that the point to be remembered is that within the framework of the long range plan, many intermediate decisions are made with each bearing on the quality and quantity of the end product.

The product to be produced on a given block, after site and species is detemined, has a direct bearing on size of tree for economical harvesting. In size we have the midpoint for equipment combinations. Size may be expressed in its dimensions--diameter and height or age. It is the second form most commonly used. From it are calculated average returns based on average stem counts of average dimensions. In recent years another measurement is coming into use, cubic feet. As the common denominator for all products, it has the advantage of a uniform measure of usable content and puts price differential of product as a criteria for determining how much goes where.

If we use cubic foot content as a base, then the next choice, if each tree goes to its highest economic use, is whole trees vs. parts of trees, logs, or bolts. Based on available wood supply and replacement cost, a whole range of combinations spring up--tree length, double length logs, single logs, sorted tops, woods run, etc. This then is a point of decision and judgment. In the long run, what combination is best at that given moment to serve management objectives? Actually this is one of the difficult decisions because it calls for understanding of the product needs of a whole range of plant processes.

As many of you know, weight is used at many locations for the buying and selling of pulpwood. Through its wide use, a large spectrum of data is being accumulated as to content, solid wood, percent bark, and variations by species if any. More recently in the South, sawtimber is being bought or sold on a weight conversion basis. Applications vary depending on log scale in use, type logging, (tree length vs. log multiples) and corrections for trim and cull. However, all reports indicate complete satisfaction by both buyer and seller, and scaling differences by check scale well below 1/4 percent on volumes over 200 M. board feet. This gives both parties an unbiased, uniform base for negotiations on price. I know some of you will question this, but remember cull in second growth southern yellow pine is a minor quantity.

Up to this point we have discussed regional location, summer rainfall, density, regeneration, yields, production mix, and scaling by weight. One last variable remains. What happens to the wood in processing? Suppose wood of a higher density or yield, quality, form, ring count, or knot size is produced. What percent is it of the mill's comsumption? (By mill I mean a manufacturing facility.) Is it 50-50, 60-40, 80-20; the shear ratio is point one. Secondly, is it processed separately and blended at a later point or is it random mix?

If I had a suggestion to offer, it would be that through complete exchange of ideas and objectives within an organization would come step-by-step answers to certain unknowns. We really know a little more about wood and are able to produce a more uniform end product than our competitors give us credit for.

Lastly, remembering the minor ownership (15 percent of the growing stock) industry represents, it carries a responsibility that by demonstration and example we in industry lead the way for farmers and other private ownerships (38 percent) to follow. Known variables exposed to research can and will become the stepping stones for progress in the forests. Decisions made in the forest have an impact measured usually in decades, not years.

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THE NEED FOR MORE MEANINGFUL INFORMATION ON THE QUALITY OF HARDWOODS

By

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This symposium is concerned almost exclusively with softwoods, and more specifically with the measurement of softwood quality through information on its specific gravity. The purpose of the meeting and the objectives are good and it is not my aim to detract from them in any way. I have been given the opportunity, however, to crack the door a little with regard to hardwoods.

First, let me remind you that hardwoods are important to our national economy and constitute a major part of our forest resource. In the United States, hardwood types cover about 53 percent of the area of our commercial forest land, with softwood types covering 47 percent. In the eastern part of the Nation, there are more than two acres of hardwoods for every acre of softwoods.

If we look at the volume of timber on the land, however, 66 percent is softwood and 34 percent is hardwood. Furthermore, our domestic roundwood timber production is 70 percent softwood as against 30 percent hardwood. The high ratio of softwood production has not always been and it is not likely to remain this way in the future. As we put our forests in order, I expect that we will see a more even balance between production and consumption of softwoods and hardwoods.

This audience need not be reminded that we have witnessed a drastic deterioration in the quality of our hardwood forests. The reasons could be the subject matter for a paper longer than the one I am presenting, so I will merely recognize the fact and not discuss the cause. My object is to stimulate your thinking on the components that go to make up quality in hardwoods and the ways and means of measuring them.

It is my opinion that wood from hardwood trees is the most versatile raw material known to man. Its major components are cells with a wide variety of structure from long fibers to brick-like parenchyma and stacked cellular tubes. The cells are primarily cellulose, making up about two-thirds of the material, bonded with lignin making up about one-fourth. The remainder of wood is made up of a variety of chemical extractives varying from maple syrup to medicinals and oils. The bark of a tree is entirely different in structure, varying from a corky substance to a stringy fibrous material.

Because the wood from hardwoods is so variable, within trees and between trees, within species and between species, there is no single measure of quality; in fact, there can be no general measure of quality. Whereas softwoods are used primarily for structural purposes in which strength is a major factor, hardwoods are more often used for products in which strength is of minor importance. Thus, we must look at many properties in hardwoods to determine quality, and we must recognize that quality is determined by the needs of the final product. May I elaborate on this point?

Many people would like to measure quality of hardwoods by its specific gravity, but this will not suffice. High specific gravity generally means high strength properties, but if you examine this premise closely you will find that it does not hold true with all strength properties. Fiber bond, cell structure, and cell orientation may be more important. Take a picker stick in a textile mill for example. This stick, fastened on each side of a loom, knocks a shuttle back and forth from 150 to 300 times a minute. It must have a high strength and also resilience and toughness plus other properties not fully understood. Hickory, with a high specific gravity, has what it takes, and you might deduce that specific gravity is the clue to quality in this case. However, oak or birch or osage-orange with equally high specific gravity will fail miserably for this product. Look at an archery bow that demands fairly high specific gravity and what archers call cast--the ability to impart energy to an arrow as it is released. Hickory, with a high specific gravity, has a low cast and makes a poor bow, but osage-orange, Pacific yew, and tropical lemonwood produce a high cast and make a better bow at an even lower specific gravity.

High specific gravity of hardwood produces a high yield of pulp fiber, but the paper produced may not have suitable characteristics of tear strength, opacity, printability, or other desirable traits.

No, specific gravity is <u>not</u> the answer to a gross measurement of hardwood quality, but it is an important factor which cannot be ignored.

What about fiber length, fiber angle, amount of parenchyma cells, size of vessels, amount and kind of extractives, color, amount of heartwood, growth rate, presence of abnormal wood, and even the chemistry of the wood components? All these play an important part in some products, but none of them furnish a common denominator for measuring hardwood quality.

Since furniture consumes a good proportion of our hardwoods, what are the standards of quality required by the furniture industry? I have talked with many furniture manufacturers about this and came up with answers almost as varied as the wood itself. One manufacturer wants clear lumber to permit long clear cuttings, another wants a wood with good sanding properties, another wants wood that machines easily, and still another puts a premium on color uniformity or grain characteristics. All of them are looking for stability and freedom from warp. Tupelo gum is desirable for solid exposed parts like table legs because it can be stained and finished to resemble the more costly woods. Old-growth yellow-poplar is desired because it is easy to work and relatively free of warping characteristics, but second fast-growth yellow-poplar is hard and horny and gives considerable difficulty. Many furniture manufacturers purchase costly clear lumber and sand it to a smooth finish, only to mar it with cinders and flyspeck it with black paint to acquire character markings. Others relish natural character markings of bird peck, small knots, and curly grain. As I have insisted before, there is no single answer and we must start with the desired characteristics of the finished product and work backwards to the specifications of the wood needed.

How then can we make a decision in the forest as to what kind of wood quality to strive for in hardwoods, or how can we measure the quality of the trees that we have? These are questions that perplex most foresters today and many are seeking answers. We would like to be able to sample hardwood trees in our National Forest Survey to determine quality, but the best we have been able to do so far is to try to grade the logs in the standing trees to give an indication of the factory lumber grades that might be produced. This is a poor excuse for the needs of modern forestry. The geneticists are asking us embarrassing questions about the kinds of hardwoods we should breed for the future. The silviculturists are asking us equally embarrassing questions about cut and leave problems in hardwood stands. The industries using wood are asking better guides to purchase wood for their product.

The answers to these questions are not available, nor can they be obtained this year or next year. It will take time and money and much patient research, but the job is not insurmountable.

We know that the laws of nature are infallible; when there is a difference showing up in two pieces of wood, there is a good sound reason behind this difference. There is no hocus-pocus or mystery back of the things that make quality in wood. These are measurable things if we can only develop the knowledge, skill, and tools to measure them.

The Forest Products Laboratory has been the fountainhead for the measurement of wood properties, and the Wood Handbook is the Bible. Do you realize, however, when you take a factor for a strength property out of the Wood Handbook, it represents the average of many tests, and any individual piece of wood of the same species may vary greatly from that average? You may recognize this, but we don't know why these variations occur, nor can we predict them. It is high time that we delve into this problem and establish the fundamental background that will permit us to measure the intrinsic quality of the material that we are working with.

The job is too big and the unknowns are too great to apply the shotgun technique. We must point a rifle at a specific segment of this problem; in fact, we must point a battery of rifles at the same target to be sure that we make a start towards winning the battle. The Government researchers, the university researchers, and the industry researchers should join forces in making a breakthrough on determining quality in hardwoods. I have an expensive plan to propose to you to get the job under way.

First, I believe our rifles should point at one hardwood species until we can develop our techniques. This species should be one that has a wide geographic range, a wide variety of properties, and a wide use for various products. You may have already guessed that I nominate hickory, but I hasten to add that it could be one of a dozen other species. I nominate hickory because:

1. It is used for an extreme variety of products from the very restrictive requirements of picker sticks, skis, and handles to modern furniture.

2. It is a wood of wide extremes from very high to a relatively low specific gravity, from fast to slow growth, and a wood with widely varying properties.

3. It is an important hardwood peculiar to eastern North America and it commands a place of importance in our forests.

4. It is one of the least understood of our hardwoods.

5. It is relatively free of disease and danger of extermination.

I propose that we approach the problem of understanding the quality of hickory by combining the skills of our engineers, anatomists, chemists, and wood technologists.

We should select a sizable number of hickory trees throughout its natural range, and these trees should have widely varying characteristics as well as we can now define them. We should break these trees down in disks and bolts from stemwood and limbwood. The anatomists should use all their skills in determining the cellular characteristics of the disks. The chemists should join in to develop full information on chemical variations and extractives. The engineers should develop as much information as possible on the properties of the wood from the bolts between the disks. This should be done for limbwood as well as stemwood.

Next, we need to determine the correlations between the physical properties and the cellular and chemical structure of individual trees and determine the reasons for the variations in properties. This should lead us to the reasons why we have variations within trees and between trees. It should give us the clues as to the wood structure we need to measure quality for various products.

The wood technologists have the responsibility for studying the many products produced from hickory and ascertaining the combination of properties required for each of the products now in use and the potential products from the species.

Why did I suggest that we also study limbwood? Well, we have found that one of the best ways to lower quality and to promote disease in hardwoods is to extract increment cores. Furthermore, an increment core is not large enough to permit machining tests, strength tests, and other measurements requiring more than a pencil-sized piece of wood across the grain. Therefore, we need a sampling technique to use to apply the information we develop on quality in hardwoods. It is my belief that the things that make for quality in hardwoods are strongly hereditary. I also believe that there is a strong relationship between stemwood and limbwood of an individual tree and that we may be smart enough to establish a strong enough correlation between limbwood and stemwood so that we can devise a simple sampling technique of using limbwood; this will not do permanent damage to the quality of the tree sampled.

Once we have identified and classified the characteristics of wood that produce the desired properties of the many hardwood products, we can then devise a method for estimating these characteristics in a standing tree, a log, or a board. We can determine the quantity of different products required today and we can project our future needs with some degree of accuracy. Only then can we give the answers necessary to guide the forester in producing our future quality requirements and some idea of the quantities of each type of wood he should attempt to produce. We may well tell him to slow down the growth rates of some species and speed up the growth rates of others. We may guide him in breeding trees for grain characteristics rather than volume. We will probably ask him to produce a variety of characteristics for each species. In other words, the forester should begin growing trees for intended products rather than asking the manufacturers to develop products to fit the wood available.

You may not agree with my choice of species or some of the techniques that I have suggested, but I do not believe you can deny that we must take a bold approach to studying quality in hardwoods if we are going to make any progress.

I can imagine that the beginning of our search for nuclear power or the launching of our space program must have seemed insurmountable to the few who first attempted to secure the funds and manpower to start these research programs. Our problem should not be nearly so difficult or so expensive, but it must be started now and with a great effort if we are to measure hardwood quality with any precision in our lifetime.

FRAMEWORK OF QUALITATIVE RELATIONSHIPS IN WOOD UTILIZATION[1]

By

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The wide variability in the wood characteristics of our forests and the need to improve the quality of timber resulted in considerable thought and discussion on timber quality during the past decade. Although numerous articles were written on the subject during that period, it was not until May 1957 that a concentrated effort was made by the U.S. Forest Service to analyze the situation. At that time, 45 presentations were made by Forest Service personnel at the Forest Products Laboratory on many phases of timber quality. A review of these unpublished papers and other articles reveals a diversity of opinion on the concept of timber quality and the means of improving it. As a result of this conference and one held in 1961, the Forest Service proposed that an analysis of the research needs of timber quality be made.

The interest in timber quality is not limited to the Forest Service, but is the common property of all concerned with the growing, marketing, and utilizing trees.

The results of this analysis, then, should have universal appeal and it is hoped that they may serve as a guide in formulating plans and cooperation.

Background

The concept of timber quality is not new. John Evelyn had an insight of it in 1664 when he wrote in Sylva: "Every person who can measure timber thinks himself qualified to value standing trees; but such men are often deceived in their estimates. It is the perfect knowledge of the application of the different shape trees that enables a man to be correct in his valuation. A foot of wood may be of little value to one trade, but of great value to another. This is the grand secret which enriches the purchasers of standing timber." In other words, Evelyn was considering the requirements of the end use in evaluating the timber.

[1]Condensation of a more comprehensive report on the technical aspects of timber quality to be published later. The author wishes to acknowledge the assistance and guidance of Charles Lockhard, whose interest helped to make this report possible as well as the helpful comments and suggestions from personnel of the U.S. Forest Experiment Stations and the Regional Offices.

While many undoubtedly expressed opinions on timber quality since Evelyn's time, it wasn't until 1927 that Leopold stated that the objective of products research was to enhance the quality by: (1) controlling the properties of the wood grown through manipulation of the growth processes, (2) sorting the material to segregate the properties required in each use, and (3) modifying the properties where sorting is not sufficient.

Herman, in 1940, stated that our knowledge of the required properties of lumber for familiar uses is incomplete. At that time Ericksen commented, "Mr. Herman's emphasis of the need for analyzing use requirements and attempting to correlate properties of wood to them brings out a point frequently overlooked in approaching utilization problems." This is a refinement of Evelyn's concept, and is the basis for the modern definition of timber quality proposed by Mitchell. That is, timber quality is that combination of physical and chemical characteristics of a tree or its parts that permit the best utilization of the wood for the intended use.

The physical characteristics may be divided into anatomical, structural, and aesthetic characteristics if one chooses to do so. In this definition, the intrinsic quality of the wood is evaluated solely in terms of its suitability for various products or end uses. This concept, which is generally accepted worldwide, is not an attempt towards an all-inclusive unambiguous and completely satisfactory definition to all persons for all purposes. Instead it provides a useful basis on which to analyze and evaluate the technological aspects of quality involved with the utilization of forest timber.

The outstanding needs for a program of timber quality research were suggested by Lockard. These were:

1. Preparation of a list of the specific chemical, physical, and other characteristics which affect the suitability of a wood for its several uses under current technology.

2. Preparation of a list of individual end uses with similar wood performance requirements.

3. Preparation of a list of wood and tree characteristics affecting use suitability.

Lockard saw the need to classify and organize the end-use requirements of the various products and then relate these to the tree characteristics before we could follow through on Leopold's proposal of sorting the material for alternate products. Others also have stressed the importance of determining the end-use requirements.

Aspects of Timber Quality

Two aspects should be considered in timber quality research. One is to find better methods of identifying quality characteristics that can be used in grading and sorting for the materials for present markets, and the other is growing trees tailored for future use. In both, the end-use requirements of the wood should be known. An understanding of both aspects depends upon: (1) the definition of timber quality, (2) the factors that influence it, (3) the recognition of these factors, and (4) the evaluation of their qualitative effect.

Although the end-use requirements of the product are of primary importance, the processing requirements should also be considered. This inclusion does not conflict with the accepted definition of timber quality, since good machining, for example, is essential for the best utilization of wood for some uses.

