U. S. FOREST SERVICE
RESEARCH PAPER
FPL 45
JANUARY 1966

UNITED STATES DEPARTMENT OF AGRICULTURE • FOREST SERVICE • FOREST PRODUCTS LABORATORY • MADISON, WIS

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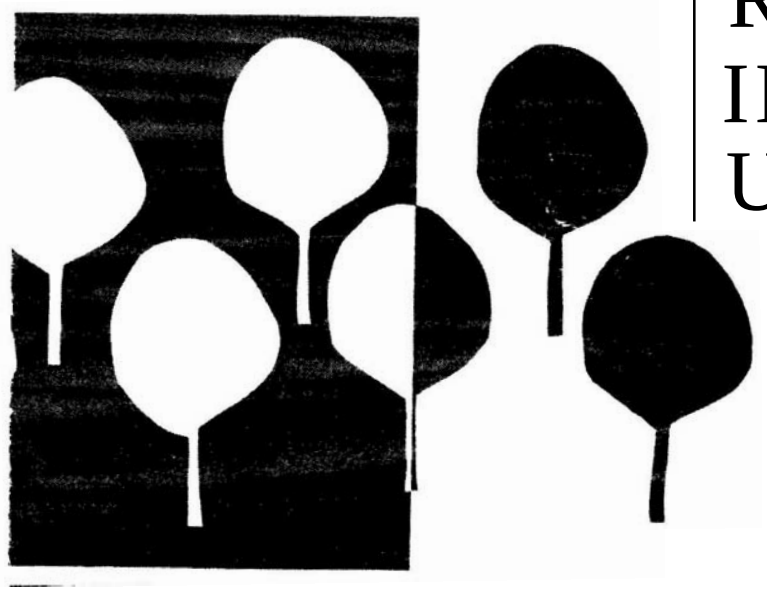

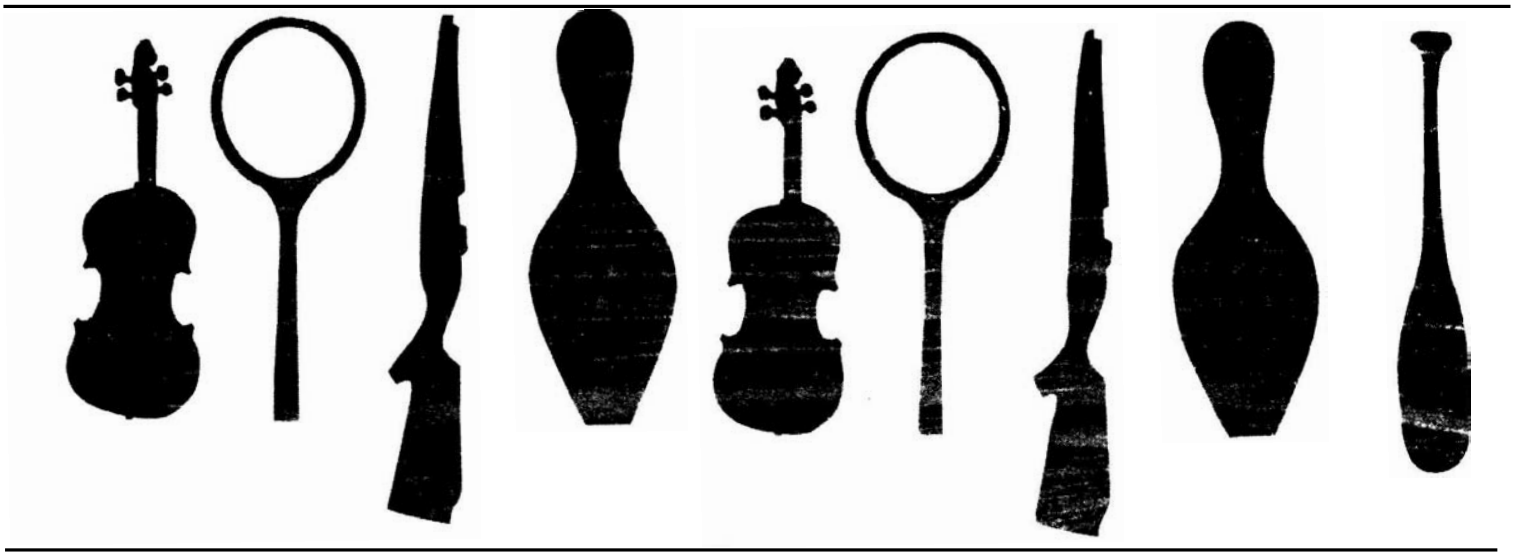

ABSTRACT

Provides a guide to evaluate the technical aspects of timber quality. Tree and wood characteristics are discussed in relationship to end use and processing requirements, and the role that environment, silviculture, biological agents, harvesting, and processing exert on these characteristics.