To illustrate the concept of timber quality more clearly, let us consider the elements that affect it. These are shown in figure 1 as satellites orbiting around the central nucleus which represents the product or end use. According to the accepted definition of timber quality, the wood for specific end uses possesses those attributes which make it suitable for those uses. Each of the elements may influence or affect the wood characteristics.

Starting with environment, it is well known that site has considerable influence on the ring width, percent of summerwood, and taper, among other things, and these in turn may affect the quality of the tree or its parts for a specific use.

Silvicultural operations can modify the environment, which again directly affects the characteristics of the tree and the wood. Pruning and thinning are silvicultural operations which have considerable influence on the type of wood produced.

Genetic improvement of many wood properties is possible because of the genetic variation in the forest population. Growth rate, summerwood percentage, form, concentricity, and branching are some examples of heritable characteristics.

Biological agents, such as insects, fungi, birds, and mammals, may deteriorate (infrequently they may enhance for specialized uses) otherwise high-quality trees and wood. Decayed wood is decidedly objectionable for most uses, with the possible exception of some decorative paneling, and should be avoided. Likwise, insect galleries in the wood are cause for rejection for many uses. Bird pecks, common in some species, are undesirable in many uses of solid wood.

Poor harvesting, conversion, and processing methods may deteriorate the quality of the tree, the wood, or the product in a number of ways. Improper felling and bucking, miscut lumber, inadequate control of stain, decay, and insects in any stage of production, and inadequate control of moisture are only a few of the many ways that the quality can be lowered. In this analysis, however, it is assumed that the harvesting, conversion, and processing methods will be adequate, and that the best technological knowledge will be used to maintain high wood quality in the products. These processing defects are unrelated for the most part to the intrinsic character of the wood, and are a side issue in determining the suitability of wood for specific end uses.

The product, represented by the nucleus in the chart, has a combination of requirements which relate back to the characteristics of the tree. The conditions under which the tree grew determined the nature of these characteristics. One of the major problems in timber quality research is determining and classifying these characteristics as they occur in the tree or a portion of it, and determining how they affect the processing and the use of the product.

Grades are a measure of quality, and serve a basic function in practically all transactions. In wood utilization they may apply to the tree as a whole or in part, as well as to most of the stages in the manufacturing of a product. It is necessary to know the significance of the wood characteristics in relation to the intended use to formulate meaningful grades. The recognition and evaluation of these characteristics are again necessary in applying the grades. The value of a given grade at a given time may vary because of demand, available supply, and market conditions, but the grades, if properly made, should be relatively stable. Changes in grades may occur, however, when new information on the wood characteristics becomes available, when techniques in the recognition of them are developed, and when these techniques can be incorporated in the grading system.

Basically, timber quality is dependent on the suitability of various tree and wood characteristics for the end-use requirements of a product. Some of these characteristics are well known and are incorporated in grading systems; others, though known, have not been evaluated in terms of the end use. While we are aware that variations exist in these characteristics within and between trees of the same species, we do not know the range of the variations, nor do we have techniques to detect or evaluate them.

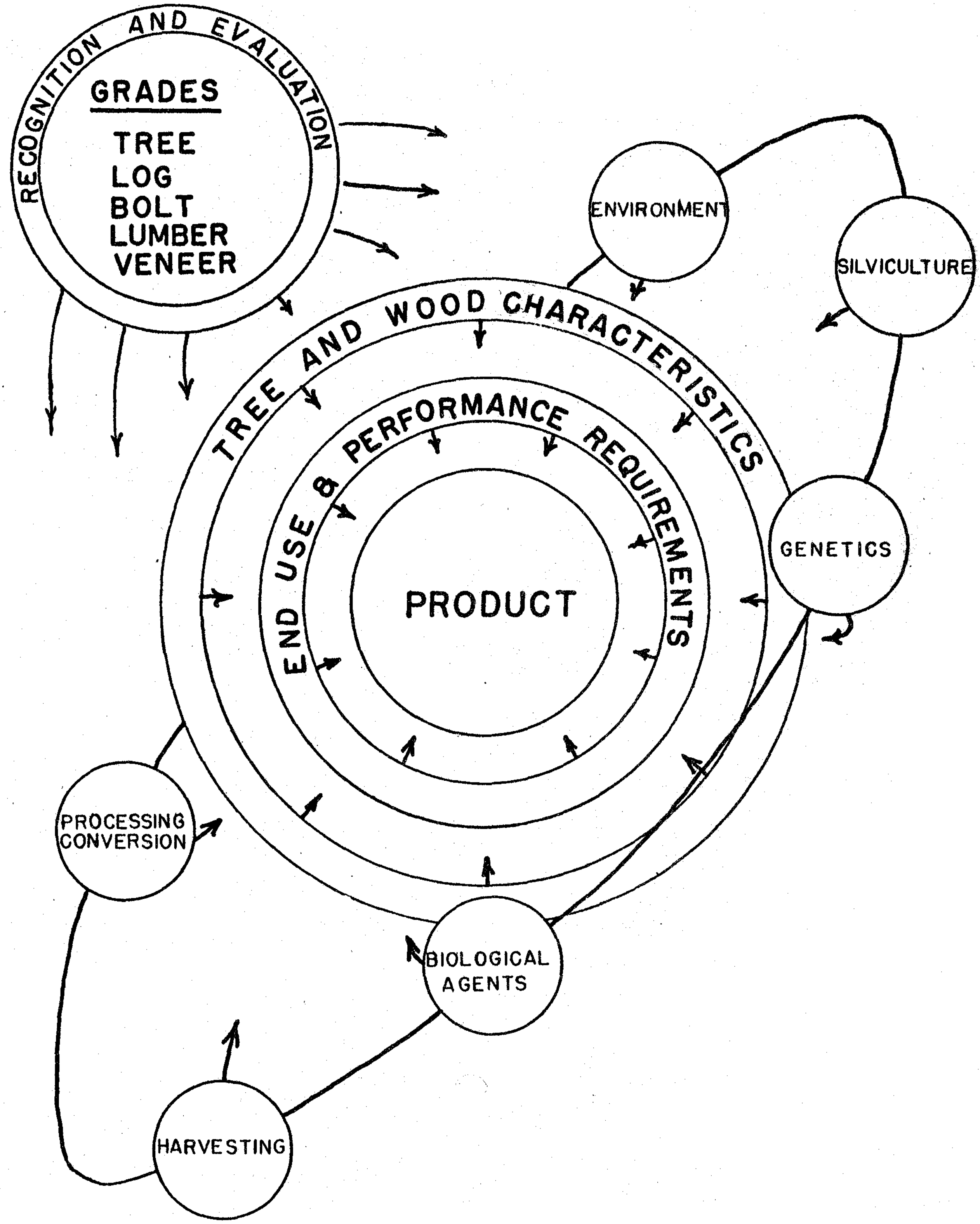

Figure 1.--Interrelationship between wood and timber quality and factors affecting them.

A total of 49 end use and 20 processing requirements are listed in the report. These are related in one way or another to the tree and wood characteristics. For instance, decay resistance is dependent on the amount and kind of extractives in the wood, while good planing in hardwoods is primarily dependent on freedom from tension wood and freedom from grain deviations. The other requirements likewise are dependent on one or more tree and wood characteristics. However, we do not know the relationship between some requirements and characteristics, and therein lies the problem. I attempted to relate the relationship of some of these but encountered difficulty because information is lacking or incomplete on the range of variations within a species.

QUALITY--A LINK BETWEEN WOOD PROCESSING AND MATERIALS AND MARKETS

By

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Introduction

Purpose of This Paper

What is quality? What place does it have in forestry and forest utilization? These are questions that we have asked and will be asking ourselves many times during this symposium. As the title of this paper suggests, I visualize quality as a link between the main elements of the forest enterprise, a link for the purposes of management. My aim in this paper will be to explore this role from both a philosophical and a practical point of view with the hope of shedding some light on the management potentials of quality. In a sense this is a very presumptuous undertaking. Quality is an illusive concept, at best, and I can claim no unusual insight. The real reason-for-being of this paper is that circumstances have required me to give more than an ordinary amount of thought and study to quality in the last few years, with the result that I have developed a few unconventional and, I hope, provocative ideas to offer for your critical scrutiny.

This symposium is mainly concerned with density of wood in standing trees and with its implications for the forest industries. Wood density, as an index of quality, is a complicated subject, as most of us have found. I doubt that we could fully comprehend its significance without the intensive treatment given it here. There is danger, however, in concentrating so strongly on any one aspect of quality that we will lose sight of the broader implications of the quality concept. This paper and others in this session should therefore add dimension and perspective to our discussions of quality and consider additional opportunities to use quality effectively as a management and research tool. This paper will be particularly concerned with these management opportunities.

Background

In 1962 Dr. George Englerth, of the Forest Products Laboratory, and I were assigned the job of analyzing the quality interests of the Forest Service and of forestry and timber utilization in general. This analysis was intended to provide guidance for research in the field of timber quality. Almost immediately, we ran into the problem of how to define quality. Quality obviously meant different things to different people. Even after talking with over 300 professional workers in forest-related activities, we found that there were apparently many separate, and not particularly compatible, connotations attached to the term "quality."

The simplest way to resolve this problem, of course, would have been to arbitrarily choose some existing definition of quality and proceed with our analysis. We tried to do this. First, we considered adopting H.L. Mitchell's (4, p.3) definition for "wood quality," which states,

> Quality is the resultant of physical and chemical characteristics possessed by a tree or a part of a tree that enable it to meet the property requirements for different end products. In other words, the intrinsic quality of wood evaluated solely in terms of its suitability for various products or end uses.

This definition is widely accepted by scientists working in the field of wood quality. I had reservations, however, about its usefulness for broader utilization purposes and found it difficult to reconcile this concept of quality with the constantly shifting quality standards of the marketplace and varying degrees of quality attached to a given property of wood as economic and technological conditions change. I could not accept the premise that the quality of wood is intrinsic or fixed.

Subsequently, we considered other accepted definitions of quality and attempted to formulate some of our own. But none seemed to provide a concept that would satisfy or include all the uses made of quality throughout the forest enterprise. (The term "forest enterprise" will be used frequently in this paper. Therefore, I should explain that it is used as a convenient term to cover the entire endeavor of growing timber, processing it, and distributing the products made from it, regardless of who performs these functions.) When we did not find a definition of quality that was fully acceptable, I began to delve more deeply into the fundamental purposes of quality to see if I could identify a concept that would be more useful than any we had come across in forest-related fields.

During this search for a clue to quality's fundamental meaning, the works of W.A. Shewhart (5) and J.M. Juran (3) came to my attention. Shewhart, usually recognized as the father of the modern quality control movement, did his work a generation ago, and Juran is a leading current authority in this field. Both of these men concern themselves primarily with the practical results of quality control in production. Each of these authorities has also devoted considerable attention to the philosophical foundations of quality and suggested a number of useful definitions for purposes of industrial management. These ideas will be discussed in greater detail later.

This initial excursion into the quality literature outside forest-related fields encouraged me to look for further leads in other management disciplines. The field of marketing proved to be particularly fruitful. The concept of market orientation, which has been so prominent in recent management thinking, seemed to have a very strong bearing on quality. Also, marketing-research techniques, used to diagnose the wants and needs of the market, apparently offered some new insight into quality relationships.

The end result of this search for the fundamentals of quality was the emergence of an idea that the many individual functions of the forest enterprise are linked together through a quality "system." The "system," as it now stands in the forest enterprise, is actually a hodgepodge of many almost independent systems. It is made up of many rather poorly meshing parts and often responds to the wrong stimuli. It is overburdened by monumental inertia and is completely understood by no one. In the discussion that follows, I will try to describe the general quality structure of the forest enterprise, as I view it, and suggest some possibilities for improving it.

Quality As A Management Concept

Fundamental Implications of Quality

Shewhart (5) was one of the first to recognize quality as a scientific management tool. He listed seven distinct conceptions of quality that he considered to be relevant to industrial production. While he failed to focus on any overall quality philosophy for industrial management, he did provide valuable insight in what he termed a working definition of quality. He indicated that quality has two common aspects--the objective and the subjective. The objective side of quality is a reality independent of men. The objective quality characteristics of a thing are constant and measurable in the sense that physical laws can be quantitatively expressed, independent of time. Wood density, for instance, might be considered an objective quality characteristic. The subjective side has to do with what we think, feel, or sense as a result of objective reality and is "closely tied up with the utility value of the objective physical properties of the thing itself." An example of this side of quality might be an end-user's preference for a light-weight chair made from low-density wood. There is no universally accepted quantitative measure of the subjective values, according to Shewhart, since they fluctuate widely with conditions.

Juran (3) is more specific. He offers 13 separate ideas of quality, but indicates that for industrial purposes one of these meanings is more fundamental than the others. This one he labels "market-place quality" and defines it as follows: "The degree to which a specific product satisfies the wants of a specific consumer." Elaborating, he says that this definition prevails only when commerce is transacted directly between a one-man producer and the individual consumer. Since this relationship rarely exists, he sums up the meaning of quality in a modern industrial context with a more practical definition. "Quality," in this definition, is "the degree to which a class of product possesses potential satisfaction for people generally."

Juran comes close to an overall management philosophy of quality, but it is still hard to see just how we might apply his rather abstruse definition to practical management of objectives. It may be helpful, therefore, to carry these ideas of Shewhart and Juran a step further and attempt to formulate a quality concept that is more relevant to the practical needs of the forest enterprise.

Management Functions of Quality

Before attempting to spell out any overall quality concept for forest products, I believe we should ask what it is that we expect of quality as a practical management device.

We know, for one thing, that quality serves as a channel of communication between buyer and seller. This function has been the main impetus behind the creation of quality standards and quality assurance procedures.

We know further that quality provides a basis for internal controls of skills, materials, and processes. It is inconceivable that the flow of these elements of production could be efficiently managed without quality evaluations and compensations.

Quality is also useful as a medium for long-range planning of market, product, and resource objectives.

These are functions that we usually associate with quality. With them in mind, we can begin to think about some overall concept of quality. But first, I believe it will be useful to consider some of the quality-related complexities that are unique to the forest enterprise.

Quality-Related Complexities in the Forest Enterprise

The forest enterprise undoubtedly has the most difficult quality situation of any major industrial field. At the resource end, the enterprise is faced with an almost infinite variety of raw materials, most of which defy detailed analysis and classification. Furthermore, the properties of timber are continually changing with time. Part of this variation and change can be controlled through forest management, but only when policy and economics will support it and when nature will cooperate in a reasonably predictable fashion.

Complexity is heightened by the fact that timber growing is a long-term process, rarely carried to conclusion by one management. Time introduces another confounding element in that it is impossible to predict in the early stages of timber growth what kind of wood will be in greatest demand at the time of maturation.

Still another unique complexity is the highly ubiquitous distribution of timber, which means that it cannot be easily collected at central points for processing and evaluation, even after harvest. This might be contrasted to other extractive industries like petroleum where the resource is more concentrated.

The processing of timber is also a highly diversified business. Wood, being an extremely adaptable material, is suited to a multitude of uses. Processing, therefore, ranges all the way from the simplest production of fuelwood to the most sophisticated chemical manufacture. In practice, the raw material from one stand of timber may enter into almost this full range of processing. The uniqueness of wood is that it can be and is manufactured into more fundamentally different forms than any other basic raw material. For each of these kinds of processing special quality relationships must be developed; and where several kinds of processing are integrated into a single enterprise, drawing from a single timber source, there is a strong interaction between these quality relationships.

Next, we might think of the complexities of the distribution channels for timber and timber products. These channels first of all reflect a wide variety of customers. They also reflect both a strong traditional trend to market forest products as commodities and the high degree of innovation that is beginning to be applied to the development and marketing of forest products. We are going through a period of radical change and increasing complexity with respect to channels of distribution.

Finally, we should recognize that markets for forest products are uniquely complex. Although part of this arises from the thousands of uses that have been found for wood over the centuries and the rapid expansion of these uses today through technological development, the really significant difference that sets wood apart from other raw materials is its esthetic appeal. This has always been and likely will continue to be one of wood's strongest selling points. The complexity that arises from this psychological attraction of wood in the marketplace, with respect to quality, is the difficulty of assessing it. Obviously, it has a very important bearing on people's reaction to most wood products, but how does it affect their buying decisions, and how can we take advantage of it?