ACKNOWLEDGMENT

The author wishes to acknowledge the guidance of Charles Lockard, whose suggestions and help made this report possible, and to numerous personnel from the U.S. Forest Service Experiment Stations and the Regional Offices for their comments and suggestions.

FRAMEWORK OF QUALITATIVE RELATIONSHIPS IN WOOD UTILIZATION

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INTRODUCTION

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 the past decade. This interest in timber quality is the common property of all concerned with the growing, marketing, and utilizing of trees.

Objective of this analysis is to provide a guide to evaluate past, current, and proposed research involving timber and related wood quality, and to suggest research needs in this field of activity. The problems of wood quality are essentially national in importance and their solution may conceivably extend to many Federal, State, educational, and industrial research agencies.

The scope is confined to the technical aspects of timber quality. That is, it is intended to show the relationship of tree and wood characteristics to end use and processing requirements, and the role that environment, silviculture, biological agents, harvesting, and processing exert on these characteristics.

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

CONCEPT OF TIMBER QUALITY

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 fool 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" (45).[2] In other words, Evelyn was considering the requirements of the end use in evaluating the timber.

A refinement of Evelyn's concept is the basis for the modern definition of timber quality proposed by Mitchell (54, 55). 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 (79, 90). is not an attempt toward 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.

Aspects in Wood Research

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, 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 qualitatire 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, consider the elements that affect it. These are shown in figure 1 as satellites orbiting around the central nucleus that 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 element 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 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 characreristics.

Biological agents, such as insects, fungi, birds, and mammals, may deteriorate otherwise high-quality trees and wood (infrequently they may enhance for specialized uses), Decayed wood is decidedly objectionable for most uses and should be avoided. Likewise, 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,