Considering the quality-related complexities just described, there is small wonder that we are slightly confused as to how to develop meaningful quality criteria. It is certain, however, that we cannot ignore these complexities. It is also apparent, in my opinion, that the worst thing we can do is to oversimplify them. The only approach that seems to make sense under these circumstances is to find a basic concept of quality that we can agree upon and then proceed in an orderly way to refine our existing quality systems and to develop new ones that can cope with the inherent complexities of our activities.

Basic Concept of Quality for the Forest Enterprises

A concept of quality that I would like to propose for consideration by the forest industries is this:

> Quality is a systematic means of deciding about the suitability of a material or product for its intended use.

As you will note, this definition contains some of Juran's concern for the degree to which products satisfy customers and some of Shewhart's idea of quality as related to utility. It also encompasses, but goes beyond, the definition of wood quality proposed by Mitchell. Mitchell has specifically pointed out that his concept of wood or timber quality "rules out consideration of accessibility, operability, markets, cost of harvesting, or cost of utilization for specific end products," but says further, "It in no way belittles the importance of these other considerations...in the formulation of utilization and management decisions."

Bearing in mind that Mitchell's interest has been concentrated on the biophysical aspects of quality and that Juran and Shewhart were keenly aware of quality's economic implications but did not contemplate the complexity of timber as a raw material, I find it logical to combine their viewpoints to take in the entire management interest of the forest enterprise in quality. I have attempted to do this in the conception of quality proposed above.

There are four keywords in the proposed concept: <u>suitability</u>, <u>systematic</u>, <u>deciding</u>, and <u>intended</u>. Each of these has a calculated purpose.

The word "suitability" seems to express better than any other single word what quality means in the practical sense. Whether we are making a quality cruise of timber, grading lumber, or projecting the marketability of a new furniture finish, we are attempting to establish the suitability of a product for the use or uses to which it may be put.

The term "suitability" also implies that materials and products must possess not only certain physical attributes but that these must fit the user's purposes. It orients quality evaluation toward markets without excluding the important suitability relationships that are internal to production, such as suitability of the raw materials for the process and product and the suitability of the available physical plant and skills for making a product that can be marketed at a profit.

The "suitability" viewpoint of quality, further, eliminates the notion that quality is an inherent characteristic of a material or product that remains unchanged regardless of time or circumstance. Juran terms this aspect of quality as "the inherent nature of anything independent of human interest or volition," and concludes that it has little significance for industry, since quality in the industrial sense is determined by the attitudes of customers and the changing economics of the marketplace.

The term "systematic" suggests that, to be effectively used in industry and commerce, quality concepts must be converted into a system of rules that will be objectively followed. Compliance with such rules is necessary to develop customer confidence in products. System is also needed to establish reliable lines of communication within the forest enterprise and through the various agents of distribution.

The word "deciding" emphasizes the fact that quality is fundamentally a decision-making device. This decision-making role pinpoints the crux of management's interest in quality, since, through the various quality-evaluating techniques at their command, managers must decide what kind of wood resources are available, how much they are worth, what must be done to process them, what kinds of products they will make, how to control the uniformity of the product, how to market it, and what the customer's reaction will be. The customer also bases his buying decisions on available quality indicators, such as grade and brand marks, manufacturer's reputation, and warranties. He uses these quality indicators to decide whether or not he is willing to pay the asking price.

The word "intended" in the definition recognizes that materials and products often find use in ways that were not envisioned by their designers or producers, and often not by the user himself. Confusion as to the intended use of a product frequently becomes a major point of contention between buyer and seller. This is accentuated by the fact that wood is a "forgiving" material and that historically the buyer has been able to get more service from wood products than they were intentionally designed to give. As wood is used more scientifically in products, however, some of this unplanned safety factor will be lost.

It therefore becomes more critical for the seller to communicate clearly what it is that the product is intended to do. This can best be accomplished through a clear statement of quality or suitability. Although clear quality standards cannot assure that products will never be misused, they can provide a basis for understanding between buyer and seller in the event the product does fail under misuse.

The term "intended" also emphasizes the importance of the customer or user's attitudes toward a product and its suitability for his purposes. The customer's needs and wants are frequently quite different than superficial evidence would indicate. The user himself is seldom able to describe them articulately.

One crucial quality function, then, is to describe what it is that customers really want.

This rather labored dissection of my definition of quality may seem unnecessary and overdone. If so, I hope you will bear with me. Experience has made me "gun-shy" of semantic difficulties in defining quality. Consequently, I want to explain to the highest degree possible just what I mean by this definition.

Quality As A Management Tool

Using the concept of quality proposed above as a framework, I would now like to turn to the possibilities for applying this concept to the forest enterprise.

The major quality-related functions and relationships in a forest-based enterprise are illustrated by figure 1. This model represents a simplified version of the management structure of a typical forest products operation. Major operating functions are indicated by heavy-bordered boxes and major planning and control functions by light-bordered boxes. Lines between boxes represent quality relationships, with the direction of the arrows expressing a one-way or two-way flow of decisions.

The planning and control functions depicted by the light-bordered boxes represent the management areas where major decisions are made. Typically, the coordination between these functions is weak, even when they are discharged within the same organization; and often, of course, there may be several separate firms or organizations involved in making these decisions. There are valid historic reasons for this. Forest industries have typically been small businesses developed to produce single product-lines. Each kind of production existed largely as an entity unto itself. Each had its own particular raw material, its own type of processing plant, its own independent distribution and marketing channels, and its own segment of the market. Management was relatively simple and straightforward, and there was no compelling need for an integrated decision-making structure. Neither the managements nor the customers of one sector were much concerned about what went on in the other.

It is not necessary to elaborate on how vertical and horizontal integration in the forest enterprise has changed this in the last two decades. It has become the rule rather than the exception that one management is concerned with numerous product-lines--if not as the producer, at least as a competitor. Several product-lines are now typically produced from a single timber source, often manufactured at one plant site, and more and more frequently compete for the same markets. Management obviously has an entirely new set of problems as this complex pattern of integration develops. It is, therefore, reasonable to expect that they will need a different kind of decision-making machinery than that which sufficed in the past.

My thesis here is that most of the important decisions to be made in the forest enterprise can be related to quality--that is, assessing the suitability of a material or product for an intended use. To support this thesis, I would like to discuss in some detail two critical areas of decision making that vitally concern all forest enterprise--market evaluation and timber evaluation--and show the role these play in the quality system of the enterprise. First, let us consider market evaluation, or market analysis, as it was shown in figure 1.

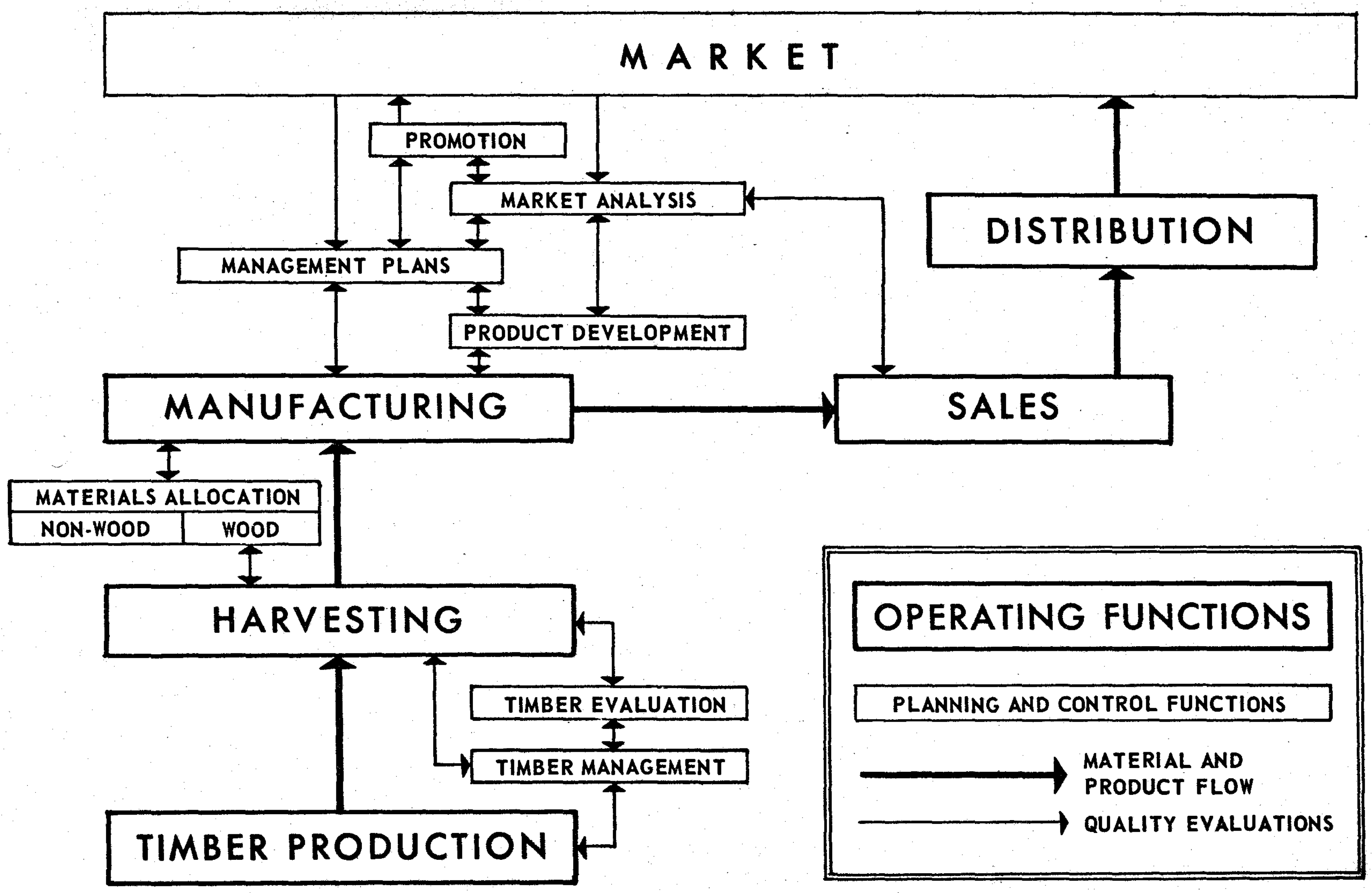

Figure 1.--Quality structure of a forest enterprise.

Market Evaluation

Today, industry is rapidly accepting a theory of management that is sometimes referred to as the "marketing concept." This concept views an enterprise as being primarily a customer-satisfying organization and places great stress on knowing what it is that customers need and want. The purpose of market evaluation is to find this out.

It seems likely that the "marketing concept" will increasingly dominate management thinking and that market evaluation will, therefore, become increasingly important. If, as suggested by this concept, the customer becomes the central concern of the enterprise, we may expect that this will have an important bearing on quality. As Juran (3) proposed in his definition of "marketplace quality," quality becomes first and foremost a measure of how well a product suits the user. The implication is that the cornerstone of quality is the market, not the raw material or the manufacturing process as many have long regarded it in the forest enterprise.

Consequently, unless we reject the "marketing concept" of management, it follows that all quality criteria will originate in the marketplace. A corollary of this idea might be that market evaluation is the most basic of all quality determinations. I recognize that this thought may be a little abstract, so I will try to focus on some of the implications of this market-oriented approach that are at variance with traditional management thinking.

It would be fair to say, I think, that we have been preoccupied in the past with the supply end of quality. The primary function of our quality apparatus has been to segregate a relatively cheap and plentiful raw material into broad grades and classes of commodities that could be easily manufactured and conveniently marketed. Competition was not so keen because wood is a remarkable material and has had substantial cost advantages. With only a modicum of ingenuity, wood could be used for thousands of miscellaneous purposes with only minor refinement beyond primary breakdown. Under these unusually favorable circumstances, the wood supplier's conception of quality came to be related more to the problems of extraction and manufacture than to the needs of users. In recent years, this strong supply orientation of quality has dissipated somewhat in the face of rising competition from nonwood products. We can hardly claim, however, that quality in the forest enterprise is yet strongly market-oriented.

Under the traditional management approaches to the market, there was, of course, some feedback with respect to quality. Customer complaints and radical gains or losses in sales did not go unnoticed. But there was rarely anything built into the quality systems of the enterprise that would permit management to know with precision what the market's demands were or how they were likely to change. There was little or no factual information flowing between the customer and managment that was detailed enough to provide a base for effective quality criteria.

In recent years, a number of industry associations and several of the larger firms in the forest products industries have intensified their efforts to evaluate markets. Some now have full-time marketing research staffs whose function it is to probe customer interests and test market response. At this stage, these groups are composed mainly of marketing specialists and economists who are capable of predicting overall trends in markets and, to some extent, project customer preferences for specific products. Rarely, however, do these groups formulate specific quality criteria.

To develop adequate quality criteria, very precise ideas of what customers will buy and how much they will pay for it are needed. From such information, a qualitative description of a marketable product can be developed. For want of a better term, I will call this a "consumer-use specification," a term H.L. Hansen (2) attributes to C.G. Mortimer, former president of General Foods. Such a specification, according to Mortimer, can be used to govern the collection of raw materials for the product and for the various operations performed on it. As I visualize this kind of a specification, it is a set of quality criteria derived from a detailed analysis of the market, as tempered by the capabilities of the producer. To be effective, it must reflect both the measured physical and economic requirements of the product, such as strength and cost limits, and the subjective characteristics that cannot be readily measured or quantified, such as beauty or status appeal.

Once a "consumer-use specification" is established, it becomes the basis for all decisions to be made about that particular product. Most directly, it becomes the guide for product development, determining what materials can be used, what skills and facilities must be mobilized, and what processes are required.

Many producers in the forest enterprise use some equivalent of a "consumer-use specification." In general, however, such specifications are not very highly developed and seldom reflect adequately either the market demands or the peculiar capabilities of the producer.

To be most effective, the formulation of detailed quality criteria needs to be a team effort. As product needs become more complex, it takes several kinds of skills working together to produce a good "consumer-use specification." Those who are responsible for product development and production and raw materials management should work actively with marketing specialists and economists to make sure that the specification reflects as precisely as possible both what the customer will buy and what the producer can produce at a profit.

In this discussion of market analysis, I have attempted to show that, regardless of what our particular interest in the forest enterprise may be, all quality dictates stem basically from the marketplace. It therefore behooves us to know how to analyze markets precisely and how to translate the market's demands into quality criteria that are meaningful at every level of the enterprise. And since market evaluation is the most basic of all quality functions, it seems like a very fruitful place to look for greater management potentials. To summarize the quality opportunities open to management through market evaluation, I would like to suggest these points:

1. The foundation of quality and quality management throughout the forest enterprise, from growing the tree to marketing the final product, is knowing what the market needs, wants, and can buy.

2. The qualitative demands of the market are extremely complex and therefore extremely difficult to interpret. Existing methods for analyzing these demands are still imprecise but are rapidly improving.

3. The technical and economic capabilities of producers temper market demands but do not in any sense dictate these demands.

4. Successful product development results not only from a producer's financial and production genius but even more from his ability to create products that will find a high degree of favor in the marketplace.

5. Market analysis and product development have the common objective of creating effective product specifications. It is therefore logical to knit these functions closely together in management.

Timber Evaluation

Turning now from a management function most closely related to the market, I would like to consider timber evaluation, which we would usually think of as being the farthest removed from the marketplace.

The term "timber evaluation" has numerous possible connotations and therefore needs to be defined. For purposes of this discussion, timber evaluation is considered to be the process by which physical and economic characteristics of a tree or its components are assessed prior to primary manufacture. Physical characteristics will include the size and form of the tree or log and the physical and chemical properties of the wood in it. Economic characteristics will include geographic location, harvesting feasibility or cost, and market potential.

Assessing the characteristics of individual trees and their parts is the basic concern of timber evaluation. While gross quality evaluations of stands of timber or whole forests may be needed for some management purposes, such evaluations must be regarded for product purposes as summations of the characteristics of individual trees. A tree is the largest unit of timber that we can hope to deal with effectively with respect to wood properties, and since the properties found in a given tree are themselves quite variable, we are more likely to think of timber quality in terms of logs and bolts.