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

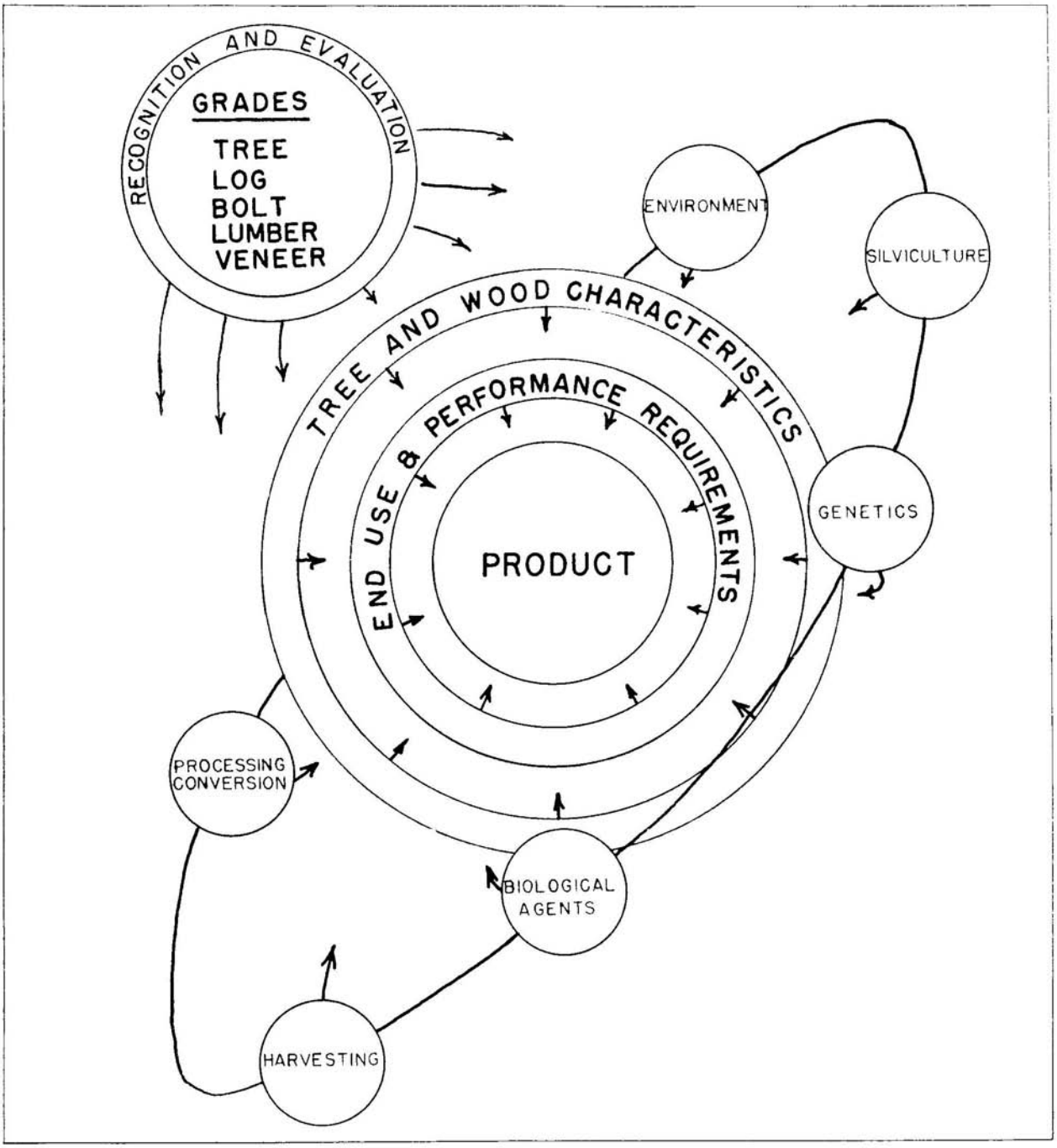

Figure 1.--Interrelationship between wood and timber quality and factors affecting them.

inadequate control of stain, decay, and insects in any stage of production, and inadequate moisture control 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.

The product, represented by the nucleus in the chart, has a combination of requirements which are related 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 determing 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 (20, 91). 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. A knowledge of the significance of the wood characteristics in relation to the intended use is necessary 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. Furthermore, 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.

END-USE REQUIREMENTS AND WOOD CHARACTERISTICS

Performance and Processing Requirements

Many properties of wood are well know through centuries of use. On the other hand, the variations in these properties as they might affect the performance of end uses are known only imperfectly. Species differences are generally recognized, such as information on decay resistance, gluability, and strength properties, but little information is available on variations within and between trees of the same species. Allowances, therefore, are often made to account for these variations. Some of this information, moreover, was obtained on laboratory specimens rather than on the actual performance of the product.

The selection of wood for specific uses oftentimes is a rule-of-thumb operation based on experience rather than on scientific information. Methods of applying this experience unfortunately are lacking in some cases, while in others the methods are know but the potential user is unfamiliar with them. Better selection by the use of grading systems, which in turn depend on the recognization and the evaluation of the wood characteristics for particular end uses, should be one of the primary aims in timber quality research.

It was deemed advisable in this analysis to list initially the various requirements that are known or may be needed in the performance of a product and then relate these requirements to the tree and wood characteristics. Most of the known requirements applicable to solid wood products are listed in table 1. Additional requirements as they become known, can be added to the list.

Processing requirements frequently may be as important in the use of wood as those of the end use. That is, a wood difficult to machine or season is avoided even though its characteristics are otherwise suitable for the product performance. The processing requirements are listed in table 2. Occasionally, both the end use and the processing requirements may be identical.

When wood may not possess the characteristics that impart the desired performance, modifications in these are sometimes made to improve the performance. For example, preservatives are added to impart decay resistance if natural durability is lacking. Here other wood characteristics, such as permeability or amount of sapwood, are important characteristics in the processing of the product.

One important task is devising a rating system for each of the requirements as they apply to specific products. For instance, what is good, fair, or poor machining as it applies to the processing or in a product, and what wood characteristics are involved? How can good or poor machinability be recognized in the tree, log, or lumber, and how can such information be incorporated in specifications or in grading systems?