Timber evaluation involves at least three distinct functions: (1) the forest manager evaluates timber to decide what cultural and protective practices to apply and to determine when the timber is ready for harvest; (2) both forest manager and product manager depend upon timber evaluation to establish a fair exchange value for timber; (3) the product manager evaluates the characteristics of timber as a basis for deciding how to process a tree to best advantage--to obtain the maximum product yield. These three functions fit nicely into the quality framework proposed earlier; that is, each function calls for a systematic decision about the suitability of a material--timber--for some particular use.

If we accept modern management theory, timber growing is just as much a customer-satisfying function as marketing or servicing the end product. Therefore, timber resources, as remote as they may seem from a final product or the eventual user, should be evaluated on the basis of their ability to satisfy customers. In the final analysis, not only the immediate customer needs to be satisfied but also the ultimate consumer. Since it is a long tortuous path between the consumer and the timber manager, however, the customer-satisfying function is a point that has been largely overlooked up to now in our approaches to timber evaluation. Lacking any effective way of transmitting consumer market demands to timber producers, we have come to think of timber evaluation as an isolated quality function that concerns only buyers and sellers of timber. W.A. Duerr (1) has said with respect to this problem,

> In the timber-growing game, society's telegraphic signals through the market always reach producers as a garbled message, and the latter fail to respond as they were meant to.

This leads me to believe that another really promising opportunity for management through quality is to establish the kind of communications link that will allow timber producers to respond to the demands of the market. To unscramble the messages of the market for timber producers, the processes of timber evaluation will need to be integrated with an overall quality system based on knowledge of what customers want and need and of what can be done to meet these demands through processing. Also, to respond to these messages, the timber grower will need to know the actual character of the timber he has available for harvest.

In the past, the timber producer has been left largely to his own devices in establishing timber quality criteria. In the future, processors will have to provide better estimates of what their needs are and will be, which, in turn, must be predicated on projections of market demand and technological change. Armed with such knowledge, the timber producer is in a better position to evaluate his timber crop in the light of currently expected demands rather than some outmoded impression of what constitutes quality.

Unfortunately, analyzing trees is only slightly less complicated than analyzing people. Trees, like people, and forests, like markets, are inherently complex and continually changing in rather unpredictable ways. Timber evaluations, therefore, have to be made "on the run," and projecting the nature of timber characteristics at the time of harvest is an exercise in probabilities rather than a direct measurement.

Our ability to cope with timber evaluation for management purposes rests on the possession of three kinds of intelligence--what characteristics a tree has; how these characteristics can be influenced; and how to relate characteristics of trees to the characteristics needed in products. Progress is being made in acquiring all three kinds of knowledge but, compared with the need, the progress is painfully slow.

At present, we find out what we know about a tree's properties primarily by visual appraisal and by making some rather rough measurements of its dimensions. By these methods, we identify its species, its approximate volume, and some of the defects it has, or may have, for a particular pattern of utilization.

Through new techniques, such as the wood density survey method, we can learn something about a tree's internal properties by analyzing specimens harmlessly removed from the living tree. This yields information on the tree's age, its heartwood-sapwood dimensions, its growth rate, its density, and, if we wish to devote sufficient laboratory efforts, something can be learned about its cellular structure, chemical nature, etc.

The eventual ideal in evaluating timber, as I foresee it, calls for some means of "scanning" a tree to classify and measure its significant characteristics. This device must go beyond human observation, both in what it can "see" and the speed with which it can measure and evaluate the characteristics of the tree. Tree characteristics will be automatically recorded on punch cards or tape or telemetered directly to a computer. The computer will be programed to compare the properties of the tree with the physical and economic requirements of one or more products. By means of optimization analysis, the computer can supply management with the facts needed to decide whether harvesting the tree should be deferred, whether special silvicultural or protective treatments should be applied, or whether to proceed with harvesting. If the decision were to harvest, then it should also be possible to decide which channels the tree or its parts should take to yield products of maximum value.

Any such "ideal" system of timber evaluation is probably many years ahead of us. However, we need to visualize some such system now as a model for what we eventually hope to achieve.

Most of us intuitively recognize that our conventional systems of timber evaluation must be improved. We are not happy about our capabilities as they exist, regardless of what our interest in timber evaluation may be, but we are somewhat at a loss to know how to go about improving the situation.

In the Forest Service, we have been deeply concerned with this problem for a number of years, and a substantial portion of our research and administrative efforts are going into the refinement of timber evaluation methods. Spurred on by an ever-present administrative problem of establishing fair market value for National Forest timber, the Forest Service has been particularly concerned with stumpage appraisals. The Forest Service also recognizes an obligation and opportunity to assist in developing better timber evaluation techniques for industry's purposes. These combined interests in timber evaluation have led to intensified research in log and tree grade development and product recovery studies.

As might be expected in such a difficult problem area, every bit of progress is hard won. There are few precedents for this kind of research, and certainly none that has attempted to go so far in relating specific combinations of timber characteristics to the values recovered in products. Just what we may eventually learn from this log and tree grade research is not certain, of course, but it is already becoming obvious that the old concepts of evaluating timber by simple grading systems will not be adequate for the complex timber evaluation needs of modern integrated forest enterprises.

My own impression of where this new knowledge and these new capabilities are leading is that ultimately an initial evaluation of timber can be made that has no product dimension. That is, the evaluation will be confined to assessing only the physical attributes of the tree or log, without reference to any particular product use. All attributes will be considered that can be identified and quantified by available techniques, provided research has indicated a significant effect on the attributes of the product. These timber attributes, assessed without any preconceived idea about the end use of the wood, can then be compared with whatever product requirements management may wish to consider. This kind of evaluation of timber would give management the opportunity needed in a multiproduct operation to allocate specific trees, logs, or smaller components to products that will yield the highest values.

As new techniques develop, management should be quick to seize opportunities to evaluate timber more effectively. Timber is no longer a cheap commodity, and therefore establishing timber values as precisely as timber evaluation techniques will permit is of major economic importance. The degree of economic importance implies that industry should become actively interested and involved in all the various aspects of research that pertain to timber evaluation.

Those in research should be aware that their contributions are likely to be misdirected, unless they see the problems and opportunities of timber evaluation as a whole. It will not be rewarding for the timber economy for researchers to work intensively on any limited segment of the problem unless they relate what they are doing to the practical problems of management. Timber evaluation research will necessarily be set in an economic frame of reference as part of the overall quality system of the forest enterprise if it is to have more than academic significance.

Conclusions

Quality has numerous accepted meanings, each of which may be valid for some particular purpose. Most ideas of quality, however, are either too indefinite or too limited to serve the practical needs of industrial management. This is especially true for the forest enterprise which because of its widely varying raw materials and its highly diversified processing and markets, is uniquely complex.

Existing quality apparatus is being challenged in nearly every phase of the forest enterprise due to rapid changes in factors that determine quality. Traditional markets are declining and new ones emerging. Merchandising is assuming new patterns. Channels of distribution are changing radically. Technology is progressing at unprecedented rates. The understanding of timber and wood as raw materials is increasing, as is the knowledge of how to change their character in the growing tree. And, most important, the needs and wants of customers are rapidly shifting and expanding. In the midst of all this, forest managers are being called upon to accommodate the growing of a timber crop to numerous other uses for the forest that may be competitive. These elements all have a most significant impact on the values associated with timber as a resource and with wood in products. They will inevitably give rise to new procedures of management and to ideas of quality that are more closely geared to changing conditions.

Modern industrial managment views all functions of the enterprise as customer-satisfying functions, regardless of how remote they may be from the marketplace. This means that we should be prepared to look upon timber growing as a customer-satisfying business as much as the production and marketing of a finished product. For industrial management, quality is therefore most usefully regarded as a reflection of the suitability of a material or product for a potential buyer's purposes.

To take maximum advantage of quality as a management tool, the forest enterprise will need to adopt an overall philosophy of quality that is consistent throughout all functions of the enterprise. Without such a central conception of quality, communications inevitably break down between the various divisions and activities of the enterprise, and decisions must be made without an adequate grasp of quality problems and opportunities.

A definition of quality that seems to be adequate for the total needs of the forest enterprise is this: Quality is a systematic means of deciding about the suitability of a material or product for its intended use. This definition is a synthesis of several ideas expressed by quality authorities in the management and forest sciences. It brings together the philosophical and practical aspects of quality into a single working concept that can serve all of management's purposes. If adopted as the basis for an integrated quality system, it would provide a much needed link between wood processing, materials, and markets in the complex and rapidly changing forest enterprise.

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A RELATIONSHIP OF WOOD DENSITY SURVEYS TO PLYWOOD STRENGTH VALUES

By

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The fact that plywood is produced by cross-laminating thin sheets of wood veneer provides it with some unique and desirable properties. In strength property studies, however, the realignment of grain direction of alternate layers introduces complexities which are not encountered in the case of solid wood products.

When, in addition, consideration is given to the many combinations of thickness, species, and grade of veneer which may be involved in any nominal thickness of plywood, these complexities multiply rapidly and tend to create an appeal for a mechanical system of determining the properties of individual panels.

Those of us on the technical staff of the Association have a definite interest in the future possibilities of machine-grading of plywood. This, however, is not the area in which we are concentrating our effort at this time, nor will it be the principal subject of my remarks today, as suggested by the original topic which I was assigned which appears on the program.

We are confident that commercially feasible production-line methods for determining the strength, or at least the stiffness, of individual plywood panels can be developed. Such methods, however, will not provide the refined basic strength data which is needed, nor will they offer a suitable substitute for such basic product knowledge.

The same variables which I mentioned a moment ago as sources of complexity in studies of strength properties also offer an opportunity for the plywood manufacturer to exercise control over the properties of the products he produces. For example:

> He may vary the section properties along either panel axis by changing the thickness and arrangement of veneers in the assembly and, in so doing, compensate within limits for other deficiencies.
>
> He may utilize both high and low strength species in the same panel without necessarily degrading the property or properties of interest.
>
> --And he can limit the occurrence of grade characteristics in critical plies while utilizing lower grades in those plies which are not critical.

We believe that the industry's interest will be best served at this time by developing and refining our ability to accurately predict the mechanical properties of plywood and the effect on these properties of species, grade, and manufacturing variables.

Refinement in both strength value assignments and procedures for deriving such values are necessary if plywood is to expand its share of the construction market.

Slide No. 1--Need for Refinement

Neither plywood products nor industry markets remain static.

Raw material resources are rapidly changing. Plywood is being produced in new regions and from new species. Logs of smaller diameter and of lower quality are being utilized.

Old manufacturing practices are being replaced by more efficient mass-production methods.

The market is also changing to one which is more demanding and more competitive. New products continually threaten old established markets.

Not all of these are changes which we might wish for, but they arise out of economic need and will occur, nevertheless--and they need not be bad if they are anticipated and recognized in the industry marketing program.

As changes in industry standards occur, we need both the knowledge and the procedural flexibility to immediately make appropriate adjustments in design values.

Plywood, in the large majority of its end-uses, is a structural material. Some uses, of course, are far more demanding than others. Many engineered applications have become rather highly sophisticated.

Slide No. 2--Further Requirements

Obviously, design values need to be safe and reliable--but they must also be efficient. If our products are to remain competitive, they cannot afford the luxury of design reduction factors to compensate for ignorance.

Neither can strength values be based on the assumption that all wood products are identical. They are not, of course, and the individual characteristics of all major products, as well as the uses for which they are intended, need to be recognized in deriving design values.

I have already referred to the need for flexibility. This can be achieved through the adoption of procedures designed to assure valid values--in lieu of fixed, inflexible values. Dick Kimbell discussed such procedures in his presentation yesterday.

The grouping of species for marketing purposes, as well as product standards are properly prerogatives of industry--which involve judgment decisions influenced by market and economic considerations as well as the conformance to technical limitations.

A further advantage of the procedural approach now under study in ASTM D-7 is that it assures fair and equal treatment to all species and regions. The previous, less-refined methods, as a result of variability and wood properties, were vulnerable to claims of discrimination against almost any lower-ranked woods.

In the past, these apparent and sometimes real inequities captured a large measure of the technical interest by industry groups, and there was no satisfactory answer to their concern.

The recent, more active participation by industry in the activities involving strength value assignments offers advantages also. First, we believe that constructive technical contributions will, and in fact already have, resulted.

Additionally, through direct participation in activities such as those of the Western Woods Technical Committee, joint conferences with the FPL staff, and meetings of ASTM committees, industry representatives, I believe, have already acquired a new respect for technical considerations.

This new industry technical consciousness is closely related to the Forest Service-FPL "Western Wood Density Study." First, industry interests made the study feasible on an accelerated basis through cooperative financial support.

The manner in which the findings of the Density Study were to be utilized, however, was the strong area of mutual interest which sparked inter-industry technical effort and resulted in the creation of the Western Woods Technical Committee--a group which has functioned with increasing effectiveness over the past five years.

The Density Study, in itself, provides only a portion of the data necessary to implement the revised, refined working stresses for plywood which we are seeking.

What it does provide is unadjusted clear wood values for various mechanical properties and associated variability data which give us a more detailed and reliable picture of each species than has previously been available. This serves as a base for other related steps leading to working stresses.

Slide No. 3--Plywood Strength Study--Master Plan

In the case of plywood, two additional major programs are involved--a plywood strength study of three phases and a panel stiffness survey. The final objective, of course, is the establishment of reliable and efficient strength and stiffness property assignments for plywood made of any combination of species, grade, and construction.

This chart, which is an abbreviated outline of all phases of the plywood strength studies, establishes the perspective of all separate phases which will be discussed individually.

Because of the prohibitive volume of testing which would be required, it is not feasible to develop plywood strength data directly from tests of in-grade panels, considering all combinations of species, grade, and construction.

Furthermore, subsequent changes in industry standards affecting any one of these variables would invalidate strength data developed in this manner.

Accordingly, we have taken an approach which bases plywood strength and stiffness on solid wood data.

Slide No. 4--Strength Properties of Clear Wood

This is accomplished in the following order:

1. The density surveys which have been completed for the important species in the West act as a base for all of the work to be described.

2. Procedures developed by the Western Woods Technical Committee which have been described by Dick Kimbell will establish the approach to utilization of the Density Survey data for clear, unadjusted solid wood assignments.

3. ASTM D-7, through the new Subcommittee XVII and product subcommittees, will establish procedures, based on the WWTC approach, for making unadjusted clear wood strength assignments, and covering reduction factors applicable to plywood through the Plywood Subcommittee.

Slide No. 5--Strength Properties of Clear, Straight-Grained Plywood

The first phase of the test program conducted by the Association deals with the relationship between the strength properties of solid wood and those of parallel laminates and plywood. The objective is to determine if existing average strength data for clear, straight-grained solid wood can be applied to clear, straight-grained plywood.

This information was developed through cooperative FPL-Plywood Association tests on matching blocks from white fir and hemlock trees selected by the Forest Service.

Plywood data for bending strength were based on laminated veneer specimens and compared with solid wood data for matching FPL tests. The comparisons included confirming tests of methods previously developed by the FPL for calculating bending strength of plywood from the strength of laminated veneer.

Solid wood and plywood compression parallel-to-grain data were compared, as was the solid wood horizontal shear strength and the strength of plywood in shear-through-the-thickness. Rolling shear strength of plywood was also compared with the horizontal shear strength of solid wood.

Next, the method for calculating the flexural and direct stress strength properties of plywood was examined, including a study of the effect of shear deflection on panel stiffness.

Essentially, we have confirmed the FPL-developed relationship between solid wood and plywood. Additional data are needed on mixed veneer thicknesses, a variable which has not previously been investigated.

This phase of the study relating to actual and calculated bending strength and stiffness of plywood has been broadened to include a study of the variation in effect of shear deflection on panel stiffness that can be expected in actual mill production.

The final project in this phase of the study involves the relationship between plywood strength properties and moisture content. To date, the relationship between solid wood strength properties and moisture content has been applied to plywood due to the lack of data specifically relating to plywood.

This project will cover the moisture content-strength and stiffness relationships of plywood directly.

All projects under this phase are well advanced, with most of the work completed on items 1 and 2. Except for the previously noted need for additional information on solid wood-plywood relationships for mixed veneer thicknesses, we expect to be essentially finished with Phase I projects in June.

The following series of slides illustrate Phase I projects in progress:

Slide No. 6.--White Fir Lots

This represents one log of white fir logs used in the Phase I study. There were four lots each of white fir and hemlock--each matched with lots shipped to the FPL for solid wood strength testing.

Slide No. 7--Marked Blocks Prior to Peeling

In order to identify the location by quadrant and radial cell of every piece of veneer in each block, an elaborate system of marking and checking through the peeling operation was necessary.

Slide No. 8--Technologist Marking Face of Veneer at the Lathe--and--

Slide No. 9--Technologist marking veneer at the clipper to insure cutting by operator at the quadrant line.

Slide No. 10--This 40 ft. trailer load of veneer from the white fir study alone serves to illustrate the scope of the work involved.

Slide No. 11--Reassembled block (without core) showing all original pieces back in place prior to marking for specimen cutting.

Slide No. 12--Identified block end, matched with similar photographs from FPL of clear matching blocks to insure proper orientation for specimen location in matching blocks.

Slide No. 13--A few of the thousands of small, straight-grain, clear plywood bending specimens fabricated from the test veneer in this project.

Slide No. 14--Flexure test in operation, using small ASTM flexure method.

Slide No. 15--Compression parallel test, of which thousands were run.

Slide No. 16--FPL type rolling shear test.

Slide No. 17--Rolling shear close-up. This is one of a few properties for which we have not yet found a good correlation between plywood and solid wood.

Slide No. 18--Chart--Effects of grade and manufacturing variables.

The next phase of our program relates to studies of grade and manufacturing variables. This constitutes the major phase of our overall plywood strength study.

The first item deals with the effect of short grain, knots, knotholes, and repairs on flexural and direct-stress strength properties. Provisional laboratory grading rules were developed for estimating the effect on strength of grade characteristics located in the compression face as well as in the tension face of flexural panels.

Several hundred large flexural specimens were fabricated, representing a wide range of grade combinations. After testing these special panels, small, clear controls matched to the larger panels were tested for stiffness and strength. Comparison of estimated and observed strength ratios were used to refine the grading rules.

This refined visual grading system was used with all panels tested in the sheathing panel stiffness study, to be discussed later. Special equipment for two-point loading of small, clear specimens was developed for determining stiffness in pure bending. In addition, the large panel flexure machine, which will be discussed further, was developed for this work.

Next is the effect of glue type, veneer thickness, construction, and lathe-checking on shear properties. While a great amount of work has been done on the effect of check depth and frequency as affecting shear properties, considerable work is yet to be done. The shear work is in abeyance due to the more urgent press for other phases of the study.

Also yet to be investigated is the effect of splits, core gaps, core laps, knots, knotholes, and short grain on shear properties.

The final project in this phase of the work concerns the effect of core laps and core gaps on flexural and direct stress strength properties. The flexural properties effect of laps and gaps has progressed to the point where results have already been utilized by the industry Commercial Standards Committee.

While some additional work will eventually be done, it has been placed in a low priority classification.

Slide No. 19--FPL four-rail large panel shear-through-the-thickness test. It was initially used in all of our shear-through-the-thickness work, but was found to be insensitive to characteristics located in the center of the panel. This necessitated the development of a new shear test specimen by our laboratory.

Slide No. 20--This is the resulting two-rail shear specimen. The specimen is 24 inches long and has 8 inches clear space between rails. It has been found to be quite sensitive to grade characterisitics falling anywhere in the plywood area between rails.

Slide No. 21--This slide shows a 2 ft. x 4 ft. panel being tested in a Universal testing machine for bending properties with the face grain parallel to span. The test was slow to conduct and required three to four men reading deformation and tangent angle gauges at the reactions and load points, necessary for computing the horizontal component inherent in the test method.

Slide No. 22--This is a plywood bending specimen with face grain perpendicular to span, showing extreme deformation resulting in load points running off bearing plates to impinge on plywood surface, thus ending test before failure. It was generally impossible to fail panels completely by this test method.

Slide No. 23--Prototype of the Post Flexure Machine developed by Paul Post of our Product Research staff. A torque is applied by the yokes to the ends of the panel and the yokes are free to move in a near frictionless fashion as the span changes with panel deformation. Rotation gauges shown on the face of the panel were also designed by Paul.

Slide No. 24--Production model of the Post Flexure Machine built by Tinius-Olsen, with Paul testing a full 4 x 8 ft. panel. The machine can easily test to failure 3/4 inch 4 x 8 panels of Douglas-fir and can test thicker panels for stiffness.

For very thin panels, a pair of lightweight yokes are provided. While the small panel flexure test required several men and considerable time for processing, with probably 8 panels per day maximum, the Post machine, operated by one technician, can process 40 panels or more per day, with all information piped directly to an XY recorder for very simple data reduction.

It should be noted that this flexure machine is not a production test machine suitable for use in a mill. The sheathing study, however, will provide data to the industry on the feasibility of using a stiffness machine and will provide information for setting end points for machine-measured span-index ratings.

Slide No. 25--This brings us to the sheathing panel stiffness study. The study involves the random sampling of mill run C-D sheathing panels in 3/8 inch thickness, principally for stiffness measurement, but includes strength and other determinations.

It included tests of 1,500 panels of Douglas-fir. In addition, Western softwood plywood and Southern pine plywood are now included in the program. We have now tested well over 1,800 panels in full 4 x 8 ft. size.

1. One of the products of the panel stiffness study will be a picture of the variability in stiffness encountered in industry sheathing production. The study will develop a picture of the distribution of stiffness of 3/8 inch C-D sheathing as now manufactured.

2. The study will also provide a picture of the correlation, if it exists, between bending strength and stiffness of plywood, and will show the distribution of such ratios in industry production.

   Additionally, it will provide data on variability in thickness, construction, and moisture content of sheathing panels in the industry.

   Variability in equilibrium moisture content-relative humidity relationships will also be developed from material in this study.

Slide No. 26--Chart--Working Stresses

This phase of the study represents the final application of all of the foregoing.

We have already developed the laboratory visual grading rules mentioned previously, and are applying them to the sheathing stiffness study panels. Also, we are verifying the grading system by tests on full-size mill run panels in the sheathing panel stiffness study.

The development of working stresses and stiffness assignments is going forward as detailed here, with (a) ASTM clear solid wood data expected to be available shortly, and (b) ASTM grouping limits similarly available shortly. Reduction factors for plywood design and application will be developed from the strength study as data become available, and will be submitted for review by the ASTM Plywood Subcommittee.

The development of grading rules under this phase of the study will depend on the interests of the industry, but data are constantly being developed which will assist in any changes that might be contemplated.

Slide No. 27--Future Considerations

Future considerations, of course, may consist of any area in which the industry may be interested. The two shown are the alternatives of non-destructive testing of veneer quality or machine-grading of the finished panel.

In the former, such evaluation of veneer quality and, in turn, panel properties may conceivably be by density or other features. Machine grading, if it materializes, will probably be directed toward stiffness testing, since this is the critical property in most plywood applications.

It is possible that flexural strength of panels may be predicted from stiffness, although sufficient data are not developed from the sheathing study to answer this question.

COMMERCIALLY FEASIBLE METHODS FOR EVALUATING THE STRENGTH OF INDIVIDUAL PIECES OF LUMBER

By

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Introduction

The evaluation of structural properties of individual pieces of lumber without damaging them is a form of nondestructive testing. Methods of this sort have been in use for many years in the lumber industry, for example the capacitance type moisture meters. In the broader sense however nondestructive testing as a general industrial tool was originated primarily as a flaw detection system. Perhaps military requirements gave the greatest impetus to flaw detection but today nondestructive testing is widely used to detect defects in parts of both military and civilian goods.

More recently the connotation of nondestructive testing has taken on much broader meaning. Today it is considered to be any measurement of a material to examine some aspect of its physical or chemical composition without in any way impairing the usefulness of the material being examined. In this space age, in this age of high speed transportation, many kinds of materials are called upon to give service under increasingly severe conditions, consequently defect detection alone is not a wholly satisfactory testing procedure. In today's economy, nondestructive testing is expected to disclose nonuniformity in materials and provide a determination of the significance in service of this lack of uniformity. In general, nondestructive testing must be able to measure entire plant capacities at current rates of production and express the results rapidly in terms related to service of the material being tested.

In order to develop a successful nondestructive testing method, scientists must have a thorough knowledge of the properties of a material that can be measured by a nondestructive means. It is also important that these measurable characteristics have a relationship to other properties for which information is needed. In lumber, machine stress rating meets all of these requirements for a satisfactory method of nondestructive testing.

There are four widely recognized methods of nondestructive testing. These methods are:

- Nuclear radiation
- Electrical methods
- Vibration methods
- Mechanical methods

Some possibilities exist for each of these four classes of procedure in the measurement of the structural properties of lumber.

Nuclear Radiation

Nuclear radiation is in advanced stages of research for the changing of the structural properties of wood but the use of nuclear radiation for nondestructive testing of lumber has been given scant attention. Because nuclear radiation can recognize differences in density it is possible to use this method to "see" such characteristics in wood as knots (high density) and checks or splits (low density). One researcher at the AEC installation at Idaho Falls, Idaho, has used radiation either to mark the location of knots in a piece or to separate clear pieces from knotty pieces.

Electrical Methods

An electrical method of measuring wood properties that has had wide and popular appeal is the use of a television type camera to identify wood characteristics. Such a procedure developed by Battelle Memorial Institute under Western Pine Association sponsorship has been used in fairly successful plant trials to locate the presence of growth characteristics that have influence on strength. The apparatus is under further development for use as a laborsaving device in wood product plants and also as possibly an instrument for grading.

The use of the piezoelectrical effect in wood as a measurement of structural properties has been under study for some time by Dr. E. Fukada and W. L. Galligan as reported at the recent WSU and National Science Foundation Symposium on Nondestructive Testing of Wood. Galligan has shown that the piezoelectric charge developed in wood in response to a strain can be measured and closely correlated to modulus of elasticity and modulus of rupture. A correlation coefficient between piezoelectric effect and static modulus of elasticity of 0.956 is reported.

Dr. Fukada has used piezoelectric effects to measure structural properties of timbers in service. One of his interesting findings is the increase in modulus of elasticity over the first 300 years of service. Measurements have been made to disclose this interesting fact in Japanese buildings ranging in age up to 1400 years.

Vibration Methods

Some early principles for vibration testing were published as long ago as 1948 by R. F. S. Hearmon. Other reports by Dr. D. Narayanamurti show how simple torsional vibration tests can reveal values for modulus of rigidity. In relatively simple procedures which Dr. Narayanamurti has used extensively he has found that a bouncing ball can reveal structural and other properties of wood.

I.D.G. Lee has used ultrasonic pulse velocity for determinations of the structural properties of wood. He has found that his procedures are especially effective for determination of the safety of timbers already in place.

Mechanical Methods

One of the older mechanical methods of determining the structural properties of individual pieces has been used in the selection of particularly critical parts of aircraft and other specialty uses. This system was the removal of a small specimen from one or both ends of pieces being inspected with the small specimen being subjected to a toughness test as an indicator of the structural properties of the remaining piece.

There is a newly developed device for estimating wood density which of course is a good indicator of structural properties. This device developed in the laboratory of the Western Pine Association embeds a V-notched blade into wood under the influence of a prescribed impact. The V-notched blade cuts two slight notches in the face of the board. The distance between the adjacent ends of the two notches is an indication of the density of the piece being tested. Thus a low density piece of material will permit the V-notched knife to embed deeply into the wood nearly bringing the adjacent ends of the two notches together. A high density piece of wood however will have a considerable separation between the two notches.

Shortly after it became known that Potlatch was developing a method of measuring the modulus of elasticity of lumber a manufacturer of wooden arrows in Oregon visited us to learn if our methods could speed up his inspection. Unfortunately we were unable to be of assistance since our materials were so much larger than arrows. Nevertheless it is interesting to note that here was a wood product manufacturer measuring modulus of elasticity below the proportional limit by individually loading each shaft over a given span. Based on the deflection induced, the shafts were sorted into grades with the best grade being the one of the highest modulus of elasticity or stiffness.

Machine Grading of Lumber

In the latter part of 1957 when it became apparent that it would be a long tortuous trial before all Douglas-fir would be classed as one species in the marketplace I began to look for a practical means of ending this dilemma. Obviously, if some system could be developed to determine the true structural properties of each individual piece of lumber, the regional rivalries would become inconsequential because each piece would be given its proper rating.

Pondering on this problem revealed two related factors. First it is evident that our largest volume of material used in light frame construction is used for floor joists and ceiling joists, and much if not all of this kind of material is designed on the basis of its modulus of elasticity. Thus I was led to the second thought that modulus of elasticity can be readily determined below the proportional limit and therefore without damage to the piece on which the measurement is being taken.

A good many months went by with a few ideas developing such as recognition of the fact that the testing device must be able to account for bow or crook or twist and of course the need for apparatus that would handle a large volume of production. When we finally convinced R. J. Hoyle that he should join the Potlatch Staff he was assigned the problem of developing a device for rapidly and accurately measuring the modulus of elasticity of dimension lumber.

Hoyle soon had an effective piece of apparatus in which lumber on a predetermined span was loaded at the center through a dynamometer wired to convert force readings into modulus of elasticity values for the particular size material being tested. With this apparatus a large number of pieces were measured. Observing the material being tested and sorted into piles of several modulus of elasticity classes, it began to look to me that there might be a correlation between modulus of elasticity and modulus of rupture in structural sizes of dimension lumber. Consequently a preliminary test of several hundred full size pieces of white fir was arranged to be conducted at the University of Idaho. Just before leaving on a trip the raw data from these tests was handed to me. Although no statistical analysis had been made at that point it was evident from study of the charted data that the modulus of elasticity was going to be a good measure of the modulus of rupture of structural lumber. Subsequent statistical analyses proved this to be true with coefficients of correlation in excess of 0.7 in most of the material tested.

Subsequently numerous reports by other investigators have further substantiated the good correlation between modulus of elasticity and modulus of rupture.

At the recent WSU Symposium on Nondestructive Testing it was apparent that machine stress rating has received international recognition. For example Dr. F. Kollmann from Munich University seemed to be giving machine stress grading enthusiastic endorsement at the Spokane meeting. I was highly surprised but of course gratified by the broad acceptance of machine stress grading apparent at the WSU Symposium. I am sure that anyone who might still think that machine stress grading is on a trial basis would surely have recognized at that Symposium that we are long past that status in this type of nondestructive testing. Obviously, of course, even though the trial basis is ended all parties concerned are continually seeking improvements in the method.

The original Potlatch tests to form the basis of a proposed grade were conducted on five northwestern species and southern pine. These tests included about 2500 commercial size pieces of lumber ranging from 2x4's to 2x10's and from low to high visual grades. These tests were made with the member tested as a plank because it was conceived that the ultimate machine would be measuring more accurately if the deflection was induced on the flat side instead of the edge.

The correlations were highly satisfactory with this type of measurement.

Subsequently many other species have been investigated to establish possible correlations between modulus of elasticity and modulus of rupture. For example recently Dr. Kollmann reported on Baltic redwood and white wood and also on a European pine. In each of these cases good correlations were shown through statistical means between modulus of elasticity and modulus of rupture. Senft, Suddarth, and Angleton were among the earliest to consider the relationship of modulus of rupture to modulus of elasticity as well as other physical properties of wood.

The CLT-1 machine for example provides an accurate measurement and grade stratification by stiffness of the piece passing through the machine. By means of the previously mentioned test a regression line has been established for the several species so that for each modulus of elasticity grade an average modulus of rupture can be determined. A working stress in bending has been derived from this average modulus of rupture primarily following the classical reduction factors, omitting of course the grade reduction factor on the basis that the machine provides this measurement. In general the application of the classical reduction factors results in a working stress in bending being approximately equal to 0.24 of the average modulus of rupture of each grade.

If working stress in bending is indicated on the chart along with the regression line it is readily observed that the line for working stress diverges from the regression line as the E value increases. This situation results in a somewhat lower efficiency in the use of the true strength of the wood particularly in the higher grades. Although this situation was recognized at the outset of establishing working stresses the procedure was recommended primarily because it was felt that adoption by codes and regulatory bodies would be much more readily obtained.

This reduction in potential bending stress values in the higher E classes would appear to be one of the more challenging and at the same time beneficial areas of work to try to find a statistical as well as generally acceptable method of making the line for working stresses more nearly parallel to the regression line.