People famliar with each of the broad classes

Table 1.--List of end-use and performance requirements of wood for various end uses

Strength relations	Utility relations	Sensory relations
1 Shock resistance	12. Stability	41 . Appearance
2. Stiffness	13. Resistancer to splitting	42. Color
3. Elasticity	14. Ability to wear smooth	43. Luster
4. Impact bending	15. Flexibility	44. Taste
5. Flexural strength	16. Springback	45. Odor
6. Tensile strength	17. Abrasion resistance	46. Resonance
7. Compressive strength	18. Corrosion to metals	47. Sound absorption
8. Hardness	19. Insulation value	48. Resistance to color change
9. Strength-weight ratio	20. Absorbency of water	49. Thermal sensitivity (response of the skin to the material)
10. Horizontal shear	21. Electrical conductivity	
11. Size of material	22. Radiation conductivity.	
	23. Thermal expansion	
	24. Resistance to fire	
	25. Resistance to alkalis	
	26. Resistance to acids	
	27. Permeability to water	
	28. Permeability to vapor	
	29. Permeability to oil	
	30. Years of service life: from decay	
	31. Years of service life: from insects	
	32. Years of service life: from marine borers	
	33. Shelling (grain separation)	
	34. Shrinkage--radial	
	35. Shrinkage--longitudinal	
	36. Shrinkage--volumetric	
	37. B.t.u.'s per unit of wood	
	38. Twist, cup, crook--amount	
	39. Screw-holding capacity	
	40. Nail-holding capacity	

Table 2.--Some harvesting and conversion requirements for wood

a. Tree or material form	k. Machinability
b. Size of tree or material	l. Ease of nailing
c. Uniformity of tree, log, etc.	m. Bonding quality
d. Ease of debarking	n. Corrosiveness to metals
e. Springback, freedom from	o. Gluability
f. Sawing quality	p. Wetability
g. Resistance to splitting	q. Bleaching quality
h. Peeling quality	r. Permeability to water
i. Seasoning quality	s. Permeability to oil
j. Ease of working	t. Permeability to gas

of products are best qualified from experience to specify and devise rating systems for the requirements of the end uses. Some of these specifications are already considered in the grading rules for lumber, flooring, and dimension, while others are not generally incorporated in the grading systems. It should be recognized, however, that some of the present methods in deciding wood suitability for a product are rule-of-thumb operations learned through use or experience, or what the tree will produce, rather than from detailed examination of the exact requirements of the end use.

Tree and Wood Characteristics

The end-use requirements given in table 1 are

Table 3.--Tree, log, and wood characteristics that may affect or influence the end use, the performance, or the processing of the material

External	Internal	
	Macroscopic	Microscopic
Cylindrical form	Growth rate	Fiber length
Taper	Uniformity of growth	Cell wall thickness
Bark characteristics	Concentricity	Cell diameter
Size of tree, log, bolt, etc.	Specific gravity	Ratio of cell diameter to length
Flutes	Summerwood percent	Fibril angle
Forked (double pith)	Contrast between springwood and summerwood	Gelatinous fibers--amount
Butt swell	Sapwood or heartwood (percent)	Cellulose--amount
Sweep	Type of grain--interlocking, cross curly, etc.	Lignin--amount
Mistletoe-infected wood	Texture of wood	Hemicellulose--amount
Frost cracks	Wood rays--type, amount	Organic constituents--other, amount
Scars--type, amount	Tyloses--amount	Inorganic constituents--amount
Bumps	Resin ducts--size, amount	Crystallinity of cellulose
Knots--kind, number	Knots--type, soundness, color, size	5-carbon sugars kind, amount
	Tension wood--amount	4-carbon sugars--kind amount
	Compression wood--amount	Presence of chrystals--kind, amount
	Juvenile wood--amount	bordered pits--amount, open or closed
	Extractives--kind, amount	Intercellular spaces
	Pitch seams	Parenchyma cells--location, amount
	Mass pitch	Spiral thickenings
	Gum deposits	Warts on cell walls
	Bird's eye	
	Dormant buds	
	Bark pockets	
	Decay--type, amount	
	Sapwood stains--type, amount	
	Insect galleries--type, amount	
	Miscellaneous holes--type, amount	
	Scars--type, amount	
	Wind shake--amount	
	Ring shake--amount	
	Spider heart--amount	
	Wetwood	
	Pith flecks	
	Mineral streaks and stains	
	Flag worm, grease spots	
	Compression failures	

objective requirements which are related or correlated with the tree and wood characteristics given in table 3. For example, the stability of wood is dependent on a number of wood characteristics. Some of thesc are the presence of tension, compression, or juvenile wood, specific gravity, fibril angle, and the kind and the amount of extractives. In addition, the amount of case-hardening and the moisture content of the wood are contributing factors in this regard. Also, the species of wood used is important not only in the requirement of stability, but also in many of the other characteristics. It should be emphasized again that this analysis is mainly concerned with differences within a species in contrast to differences between species.