At about the time grades were being prepared for machine grading, increasing concern about tension parallel to grain values was being expressed. Consequently, the values for this property were set at 80 percent of the fiber stress bending values. Subsequent tests have indicated that this reduction is realistic. One handicap of machine stress grading, however, has been that generally lumber is being sold under visual grades with the "f" and "t" values being equal. Competition has sometimes used this difference in values to suggest that machine stress graded lumber is inferior. Although association grading rules do not show a difference between "f" and "t", for visual graded materials, nevertheless the FHA Minimum Property Standards do provide for tension design values lower than bending stresses in visual grades.

Marketing of this new type of lumber requires intensive promotion as is the case with any new product. We recognized early in our activity that acceptance by regulatory agencies such as the Federal Housing Administration would be important to the success of the idea. Consequently even in the days of simply measuring modulus of elasticity we began reporting our activities to engineers in the Architectural Standards Division of Federal Housing Administration. As the modulus of elasticity to modulus of rupture relationship began to develop, this information too was passed on to FHA. As a consequence of these and other conferences FHA issued Materials Release Number 1930 on May 1, 1963. This publication has given machine graded lumber a great boost in the marketplace. Mr. Neil Conner and his Architectural Standards Division of FHA have received our commendation for this important assistance in the development of the new procedure.

Probably the International Conference of Building Officials was the next regulatory body to accept machine stress grading. Now practically all of the major code bodies recognize machine stress grades. But it has not all been smooth sailing--there is one agency that still says machine stress grading is fine but there will be no acceptance of values above those now in use for visual grading.

As Bob Hoyle recently said, one of the problems with the acceptance in the marketplace of machine stress grading is the tendency for people who do not understand machine stress grading to freely and bounteously express advice on the subject. It is interesting to note on the other hand that, insofar as I know, every engineer who has given us the opportunity to fully explain the complete program has endorsed the idea.

Since machine stress graded lumber was first introduced into the marketplace over 100 million board feet have been sold. We estimate that today 16 percent of the trusses used in the construction of houses are made with machine stress graded lumber. Thus machine stress rated lumber has been reasonably well accepted for one use in house construction but we have not been so successful in gaining acceptance for floor and ceiling joists and conventional rafters. We suspect that floor joists in particular are not so highly engineered as we sometimes have been led to believe. Furthermore, other changes in the structural grades of lumber may have also served to confuse our customers. Such things as load sharing and new sizes may have retarded the more rapid acceptance of machine graded lumber.

All of these developments have fundamentally helped to improve the position of lumber as a structural material but perhaps so many coming at one time have tended to confuse our customers. Nevertheless it is to be expected that there will be more new philosophies proposed as the months go by so that at least for an interval it would appear that the lumber manufacturers are going to be thoroughly confusing our best friends, the customers.

Probably the next big advance for machine stress rated lumber will be in the field of laminating. Preliminary work is under way such as important discussions with interested parties including the Forest Products Laboratory and the Association staffs.

Visual characteristics also play a part in machine stress graded lumber. In the first place customers have been accustomed to relating visual characteristics to equality so a high density piece with high structural strength containing some defects is difficult for many lumber users to accept. Furthermore, a person using a piece of machine graded lumber in its full length such as floor joists must restrict an end split of that piece more than the person who trims each piece before it is used, such as the truss builder. Furthermore, the homebuilder may feel that simply to impress his customers he must use a good looking piece of lumber regardless of what some grading association back in the Rocky Mountains might have stamped on the piece to show what its strength really is.

In conclusion machine grading is typical of any product. It has gone through many of the same growing pains; it has met many problems in the marketplace a disappointingly large number of people have created road blocks in the path of ready adoption of the product. It certainly has been necessary to promote it through aggressive marketing procedures. Nevertheless these are the challenges that every new product faces and it is the meeting and overcoming of these problems that determine the success or failure of any new product.

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THE ROLE OF THE FOREST SURVEY IN OBTAINING BETTER INFORMATION ON TIMBER QUALITY

By

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The basic charter for the Forest Survey contained in the McSweeney-McNary Forest Research Act provides for a comprehensive survey of present and prospective requirements for timber and other forest products in the United States, and of timber supplies, including the determination of the present and potential productivity of forest lands, and of such other facts as may be necessary to determine ways and means of balancing the Nation's timber budget.

Quality is not specifically referred to in this charter, but quality factors have been of basic and increasing importance in Survey work. In the latest appraisal of Timber Trends in the United States, for example, we attempted to emphasize timber quality trends as indicated by changes in species, tree size, and suitability of available material for different industries.

The ultimate criterion of timber quality would probably be in terms of dollar value, to reflect both suitability for consumer products and economic availability. For various practical reasons, however, we are concerned on the Survey only with measurement of specific physical attributes of the forest resource.

Current subject-matter requirements and procedures in the Forest Survey relate to quality of both forest land and timber resources, including:

1. Quality of the land, or site classification.
2. Quality of the tree cover making up the present forest.
3. Quality of standing trees.

Site Quality

In the early years of the Survey in the Pacific Northwest and parts of the South considerable emphasis was placed upon determination of site quality. Site maps developed from this effort proved to be quite useful for a number of purposes, including the guiding of land acquisition programs of some of our major timber companies. In the past few years, we have increasingly emphasized the need to classify forest lands in terms of inherent productivity.

The poorest forest lands we class as commercial can grow about 20 cubic feet of wood per acre per year. The most productive timber sites can grow more than 250 cubic feet per acre annually. Capacity to produce net revenues from timber management varies even more than these wide physical differences. Hence, it is apparent that classification of site productivity is of basic importance for such purposes as growth projections, economic analyses of timber growing opportunities, or planning of public and private forestry programs.

We classify commercial forest lands in 6 site classes, the lowest of which is 20-50 cubic feet per acre annually, and the highest more than 225 cubic feet per acre annually. In addition, forest lands are classed by 9 physiographic sites such as coves, flatwoods, swamps, etc.

We have made a good beginning in collecting such site information. But much remains to be done to improve site identification techniques and to develop significant implications for management.

Stand Quality

Several measures of stand quality have been used since the beginning of Forest Survey work, including the classification of forest cover by species, types and stand-size classes. These latter include (a) old-growth sawtimber, (b) young-growth sawtimber, (c) poletimber, and (d) seedlings and saplings. Such information on species and stand structure is of course highly useful in describing the forest resource, indicating general utilization opportunities, and appraising the outlook for future timber supplies.

Classifications of tree stocking also provide some measure of stand quality. For many years Survey information on stocking showed only the relative occupancy of land by "growing stock" trees, i.e., all live trees except those classed as culls because of defect or species. The techniques available for determining stocking, moreover, provided only rather crude estimates of the occupancy of land by such growing stock trees.

We have recently developed a new system of "area condition" classification which is designed to show the occupancy of forest lands by (a) desirable growing stock trees (defined in general terms as the type of trees that forest managers aim to grow), (b) other growing stock trees (including trees meeting merchantability standards but of relatively poor quality or vigor), (c) cull trees, (d) inhibiting vegetation (i.e., vegetation that precludes establishment of desirable forest trees), (e) nonstocked lands suitable for tree regeneration, and (f) nonstockable areas such as small bodies of water or rock. Such information is collected on a cluster of 10 variable plots distributed over an area of about one acre. In this way it is possible to take into account the distribution of trees as well as the total number of basal area of trees in a stand.

The 6 "area condition" classes now specified indicate the degree of occupancy by desirable trees. This information--along with data on site, species, and stand size or age--can in turn be interpreted in terms of the treatments required to increase productivity, including such treatments as timber stand improvement, planting, or stand conversion. These "area condition" classifications also can be used to stratify forest areas for economic analyses aimed at showing the costs and the economic benefits of investments in forest protection and management programs.

Tree Quality

Since the inception of the Survey, considerable emphasis has been placed on the items of tree species and tree diameter. Stand tables showing such information are basic to many phases of the Survey, including estimation of volume, determination of current growth, projections of future timber supplies, and general appraisal of utilization opportunities.

Stand tables obtained by repeat surveys in the South, for example, have revealed major declines in the total inventory of southern pine timber above 15.0 inches in diameter, and major increases in the inventory of trees from 5 to 12 inches in diameter. In some parts of the South, on the other hand, recent trends show a buildup in the volume of both large and small sizes of southern pine. Such information is of obvious importance to both the lumber industry and the newly developing southern plywood industry. The trend for large sizes of hardwood timber, particularly of preferred species, is definitely downward--again a matter of major significance to lumber and veneer manufacturers.

Since 1949 it has also been our policy on the Survey to obtain data on the log grade content of trees measured on Survey sample plots. While our experience with log-grading has been somewhat mixed, we consider this classification of quality to be of rather basic importance.

For hardwoods we are using the standard Forest Service saw-log grades at all Stations. In the case of many softwoods, however, satisfactory grades are not yet available. The log grades we have for different species, moreover, are based upon different criteria and often represent quite different classifications of quality. Even in the case of an important species such as Douglas-fir, the existing log grades for coastal and interior Douglas-fir bear no resemblance to one another. Thus data for different species cannot be combined in compiling State, regional, and national data on log grades.

In addition, we encounter some serious problems in the application of saw-log grades that were designed for use with cut products where interior as well as exterior defects could be ascertained. Most existing grades also are designed to indicate only lumber yields. Finally, we have found considerable difficulty in training the large numbers of temporary field men used on the Survey to grade trees by such log grades as are available, particularly sections above the butt log.

Partly because of these difficulties in training, we now limit log-grade estimation to the butt log of trees found on Survey plots. We hope that ways will be found to correlate the butt log grade with the quality of logs higher in the tree. We also hope that more use can be made of the log-grade data now being collected in interpretations of the timber situtation. As new log or tree grades are approved, these will be adopted in lieu of systems now in use.

In recognition of the need for a better system of evaluating tree quality, we have been developing a new classification of tree characteristics following essentially the same procedure as suggested by McCormack at the first Quality Conference held here at the Laboratory eight years ago. This classification is based on several readily identifiable and measureable characteristics of the individual trees found on Survey plots. These tree characteristics include (in addition to species, diameter at breast height, and the saw-log grade for the butt log where saw-log grades are available) the following items:

1. Surface defect. This refers to the number and size of limbs, knots, or other visible surface indications of degrading defects in the merchantable part of the bole. For softwoods, surface defect is indicated by a knot index "K", based on the number, size, and soundness of limbs and knots in specified sections of the bole. For hardwoods (and probably for softwoods also in the future) surface defect is recorded in terms of the number of 2-foot clear faces in the tree face towards point center. The "K" and "clear face" count is recorded in 10 classes to permit different classifications of trees for products with different minimum specifications. Minimum "K" and "clear face" counts are specified for "desirable" trees. Tree class specifications for smaller trees make allowance for anticipated over-growth of defects with increases in tree size.

2. Internal defect. Estimated product losses in board feet resulting from internal defects such as rot, deep splits, and cracks are recorded in 10-percent classes.

3. Sweep and crook. Board-foot volume losses in the saw-log portion of sawtimber trees, resulting from sweep and crook, or prospective losses at the time of harvesting on smaller trees, are recorded by 10-percent classes.

4. Relative bole length. The length of the bole expressed as the ratio between the actual bole length to the merchantable top and the normal bole length for the site in the absence of deformities such as forks, crooks, broken top, or excessive taper not related to site, is recorded in 10-percent classes.

5. Crown ratio. The proportion of the total tree height that supports live green foliage that effectively contributes to tree growth is recorded in 10-percent classes.

6. Crown class. Trees are classed as (1) open grown, (2) dominant, (3) codominant, (4) intermediate, or (5) overtopped.

7. Damage. Nine codes are used to classify damage or presence of pathogens, including damage from insects, disease, fire, animals, weather, logging, or other cause.

These seven items are used to classify each tree into one of four tree classes including (a) desirable trees, (b) other growing stock trees, (c) sound culls (or rough trees), and (d) rotten culls. The first four of these items relate to quality of trees for products, while the latter three relate to tree vigor and thus to suitability for management.

Some interpretation of the significance of these tree classes, together with species and diameters, must necessarily be made by Survey analysts in terms of specific product suitability and implications for management. Portions of the inventory volume meeting certain specifications, as for pulpwood or veneer, can be determined by appropriate classification. Also, since specific characteristics are recorded, tree classes may be redefined at future dates if desirable to meet special needs. Continued cooperation with the log and tree grade projects will be essential to relate field observations to approved tree grades.

Trends in Quality

These new classifications of trees and stands are being made on permanent Survey plots that will be remeasured at intervals ranging from a schedule of 8 years in the South to 15 years in Alaska, with an average of 10 years in most regions. Remeasurement of identical trees on these plots should not only provide accurate estimates of trends in forest condition and total timber volumes, but will also provide specific information on trends in timber quality.

Wood Density

The measures of quality discussed thus far pertain largely to external characteristics of trees. We have of course also been rather deeply involved in a cooperative program with the Forest Products Laboratory to evaluate specific gravity, as indicated in other papers and discussions at this Conference. Beginning with the resurvey of Mississippi in 1956 it has been our policy on the Forest Survey to cooperate with the Laboratory by collecting increment cores from softwood trees tallied on Survey sample plots. In the West some cores also have been collected from cottonwood, bigleaf maple, and alder. The Laboratory has determined the specific gravity of these cores, and has conducted supplemental investigations to relate core density to tree density.

This program to date has been limited to the South and West. Thus we have not yet covered the Central, Lake States, and Northeast but this can be arranged if desirable.

We have assumed that collection of cores would be limited to softwoods, and that collection of cores during one survey cycle would be sufficient to establish the average and range in core density for the species covered.

Under our new procedures in which Survey data are obtained by remeasurements of permanent plots, we have not contemplated boring trees, partly because growth will be determined from changes in stand structure and volume, and partly because it appears essential to minimize damage to tallied trees. In the case of hardwoods, particularly, there appears to be a serious possibility of introducing disease and thereby increasing cull and mortality. Even a limited amount of cull or mortality on a plot resulting from boring trees would be multiplied many times in blowing up data to a Survey unit. Also, most of our plots are taken on private land and care obviously must be taken to minimize damage.

The future of this program is thus a bit uncertain. We have anticipated that discussions at this meeting would provide some additional evaluation of this program and some guidelines for judging the need for additional collection of cores.

To summarize briefly, the Forest Survey is concerned with a resource characterized by extremely wide variations in many variables relating to timber quality and value. We have been placing increased emphasis on measurements of all these variables, including (a) the inherent site productivity of the land, (b) the condition of the present cover, particularly as related to management opportunities, and (c) the quality of individual trees in terms of both exterior and interior characteristics. Survey data are used for many and diverse purposes. We are therefore attempting to achieve the best balance possible in the collection of data on all aspects of timber volume and quality.

WOOD QUALITY RESEARCH OPPORTUNITIES IN EASTERN SCHOOLS

By

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Wood quality research is being interpreted very broadly in this statement on the opportunities and challenges in this area for eastern forestry schools. Although wood density has been the primary emphasis of this conference, there are many other aspects of wood quality of great economic importance and scientific interest that need added research. Wood quality involves, in addition to density, all of the defects, compression wood, tension wood, interlocked and spiral grain, knots, discolorations, wetwood, stain, decay, and many other quality-influencing factors.

As has been brought out at this and previous conferences on wood quality, wood quality research is not the exclusive province of the forest products specialist, wood technologist or engineer, even though it is in the utilization area that quality becomes critical. The physiologist can play an important role in such research in determining the relationship between nutrition and other growth factors and quality. The ecologist, silviculturist, and forest manager largely determine the systems under which trees are grown, which can have a major influence on quality. The geneticist or tree improvement specialist has already clearly indicated his important role in improvement of wood quality. The forest pathologist and entomologist have contributed abundantly in this research field and will no doubt play an equally important role in the future. Many other disciplines have been and will continue to occasionally become involved in and contribute to this research.

Wood quality research, when thus broadly interpreted, can be engaged in by a wide variety of individuals with very diverse backgrounds and interests. It is a research area to which individual specialized research workers can contribute. It is likewise an area involving complex problems that only a team effort by a number of individuals with diverse backgrounds can hope to encompass.

The Eastern Schools

The eastern schools are considered those lying east of the Great Plains. Within the hundreds of educational institutions in this large area, wood quality research in the past has been concentrated primarily in the schools, colleges and departments of forestry. A noteworthy exception to this is Lawrence College at Appleton, Wis., which through its association with the Institute of Paper Chemistry, has made and will no doubt continue to make occasional contributions in this area. Also, the University of Wisconsin may be considered somewhat of an exception because, until recently, it has not had a department of forestry; but through its association with the U.S. Forest Products Laboratory on graduate study programs has made some significant contributions to wood quality research. Engineering schools occasionally have individual staff members with interest in wood quality. As the wood quality factor is better recognized in the wood processing industries, the engineering schools may increase their interest.