The strength of wood, as another example, is dependent on the specific gravity, the percentage of summerwood, ring width, fibril angle, slope of grain, the amount of extractives, moisture content, freedom from decay, insect, or bird peck damage, the kind, location, aiid amount of knots, and the occurrence of shake, splits, and checks. The crystallinity of the cellulose (46) and fiber length may also affect some strength properties as do perhaps other minute properties of wood which are only partially understood at this time. Specific gravity, however, is generally, recognized as the principal index of strength properties in clear wood, and probably will always remain so.

Relating Performance Requirements to Tree and Wood Characteristics

Performance requirements are dependent on one or more of the tree and wood characteristics. The exact relationship however, between the use requirements and the tree and wood characteristics may not always be fully understood, and a thorough analysis of end-use requirements should reveal voids in our knowledge in this regard. It is recognized that the end uses may require different graduations of a requriement. That is, the amount of stability required of a framing member is much lower than that required for a dropleaf table, or the hardness of a table top need not be as great as than required for a commercial floor. Therefore, recognizable gradations in the requirements, as well as in the wood characteristics, are needed to sort the materials for the most suitable use.

The inherent properties of a species, or a group of similar species, ghas been and still is one of the best criteria for selecting the most suitable wood for certain purposes. The main difficulty in this has been the variability in the characteristics of a species. Anything done to narrow this will improve the quality of timber for most uses. Usually, difficulty is experienced in processing or in the performance of a product when the wood characteristics deviate from the normal.

In considering the relationship of use-requirements to wood characteristics, that of appearance is most nebulous. Usually appearance has little or no connection with the actual performance or the function of a product; usually it is based on the tastes of individuals. Realizing that species is of prime importance in selecting not only for appearance but for other requirements as well, the tree and wood characteristics within a species influencing appearance most are:

1. Growth rate--ring width
2. Uniformity of growth
3. Taper
4. Sapwood or heartwood
5. Type of grain
6. Texture of wood
7. Extractives--kind and amount
8. Wood rays--type
9. Knots--type, number, size, and location
10. Tension wood--amount and location
11. Bird's eye, pith flecks, burls, etc.
12. Bark pockets
13. Decay
14. Insect galleries
15. Flag worms, grease spots
16. Mineral streaks and stains
17. Checks, splits, ring shake

These characteristics affecting the appearance apply to the entire range of solid wood products: only one or two wood charateristics may govern the appearance of a specific product.

Stability, as another example, is dependent mainly on the following wood characteristics:

1. Specific gravity
2. Flat or quarter sawn
3 Abnormal wood, presence of
4. Extractives--kind and amount
5. Fibril angle

As another example, natural decay and insect resistance are dependent on:

1. Extractives--kind and amount
2. Specific gravity (this is qustionable (15))

Nail-holding capacity, as another example, is dependent on:

1. Specific gravity
2. Resistance to splitting (type of grain--interlocking, straight, etc.)
3. Growth rate--ring width
4. End or longitudinal grain

These examples may serve as a guide for completing the relationship of the other end requirements to wood characteristics.

Product Requirements

Although each specific end use has individual requirements, uses with the same requirements in common can be grouped into broad classes. Six broad use classes are shown in table 4. The end-use requirements of each class and subclass are given in numbers which refer to those shown in table 1, and the processing requirements given in letters refer to those shown in table 2. Thus, the end-use requirements for fuel wood are 11 and 37, which refer to size and B.t.u.'s per unit of wood, respectively. The processing requirements are a, b, and g, which refer to form of tree or material, size, and resistance to splitting. The number and letters shown for the other classes of products likewise refer to the numbers and letters given in the two tables. Still other requirements sometimes are necessary for specific uses within a subclass. As an example, some baseball bats have the additional requirement of all sapwood, in addition to the requirements given in table 4 lor that product.