The eastern forestry schools number 34, and the total is growing, with the addition of new schools in Kentucky and Tennessee in recent years. All of these schools have one or more staff members offering some instruction in forest products and are similarly staffed in the forest production areas involved in wood quality research. There is thus possible potential in all of these institutions for contributions to wood quality research. However, such potential may be slow in developing in more than one-half of these schools. The individual forest products staff members of the smaller eastern forestry schools, those with staffs of up to 10-12, are normally so occupied with undergraduate teaching and the institutions are so poorly equipped, that they have little opportunity for research of any type. Because of the demanding nature of wood quality research, the prospects of the majority of these institutions making truly significant contributions to this research area are somewhat questionable, at least for the immediate future. The picture is not changed appreciably even though we include as existing or potential contributors the occasional geneticist, physiologist, and ecologist at these institutions interested in and capable of making indirect and occasionally direct contributions to wood quality research. They too are so involved in undergraduate teaching and so poorly equipped that their contributions will not loom large in the total effort.

The real potential for wood quality research contributions on the part of eastern forestry schools for the next decade appears to lie in the 12-15 schools that have broken the one- and two-man forest products and other specialization staff barrier, have developed graduate study programs, have facilities and equipment, and a modicum of time for the concentrated effort required for real contributions. Included in this group is the New York State College of Forestry at Syracuse, whose program far outranks in size, facilities, and funding, that of the next largest institution. Fortunately, the eastern institutions with present potential for wood quality research contributions are reasonably well distributed, thus assuring the possibility of attention to the abundant and varied species that make up the eastern forests.

The Dual Function of Schools

An important point in connection with the contributions of schools to wood quality research that must not be overlooked is the training of graduate students, the research personnel without which no discipline can long endure or prosper. According to Ellis[1] 13 eastern forestry schools have granted a total of 715 Master's degrees out of a total of 913 such degrees granted in wood science and technology up to 1964. The same author reports that the 8 eastern forestry schools granting Doctor's degrees with specialization in wood science and technology awarded 158 of the 176 such degrees for the same period. During about the same period the Institute of Paper Chemistry through Lawrence College granted a total of 300 Master's and 200 Doctor's degrees. However, there is some question as to the significance of the latter large and important graduate training program to the area of wood quality research.

The potential for greater contributions by forestry schools in the graduate training area was considerably enhanced by passage of the McIntire-Stennis Cooperative Forestry Research Act. This Federal program recognizes the importance of graduate training to the total forestry and forestry related research area. As this program develops, it should help provide increasing numbers of trained personnel to conduct the necessary wood quality research of the future. A valuable by-product of such training can be research contributions by the Master's and Doctor's candidates on limited, well-defined but important aspects of wood quality research.

[1] Ellis, Everett L. Education in Wood Science and Technology. Society of Wood Science and Technology, Madison, Wisconsin. 1964.

Suitability of Wood Quality Research to Forestry School Attack

Few areas of forestry and forestry-related research offer better opportunity for study by forestry schools. This is due to the tremendous range and variety of problems involved in wood quality on single species. Multiply this potential with individual species by the number of commercial eastern softwood and hardwood species requiring attention, and the possibilities for research projects suitable for graduate student and forestry staff study becomes almost limitless.

With the exception of a few of the larger schools, most of the problems selected for study must be of a rather limited and reasonably well-defined nature if the contributions are to be significant. We typically attempt to include too broad an area in our graduate training and individual staff member research projects, usually with the result that we deal in superficiality and not depth. The delineation and development of clear-cut encompassible research proposals usually requires more imagination, time, and concentration than does the sketching of broad and poorly defined efforts. Forestry schools have been particularly guilty in the past of attempting to cover the waterfront in research programs. It is a common failing. It must be guarded against in the future if what is done is to have real significance in the total wood quality research effort.

Some forestry schools are well equipped to undertake studies involving interdisciplinary approaches. A team consisting of a wood technologist and plant physiologist can better attack research problems involving the effect of tree nutrition on wood quality and growth than can either alone. The same situation applies in case of wood quality studies involving ecological, silvicultural, and genetic relationships.

Forestry school personnel should consider possible joint projects with the forest products industries and the U.S. Forest Products Laboratory on wood quality problems. The increasing attention being given wood quality by all segments of the forest products industry should provide increasing opportunity for productive joint efforts on such problems as increasing pulp yields. The outstanding regional wood density studies of the U.S. Forest Products Laboratory leave many local studies on individual species unexplored. The schools would appear to be in excellent position to take advantage of these situations and develop joint projects with the Forest Products Laboratory to fill the existing information gaps.

Emphasis on Basic Research

The forestry schools are generally better equipped to engage in well-defined and carefully delineated basic or fundamental research projects in the wood quality field than they are in applied or development research. Also, at the present stage of development of wood quality research, this is the area that needs major attention. Until we learn far more about the basic problems influencing and determining wood quality, such as nutrition, growth rate, competition, age, etc. applied or developmental research will be seriously handicapped.

This desirability for emphasis by the schools on basic research does not mean exclusion from or lack of attention to applied or development research when there is need and suitable problems are available. Nor is it meant to imply that fundamental research is the exclusive domain of any one group and applied or developmental research of another. The distinction between fundamental and applied research is frequently largely a matter of definition and separation into two clearly defined areas is impossible.

Special Problems Within the Schools

With the growth of forestry school staff there is normally increased specialization and segmentation. Forest products staffs become divisions, frequently with only tenuous ties to the forest production staff. When such specialization and separation occur, there may be lost the opportunity for communication and discussion between the forest products specialists and the silviculturist or forest manager, the physiologist, and geneticist.

In recent years there has been less rather than more emphasis on wood-quality aspects of forestry by some forest products staff members, particularly those without training or experience in forestry or appreciation of the multitude of factors involved in the growth of trees. Forest products specialists have largely accepted the product produced by the forester without sufficient attention to the basic factors that make this raw material what it is. Granting that the production of important changes in such a raw material as wood is a long range proposition, this does not excuse lack of attention to it because of specialization and less interdisciplinary effort.

Additionally, it must be recognized that the staff time available for research at most schools is limited. Therefore, research undertaken is normally in fields of value to staff and graduate student development, or in areas where special needs have been expressed. Until the expression of need for wood-quality research is equal to that for product oriented research, the research area you are examining and discussing will not receive the attention it deserves.

Although, as indicated above, there is room for a wide variety of research in the wood quality field, for the specialist as well as generalist, it will take team effort in case of specialists or broad training in both products and forest production in case of generalists to put together the pieces of this complex research area. Products specialists need some training in timber production, and forest managers need more exposure to forest products in order to speed progress in this research field.

Conclusions

The eastern forestry schools have been, are, and no doubt will continue to be the principal contributors to wood quality research.

Although all schools have some opportunity for contributing to this research, the 12-15 larger schools would appear to offer the greatest potential for expansion of research on wood quality.

The variety and abundance of wood quality problems available make possible contributions by individual specialists as well as through teamwork by specialists from several disciplines combining on more complex research involving growth and utilization problems.

There is some danger that the separation of forest products training from forest production training could result in less recognition of the opportunities for wood quality research. It will be up to the user to emphasize the importance of wood quality research if this area is to receive the attention it deserves.

The new McIntire-Stennis program, the increasing cooperative effort between the Forest Products Laboratory, and other U.S. Forest Service groups, and the forest schools, as well as the greater cooperation between industry and the schools, should help insure continued and increased research attention to wood quality problems in the future.

RESEARCH OPPORTUNITIES IN WESTERN SCHOOLS

By

FRED E. DICKINSON, Director

Forest Products Laboratory
University of California

While the theme of this symposium is density--a key to wood quality, I propose to address my remarks on research opportunities to a much broader topic: the entire area of wood quality. I am defining wood quality as the usefulness of a particular wood for a given purpose at a given time and place. Consequently, investigations which have the potential to influence this usefulness in any way must be considered. Thus, research in this field covers not only the technical properties of wood but also the factors which may be used to modify these properties: e.g., growth conditions, chemical and physical treatments, and tree breeding. Furthermore, economic aspects cannot be overlooked, as the choice of a particular species for a particular use at a given time and place will be governed, in part, by the economics of harvesting, transport, and conversion.

For purposes of this presentation, western schools are defined as colleges and universities located in the Rocky Mountain, Intermountain, and Pacific Coast states. Before giving consideration to the research opportunities in the several schools in this region I wish to present the following criteria which are important in assessing the opportunities for research at any college or university.

1. How much interest and ability have the faculty and research personnel and do they have time available for research?

   The interest and availability of the personnel are usually easier to ascertain than is their research ability. In many colleges and universities the faculty have such a heavy teaching schedule that little time is available for them to do the research in which they may be interested. In judging research ability we must rely on their past research performance or, in the case of a junior faculty member, on the recommendations of others.

2. Is there an active research program in wood quality or some closely related field?

   The expansion of an existing program is normally much easier than the initiation of a completely new one.

3. Is there a strong, active, graduate program, particularly at the doctoral level? Does it encompass some or all aspects of wood quality?

   Faculty members at institutions with good graduate programs are generally much more research-oriented than at institutions where the principal emphasis is on undergraduate teaching. Graduate students--master's and doctoral--are looking for challenging research problems and usually the faculty is looking for financial support for good students.

4. Are adequate research facilities available?

   While we all may revere the philosophy that it is the man who counts in research, not the tools, we must recognize that many if not all of the research areas touching on wood quality require some hardware. Moreover, the computer is becoming an indispensable tool in this research field as in others.

5. What is the publication record of the faculty interested in wood-quality research?

> Researchers at educational institutions may fail to publish their findings, either because they don't want to be bothered by writing or because the research is not worth publishing. The quality of his publications is the best single yardstick I know of to judge the quality of a researcher who is free to publish.

While the faculty in many departments in western colleges and universities could conduct or be interested in research relating in one way or another to wood quality, interest in wood research of any kind is confined almost entirely to institutions that have forestry schools. However, not all such institutions are conducting wood-quality research. The research opportunities at some of these schools are very meager, either because personnel or facilities are lacking or because emphasis is on other fields. Thus, of the eleven western universities and colleges that have forestry programs leading to the bachelor's degree, only six offer significant research opportunities at the present time, by the criteria given above.

At some of the six schools, faculty members of departments such as engineering, genetics, economics, chemistry, and others have shown interest in forestry and forest-utilization problems and add to the research opportunities in the forestry department.

A special research situation exists at three of these universities--University of California at Berkeley, Oregon State University, and Washington State University. Each has a forest product research organization staffed with well-qualified personnel who devote the major portion of their efforts to research. Oregon State University, in addition, has a research group in forest management.

While opportunites for wood-quality research are most apt to be found at some of the universities and colleges that have forestry programs, I would be remiss in omitting mention of other schools with evident research interests in facets bordering on the broad area of wood quality. For example, members of the faculty at the University of California, Santa Barbara, and at the University of Oregon are interested in economic studies of the forest products industry; the California Institute of Technology has a long history of plant physiology research.

In closing I wish to present the following points:

1. Faculty members in departments of forestry and closely related academic departments and research institutes are more research-conscious than they were as short a time as a decade ago. They are better trained for research and are interested in conducting and having their graduate students conduct research meeting the same standards of quality as exist in other areas of basic and applied science. Thus excellent opportunities do exist, particularly at certain schools, for productive research in wood quality.

2. Speaking as a faculty member, I can say that we recognize that one of our very important charges is to prepare the scientists of the future--both the immediate future and beyond--for industry and the public research agencies. These, in turn, can and do lend valuable assistance by bringing research problems to us--together with financial support for this research.

3. While research findings by faculty, research staff, and graduate students at the universities and colleges will make an increasingly important contribution to our knowledge of wood quality and other areas equally important in the broad field of forestry, our major impact on research must be in training future scientists. A matter of no small concern to many of us engaged in graduate programs is that of student recruitment. You in the public research agencies and in industry have research positions to fill and we have staffs and facilities to prepare the scientists. You want an ever-increasing number of scientists but we are not getting an ever-increasing number of young men and women coming into our graduate programs. This is an important problem to all of us, and I wish to suggest that Dr. Harper and his staff as heads of the greatest forestry research organization in the United States give thought to it. I am sure that my colleagues would join me in saying that we are more than willing to work with them in finding solutions.

NEEDS IN THE FOREST PRODUCTS RESEARCH AREA

By

EDWARD G. LOCKE, Director

Forest Products Laboratory, Forest Service
U.S. Department of Agriculture

For the past 2 days you have been taking a long, hard look at wood quality. I am sorry that I could not be with you for the entire session, but I have been in Washington. Even jet aircraft haven't quite succeeded in revoking the familiar physical law that a body can be in only one place at a time. In these circumstances, I was fortunate to have a very capable person, Wally Youngquist, act for me while I was gone.

I assure you, however, that I have been very much with you in spirit. This whole subject of wood quality has been one of my major interests for a long time. The papers and discussions which I have been able to hear since returning yesterday have left me with one dominant impression: A lot of other people are keenly interested in quality, too, and are thinking hard about it!

We have come a long way since that Forest Service meeting of 8 years ago when some of us here today got together for a preliminary session on what quality is, and what might be done about it. It may seem incredible to you, as it does to me now, but such a meeting as we are concluding here would have been completely impossible so short a time back as 8 years.

I do want to discuss some needs for wood quality research in the forest products area. Various speakers have already expressed some cogent thoughts on this subject; in fact, I doubt if there has been a speaker who hasn't at least by implication, referred to product research needs.

Since our main topic has been wood density as a key to quality, I shall not dwell on it. As some speakers have brought out, much work is urgently needed to develop other keys, even while we continue to increase our competence with this one called density.

Walt Smith, for example, has pointed out that specific gravity, which tells us much of what we need to know about the suitability of softwoods for most end uses, is not a good index to the quality of the cabinet hardwoods.

In passing, though, permit me to make just this one observation: Keys have a dual function; they serve to lock things up as well as to unlock them. In using these keys to quality, let us not inadvertently twist them the wrong way. This, of course, is an occupational hazard of research workers and must be guarded against constantly in the laboratory. But it is also a hazard to be kept constantly in mind by any user of research findings.

So density is not a skeleton key that will open any lock. The user who thinks it is has a jarring discovery ahead of him.

Quality is a pervasive thing diffused through everything we use. When we buy something, our chief concern is its quality. We ask ourselves, is this worth the money? Can I get something better for the same price or less? Should I pay more for something better? I think there is a fundamental lesson about quality here. One can make a thing too good--too costly--as well as too bad--too cheap. But there is always a minimum, a quality floor, as well as a maximum, a quality ceiling. It is our problem to provide for both insofar as we can. There is a reason why we sometimes hear the Volkswagen referred to as the Cadillac of the compacts. That reason is built-in-quality--the most for the money. On the other hand, what American car manufacturer competes with Rolls-Royce? Here is the ultimate, but it has a very restricted market.

So, in the Laboratory, we need to think about quality in terms of the cost of the delivered consumer product, whether that be a house, a table, a baseball bat, or a box. And what sets the boundaries of our thinking? The price at which competing products of other materials can be bought is one factor; but another, and one that is often overlooked, is the price the consumer is willing and able to pay--provided he is convinced that he is getting his money's worth. In short, are we aiming at Volkswagen customers--or for the mass market filled by the Chevies, Fords, Chryslers, and other "in-betweens?"

I think the answer lies in the department store concept of "something for everybody," whose greatest exponent these days isn't Macy's or Gimbels but General Motors. But let us make sure that at any given level we are providing the best quality possible.

As Dr. Harper pointed out, many complications arise when one attempts to develop a long-range plan for improving the quality of forest products. For the present, he suggests that we should concern ourselves with timber quality as we find it. Today's forest stands will have to support our forest industries for many years to come. There is urgent need right now for detailed study of existing timber supplies if they are to be most efficiently utilized for the manufacture of lumber, plywood, and pulp and paper products of various qualities to meet the department store concept.

Dr. Harper further stated that the ultimate value of timber quality data may lie in their use for decision making about entire production systems, from stump to market. Much greater effort is needed to develop modern mathematical tools to make such operations research effective within a minimum of time.

Alan Smith pointed out that efficient strength values for lumber and plywood are essential on account of the present high cost of material. Lack of technical data has greatly hindered the lumber industry in solving many problems in the past, and more research, such as the density survey, will be needed in the future. He feels that such research will stimulate the production of better products and will lead to the growing of better trees in a shorter time.

Eric Anderson's survey of current work in all the interested schools in Canada and the United States shows that much research is under way on the effect of density on tree quality. He especially mentioned the research on cell wall dimensions and how that work ties into density. Much research is needed on the effect of environmental factors and the use of fertilizers. He particularly stressed that work on hardwoods has been neglected mainly because of the complicated nature of the structure of hardwoods compared with softwoods.

Joe Liska pointed out the need for research to determine ways in which the effect on strength properties can be predicted for various moisture content changes.

John Wollwage stated that the proper use of density data could amount to a saving of $300,000 per year for a kraft mill producing 200 tons per day and that the use of density criteria and economics in pulp making is only one of the many uses that can be made of these data. Further research is needed by the pulp and paper industry so that they can tell the geneticists what kind of fiber is needed for a specific quality product.

Dick Kimbell said that the density survey data will give a greater degree of reliability to the structural use of wood than has ever been possible before, and that more research is needed.

Maurie Rhude said that if he wanted to open a new plant in the West Coast region on Douglas-fir or in the South on southern pine, the density survey would determine where he would locate the plant. However, if he wanted to locate in New England, he would be at a loss, because research is needed to provide similar density data for that area.

Tom Orth related his experience in establishing standards for southern pine plywood, including their discovery that the density values for stem wood did not coincide with those obtained from veneer made from the same wood.

Bob Seidl in a very interesting paper pointed out that economic intelligence and technical intelligence are needed for forestry planning. He indicated that perhaps technical changes in the use of wood would have a greater influence than would geneticists or foresters on the use of the forests of the future.

Ted Bercaw stressed the need for more research on what happens to wood quality in processing. Is high-quality wood blended with lower quality wood in a 60:40 ratio, or what? He pointed out that more information is needed on the diameter of tree that is most economical to harvest with existing equipment.

John Hess expressed confidence that a streamlined method of determining strength of plywood will be developed and called for more research on the properties of plywood in relation to those of laminated and solid wood.

George Englerth has reported to you his findings and conclusions of a Service-wide analysis of the extent to which quality is involved in our Forest Service research and timber management activities. In it he has made two points that I would like to reiterate here:

1. Although we can look for great changes in technology, these changes will not for the most part change end-use requirements.

2. End-use requirements are of primary importance in any consideration of quality, but processing requirements must also be considered. Unless the wood can be machined well, for example, it may prove unsuitable for an end use regardless of its strength, color, dimensional stability, or other quality attributes.

By far our oldest and most widely used quality keys are visual grading rules for lumber. As you know, those for yard lumber are based on the size and distribution of certain characteristics such as knots, pitch pockets, checks and splits, and cross grain; those for structural lumber on ring count, percentage of summerwood, and the like, as well as the yard-grade characteristics; and factory and shop grades on the size and number of cuttings obtainable from the piece. The yard and structural grades are based largely on experience, although a certain amount of destructive testing has been done to verify their primary assumptions.

As quality keys, these lumber grades are about the best thing we have in commercial use at present. They have filled a need; but they are cumbersome and costly, subject to judgment error and manipulation, and the sooner we find better and more precise ways of evaluating lumber for various uses, the better off both producer and consumer will be. Laboratory evaluations of light framing lumber have demonstrated quite clearly, I think, that visual grading is wasteful and insufficient.

This is one of our most urgent areas of research. If our engineers are to do a more efficient job of design and development of structural elements, building components, and the like, they must be given material whose strength and related properties are much more precisely established, piece by piece, at the mill. The variability of wood demands that this be done. Mechanical proof testing is one possibility; vibrational characteristics and radiation interactions are others.

But more precise evaluation of strength properties is only one need in this area of structural research. Dimensional stability, as controlled by moisture content, is another. Present methods of quality control in kiln drying are based on sampling. But again, the variability of wood is such that considerable variation in moisture content can exist as between pieces in a kiln truckload. What is needed is a method of moisture content determination that instantly registers the condition of each piece on the production line--possibly even in the kiln. There are several promising possibilities in nuclear radiation techniques, notably nuclear magnetic resonance, that warrant developmental research.

Dimensional instability is one of the points of attack often singled out by promoters of competitive structural materials. It therefore behooves us to devote all the resources we can to strengthening this point. Others similarly in need of strengthening are the decay and insect hazard and combustibility. You're all familiar with the siren song of TV announcers--their products don't warp, split, shrink, rot, or burn!

These bring us up against consumer preferences and prejudices that must be considered to the fullest extent possible.

Harold Worth, in considering consumer preferences, suggested the following definition: "Quality is a systematic means of deciding the suitability of a product for the intended use."

I don't think anyone in this room will ask why, since creosote is such an effective preservative, we don't use it extensively in substructures of houses to fend off fungus and insect attacks, or in window frames and other millwork where moisture can set up a decay hazard. True, we have superior preservatives now with respect to freedom from odor, paintability, and the like. Much better, however, might be a nontoxic treatment that takes something out of wood--an essential nutrient, perhaps--rather than putting something in. Here thiamine depletion is a possibility.

Chemical treatments available to armor wood against fire are even cruder and more limited in application than those designed to check decay and insects. We have a much longer way to go here--a way that must be charted by basic exploration of the chemistry of pyrolysis and combustion.

What I have said about lumber applies in general to veneer and to plywood, to laminated wood, and even particle board, hardboard, and other structural fiberboards. The same evaluational handicaps with respect to strength and durability confront us. Somewhat different techniques may be needed for their solution. For plywood, of course, gluing requirements must be considered. Even localized wet spots in veneer can affect glue-bond integrity, as may treatments with preservatives or fire retardants--or, for that matter, extractives and other chemical components of the wood itself.

And as we devise treatments to protect wood from its natural enemies, we must assess them for what they may do to its strength. Will they corrode fastenings? What about the weather resistance, the finishing characteristics, and other critical end-use considerations? We are only beginning to embark on new studies of environment, using meteorological concepts. Already, however, our research is acquiring new dimensions through this approach--dimensions that help outline the potentials as well as the problems. And the tools of physical and polymer chemistry are assuming new importance for the solution of problems of adhesion, cohesion, protection from ultraviolet and other types of degradation, and surface stabilization. We are learning, for example, that a degree of dimensional stabilization entirely adequate for certain end-use service conditions can be achieved by a dip treatment in phenolic resin, rather than 100 percent impregnation. The resulting stability gradient may prove adequate to assure much longer lived finish coatings. This is in line with the point I emphasized a few moments ago about the department store concept of quality.

Much the same kind of problems exist with regard to wood fiber products. Every processing innovation, from chipping and pulping to the final surface sizing of the sheet, has implications from the end-use standpoint. It isn't simply a question of how much pulp or paper from a cord of wood. How will strength, dimensional stability, opacity, color, ink holding and other printing quality criteria, corrugating and gluing properties--the whole gamut of end-use requirements--be affected? And these are not just the end-use requirements of paper and other fiber products familiar to us today.

Paper is still in its infancy as a structural material. Except for some pioneering work done over the years for packaging uses--pioneering work that was basically responsible for the great advances of the engineered fiberboard container--we have largely ignored paper as a potential structural material. Even the standard empirical strength tests--such as bursting and tear--have evolved strictly for old-line applications and bear no relation to conventional engineering strength concepts. Yet we are increasingly using paper in combination with wood and other materials for structural purposes. That trend will undoubtedly continue, to what ends and for what end uses we can now only guess. But that we must keep abreast of this trend, to guide it and foster it, there can be no doubt at all. And we must not forget that the Fourdrinier method of forming paper may be supplanted with entirely new properties, and we may get thereby a new fiber sheet product.

We have seen what can happen when a new material suddenly surges into big markets. Such a one has been particle board. Many millions of square feet were made and sold by companies large and small, each with its own quality requirements from raw material to end product, before the leading producers got together to form an organization and work out quality standards. In fact, a commerical standard for particle board is only now moving through the acceptance procedures of the U.S. Department of Commerce--and the basic engineering properties have still not been adequately assessed, although we are working on them. Fortunately, the uses to which this highly promising material is being put are not, in the main, structural ones, although there can be no doubt that such uses will soon come.

I have mentioned our environmental research. But deteriorative factors are also at work indoors. We need to know about them if end-use quality standards are to be applied to wood-base products. For example, we have established that paper aging follows a path analogous to other chemical reactions. This finding provides a pattern for related studies on other wood-base or wood-originated products.

Up to this point I have explored with you the pertinence of quality with respect only to some broad areas of end uses. I haven't even touched upon the product quality considerations of harvesting and conversion requirements and tree and wood characteristics affecting end use. Forest products research has in the past contributed many guides to the control and improvement of some of the factors and characteristics in these lists. Some highly reliable, if largely empirical, guides to timber management have come from studies, for example, of stand density, crown size, and rate of growth on wood properties. Every forester today is--or should be--familiar with them. And yet I sometimes wonder, when I hear enthusiastic talk about how fast a plantation shot up to pulpwood or even sawtimber size--as if fast growth were the sole criterion.

There remains much to be learned about silvicultural and quality relations, even though we in product research have sometimes grown impatient with the rate and effectiveness with which existing knowledge is put to work. Perhaps a single example of what lies ahead will demonstrate my meaning better than anything else. We have in final preparation now a paper, in cooperation with the Central States Experiment Station, in which we report some findings regarding the machining and other properties of several hardwoods that received fertilization some 30 years ago. Ash, yellow-poplar, and oak all were found to respond strongly to nitrogen fertilization. Despite a 300 percent increase in diameter growth rate, no adverse effect on shaping, turning, planing, and other machining properties was discernible in our evaluations. And the effect of the fertilization experiment--in which, incidentally, Harold Mitchell participated in his early forester years--carried over for much longer than had been thought likely.

Much more work needs to be done on the wood quality effects of fertilization. Other hardwood species need to be studied; what, for instance, would be the effect on black walnut? And of at least equal interest would be studies on how softwoods are affected.

We have been able to assess pretty well the significance of some wood characteristics that are readily measurable, such as knots and checks and pitch pockets. We still lack, however, as Englerth pointed out, ready means of measuring such quality-critical characteristics as cross grain and tension and compression wood. We have long made rough empirical use of knowledge about the importance of summerwood to strength. But we have no really good means, other than visual estimation, of measuring such vital factors as cell diameter and length, cell-wall thickness, fibril angle--all of which are significant from a quality standpoint.

And finally, we are still very far from quick quality-determining techniques for chemical utilization. Wood is our principal source of cellulose for rayon, plastics, explosives, photographic film, and many other chemical products. But, perhaps because wood of any kind is so superior to anything else as a source of cellulose, we haven't really bothered to seek some means of quickly evaluating wood from the standpoint of its cellulose:lignin ratio, for example. Certainly there are wide variations in this ratio, both between and within species--as great, perhaps, as specific gravity variations. But we do know this much: There is no relation between specific gravity and carbohydrate:lignin ratio.

These, then, are some of the areas in forest products research where we--and by "we" I mean the Universities and State Forest Products Laboratories as well as the Forest Service--we need to either increase or initiate research. If they sound pretty much all-inclusive, it is because they <u>are</u> all-inclusive. Practically everything from the gene structure of the seed cell to the finish coat of paint on a house affects end-product quality. It is our job to work, as best we can, on the most urgent problems. And those, if I may once again say so, are in large part dictated by the economy of the market place.

Competition can hurt, but it can also help. If another material has some advantage to begin with, we must match that advantage, at least to the extent that the market demands it.

It is our job in product research to find out how, and to send the necessary instructions over the complex network of quality controls to everyone from the geneticist and forester in the woods to the industrial planner in his factory office and the workman on the assembly line or building site.

SUMMARY REMARKS

By

V. L. HARPER
In Charge of Research

Forest Service, U.S. Department of Agriculture

My comments on the content of this wood quality symposium are under two categories:

First are my personal impressions of what some of the results or conclusions were. I have 6 points in this category.

My second category contains 3 points. These I am much surer about, and I label them points of agreement by all.

Personal Impressions

1. Wood quality as a term or concept is nebulous and is abstract--so much so that it has little meaning except as a generality. It is big, and you usually can see only part of it at a time. The part you see is one idea of forestry. It is difficult to focus on all parts at once--and probably not worth trying.

No matter how you try to explain it, wood quality is complex--probably because of lack of knowledge of properties and how to measure them and interpret items in terms of meaningful uses. That is the nature of things not well researched.

Recently I visited Agriculture Research at Beltsville in a party with Secretary Freeman. We were shown examples of research--completed research insofar as basic knowledge on a particular subject was concerned. One example was "What makes a hen lay an egg?" It seems the control mechanism is in the brain. The demonstrator had 3 hens. He injected a chemical in the blood of each hen and said that within 2 minutes each will lay an egg. True enough, each in its turn deposited an egg. The chemical did something to the control mechanism and down came the egg. The Secretary of Agriculture was impressed. It reminded him of the teacher who was instructing her young class in arithmetic. She said: "If I lay two eggs on this chair and then lay three eggs on this other chair, how many eggs will I have?" After a pause a hand went up. "Yes, Johnny, how many?" Johnny responded, "I don't believe there will be any eggs. I don't think you can lay an egg."

Well I am doubtful too that anyone can do much with the broad concept of wood quality that is meaningful.

2. My second point--or impression--is related to the first. It is a different slant. The broad concept of wood quality may not be meaningful in its entirety but it is an attractive generality that one can scarcely be against.

President Kennedy used a catchy generality when he said,

> "Ask not what your country can do for you
> Ask what you can do for your country."

President Johnson followed up with a variation of a general proposition. Speaking of material things of our citizens he said, "Ask not how much but how good."

It was only when he began breaking this general proposition down into specific proposals that the debate started: Civil rights, Medicare, war on poverty, wilderness legislation--all having to do with quality of living for someone.

One must break down the concept of wood quality into specific matters before we really see the significance.

3. My third point is that the arrangers of this meeting tried to break the subject of wood quality down to a specific subject of wood density and its significance for quality. And most speakers and discussers stuck reasonably close to this subject.

Some stuck right on the subject.

Some strayed a little to bring out the shortcomings of density.

Some strayed further to emphasize that quality after all may be overshadowed by changes in technology.

4. My fourth point is that wood density surveys to establish averages have been a useful step forward for some purposes, such as enabling ASTM to establish basic stress ratings of clear wood.

It also has been shown to have shortcomings or little if any meaning for some other purposes. At best it is an indirect way of getting at meaningful expressions of some aspects of quality. But density surveys are useful for certain purposes. They give average values. Unfortunately, average values may not help too much by themselves in judging a given tree or log and a product made from it.

5. A fifth impression that seems to have emerged quite clearly is that nondestructive methods of testing for specific aspects of product quality are needed. Research on this part of the quality question is lagging--maybe unduly so.

6. A sixth--and last of my personal impressions:

Technological changes should and will go on at a faster rate. This is the real salvation of the forest products industry. These changes may completely overshadow any attempt to breed quality into our future timber stands.

Points of General Agreement

Now, I come to the category of points on which I believe there is general agreement. I have three points.

1. First, all of you seem to have endorsed the proposition of more research on quality--on as many quality aspects as possible. Yes, I could go even further by saying you have endorsed more forest products research generally.

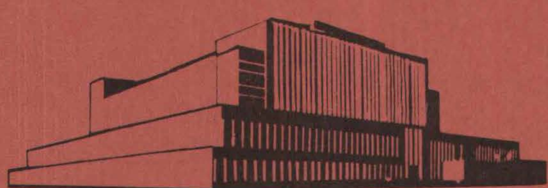
2. Secondly, I believe I am voicing a consensus when I say we commend the FPL staff generally and Harold Mitchell particularly, in arranging this conference. We are grateful to them for hosting the meeting. They have done a good job, a worthwhile job.

3. Thirdly, I believe you will agree with me that all participants have performed well. We have had frank expressions of views. And you have given them in a constructive spirit. We will profit from the results of the symposium.

Participation

Finally, a concluding comment: On behalf of the Forest Service and the Forest Products Laboratory, I thank all of you from industry, from universities, and from other locations of the Forest Service for coming to this symposium and for your presentations and discussions.

The FOREST SERVICE of the U. S. DEPARTMENT OF AGRICULTURE is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.



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