It should lie emphasized again that there are different grades of products as well as different grades in wood material. Rules and specifications for these grades already exist for most materials and products. For instance, the amount, size, type, color, and location of knots are characteristics that greatly influence the grades of trees, logs, lumber, and products. In this, the grading rules for lumber and some products are rather specific in defining and limiting the various types of knots in the various grades. Other characteristics, as a general rule, are not so well defined or are omitted entirely in grading rules, due partly to insufficient information in recognizing and evaluating their effects on the performance of the products.

A review of the use requirements given in table 4 for the various classes of products reveals that a few requirements are common to most products. These requirements, in turn, relate to a relatively few tree and wood characteristics. That is, good form with small taper, freedom from tension wood, compression wood, decay, knots, and spiral grain are attributes for nearly all products, especially those where strength, appearance, stability, and machinability are requisites.

Changes in the wood characteristics occur in the normal growth of softwood trees. Studies show that the fibers are shorter, the specific gravity is lower, and the extractives are less near the pith, and these increase outward until the tree is about 30 to 50 years old, (2, 3, 47, 49, 100). At that age these characteristics remain fairly uniform throughout the growth of the tree. In other words, the heartwood of the outer perimeter of the tree is usually stronger, more durable, and more stable, than that at the heart center. These usually superior properties of the outer wood are only indirectly segregated for many uses. That is, the outer wood generally contains fewer knots, and less shake, which usually are reasons for segregation rather than the location of the wood in the tree.

Variations in the fiber length, specific gravity, extractives, etc., occur between trees of a species, and geneticists claim that these are inheritable (23, 44, 98, 102). The within-tree variations will still exist, however, but some may be reduced by silvicultural operations.

INFORMATION ON GROWTH RATE

Factors affecting growth rate and the effect of growth on the tree characteristics and en uses is given as an example of what is know about this characteristic. similar known information should be compiled for each of the other characteristics and requirements listen in tables 1, 2, and 3.

Growth rate as determined by the number of annual rings per inch is not necessarily an indicator of quality, density, and the strength of the wood, although it is used for those purposes by some of the lumber inspecting bureaus. To illustrate, for southern pine (84): "Medium-grain lumber averages on either one end or the other

Table 4.--An example showing how classes os wood may be grouped in relation to end-use and processing requirements

Product or use	End-use requirements [1]	Processing requirements [2]
Fuel--industrial and domestic	11, 37	a, b, c, g
Roundwood (used as such)	1, 5, 9, 11, 30, 31, 41	a, b, c, h, r, s, t
posts	40	
poles	2, 21, 39	
piling	2, 17, 32, 39, 40	
Sawtimber, products from (some products may also be obtained from bolts)	11, 34, 35, 36, 38, 41	a, b, c, e, f, i
structural	3, 4, 6, 7, 8, 9, 40	
cross ties	8, 16, 17, 31	
beams, stringers, joists, planks, posts, laminated timbers	3, 9, 10, 24	
factory, shop, and yard lumber, products from	2, 3, 4, 9, 38, 39	
furniture, fixtures	14, 42, 43, 48, 49	
musical instruments	14, 42, 43, 48, 49, 46	
flooring	7, 8, 14, 47, 49	
boxes and pallets	13, 40	
sheathing, etc.	19, 40	
miscellaneous products: car, barge, decking	4, 5, 7, 8	
Bolts, sawn products from (may also be obtained from sawtimber	11, 12, 34, 35, 36,	
Sporting goods, other than baseball bats	1, 2, 3, 4, 8, 14, 49, 52, 53	
Art work, woodenware, turnery	42, 43, 49, 52, 53	
Handles, striking tools, picker sticks, baseball bats, etc.	1, 2, 4, 8, 9, 14, 49, 64, 65, 66	
Tight cooperage	7, 14, 41, 57, 59	
Veneer, products from--sliced, rotary, or sawn	1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 36, 41	a, b, c, d, h, i, n, o
Structural	27	
Marine use	27, 42	
Decorative--furniture, paneling	49	
Packaging	39, 40, 49	
Miscellaneous products: spoons, matches, candy sticks, etc.	13, 15, 42, 44, 45	
Molded products--from flakes, particles, wood flour	11, 36	b, r

[1] Figures refer to those in table 1.

[2] Letters refer to those in table 2.

not less than 4 annual rings per inch....Close-grain lumber aberages on either one end or the other not less than 6 annual rings per inch.... Dense lumber averages on one end or the other not less than 6 annual rings per inch and not less than one-third summerwood....”

For Douglas-fir and western larch: “Rate of growth requirements are sometimes a part of a grading rule for reasons of testure as well as for strength” to quote from the grading rules (94). Descriptions for medium, close, and dense grain of these two species are almost the same as to those for southern pine.

If the so-called density rule is applied, working stresses of dense lumber for structural design are increased by about one-sixth. Dense structural redwood averages not less than 8 nor more than 35 annual rings per inch with a weight of not less than 24 pounds per cubic foot as compared to not less than 8 nor more than 40 rings per inch with no provision for density for heart structural (72). The working stresses for dense structural redwood are about 30 percent higher than those for heart-structural redwood.

The number of rings per inch is not used in the grading rules of other softwood species or of hardwood species for general use. Where strength is important in some hardwood uses, however, the number of rings per inch may be specified (62).

New techniques are continually being developed to measure the ting width more accurately and faster. Hamilton developed a linear micrometer with an accuracy of 0.001 millimeter (33), and Sandermann anad others determined annual ring width by means of ß-rays (77). Wutt (99) is developing a machine for the automatic evaluation of data concerning the annual ring.

the relationship between growth rate and specific gravity was studied by a number of investigators (26, 41, 50, 64, 66, 68, 74, 78, 82, 85, 95, 103). Keith (37) and Hale (32) concluded that narrow ring widths were associated with high specific gravity for white spruce, while Smith (83) demonstrated that, in wide-ring Douglas-fir, ring width was a poor indicator of specific gravity. Paul (58) found that initial fast growth of southern pines was likely to produce poor quality wood. and concluded that ring width in itself did not determine density. Rather, he found that the conditions under which the trees grew determined the proportions of springwood and summerwood in narrow, medium, or wide groth rings. According to Paul, rapid-grown Douglas-fir trees seldom maintained a summerwood percentage of 33 percent or more (59), and the growth rings should be relatively narrow for the production of wood with high density and strength (61). He further stated that for most softwood species a growth rate of about 6 to 10 rings per inch was desirable for most uses: when five or less, the wood was usually characterized by low specific gravity strength, and high longitudinal shrinkage (67). Specific gravity was more closely correlated with the percentage of summerwood than it was witht he width of the annual ring, and in turn strength was more closely related to specific gravity (92) than it was with growth rate. Wellwood, however, found that percentage of summerwood had no effect on specific gravity in second-growth western hemlock (93).

The sapwood thickness was wider in fast-grown hickory (63) and probably in other hardwood species than it was in slow-grown trees. From observations, fast-grown softwood species also tend to have a wider sapwood thickness. More information is needed, however, to ascertain the relation of sapwood thickness to growth rate. It is probable that some trees within a species inherently have a wider sapwood zone.

Pruning affected the growth rate of trees in addition to the benefits obtained from knot-free wood (60), less likelihood for the entrance of wood-destroying fungi (5), and less variability in grain. Diameter growth was little affected when one-third or less of the live crown was removed for softwood species studies (9, 10, 21, 86, 88, 101), while 50 percent of live crown of hardwood species was removed without noticeably affecting the growth rate (18, 81). In loblolly pine (42) the top branches contributed most to the growth of the main stem, while the low branches with few branchlets contributed little or nothing to the growth of the main stem. Pruning loblolly pine while small (4 to 5 inches in diameter) checked undesirably early fast growth (12).

Although the ring width may be less with pruning more than one-third of the live crown, the percent of summerwood was increased (51). Also, while the growth rate may be reduced by heavy pruning, the form of the tree was improved. the ring width was wider than usual at the upper part of the pruned bole than it was lower down (14). In other words, pruned trees may have less taper.

Bud pruning had no appreciable effect on height

or diameter growth of slash pine after 1 year (76) and of eastern white pine after 6 years, but such pruning reduced the growth of red pine after 6 years (30).

Farrar (27) reviewed the literature on the longitudinal variation of ring width in a tree. He concluded that, within the tree crown, ring width was least at the tip and increased downward to the heaviest part of the crown. Below the crown it usually decreased downward, but may increase in vigorous trees with large crowns.

Nicholls reviewed the literature on spiral grain and concluded that the wide divergence in results precluded placing reliance on them (57). Some think that spiral grain is closely associated with growth rate, as in red spruce (51), but this apparently is a false assumption.

Site, of course, has a profound influence on growth rate (1). Trees grown on sites with moisture available during the summer months not only have increased growth, but a greater portion of the annual ring is comprised of summerwood.

Wood formation in larch started with the appearance of new leaves and stopped after July (13). Fertilizing young Douglas-fir and slash pine resulted in increased increment, but significantly decreased the percentage of summerwood (26, 96). Length of day had a decided influence on the summerwood-springwood relationship in red pine with springwood formed during long days and summerwood formed during short days (43).

Diseases and defoliation by insects or fungi affect the growth rate. Dwarf-mistletoe was found to reduce the growth rate of ponderosa pine and black spruce (4, 40, 80). The growth of quaking aspen was reduced by 90 (24) and 100 percent (75) by defoliation of tent caterpillars. Defoliation by the lodgepole needle miner had little or no effect on increment loss until defoliation approached 50 percent in young trees and 40 percent in mature trees (87). The spruce budworm, larch sawfly, European spruce sawfly, white fir sawfly, and the Saratoga spittlebug cause reduction in ring width of balsam fir and tamarack (56), spruce (73), white fir (89), and red pine (8), respectively. The growth rate of ponderosa pine can also be reduced by attack of needle blight (17). In these and other studies on the growth reduction by insects and fungi, information was generally lacking on the effect of these agents on wood quality. The defoliators apparently cause more loss of the summerwood portion of the growth ring and it may be assumed that the wood specific gravity was also reduced, but this needs further study to determine definitely.

Growth rate has some effect on the susceptibility to insect attack. Rapidly growing trees are more resistant to attack and to injury (31). One example is that the copious flow of sap or resin of fast growing trees drives out or kills the cambium borers before they become established.

Root rots not only kill trees before they reach maturity, but they also cause a reduction in growth rate. Fomes Annosus and Poria weirii are perhaps the most destructive causes of root rot in our native softwood species. Present conditions indicate that these pathogens may become more serious in futhre stands, and reduce the quality of timber by killing the trees before they reach maturity. Fomes annosus infected 47 percent of the trees in a 43-year-old natural stand of eastern white pine and 56 percent of a 33-year-old plantation, both of which had been thinned (11). Unthinned stands are only occasionally attacked. The same fungus also is a problem in thinned planted stands of loblolly pine (71) and in thinned natural shortleaf pine stands in Missouri, Poria weirii root rot occurs principally in young Douglas-fir stands.

Juvenile wood in conifers is the result of fast early groth of open-grown trees (65). Trees grown in close competition with early dying or pruning of the lower crown did not produce this type of wood. Crown-formed wood is a better designation for this type of wood since it apparently occurs in the vicinity of living branches regardless of the tree age.

Davis found no evident relationship between the average growth rate of 24 hardwood species and their machining properties, but he also stated that slow to medium growth of a ring-porous wood like oak machined better (22). He found that growth rate had a decided influence, however, on the machining of poderosa pine and Douglas-fir. Wood from slown-grown trees of these species had more defect-free pieces when planed, shaped, turned, or mortised than did the wood from fast-grown trees. In veneer cutting a slow, uniform growth rate was desirable (50). Ten to twelve growth rings per inch was recommended for producing high-grade Douglas-fir face veneer (28).

Ring width was noa a sure index of the mechanical properties of rapid-grown Douglas-fir,

but appeared to be a function of tree age and the percentage of summerwood (68).

Wide-ringed wood from Past-grown white pine for use as matches was found to be undesirable as the entire match stick may be comprised of springwood (70). The wood was weak and brash in such matches.

Fast-grown hickory and ash were more desirable lor striking tool handles and like uses, but high density was a more important index of usefulness than was the growth rate.

Uniformity of growth rate is desired for most uses. Wood of nonuniform growth presents problems in utilization due to warping, poor machining (22, 50), appearance, and strength.

Growth rate differences did not affect the pulpability of jack pine by the kraft process (16).

Pechmann (69) discussed the effect of ring width on the suitability of wood for resonance wood, veneer, and for strength, and Koehler (38) reviewed the considerations in using rapidly grown southern pine. Some such wood shrinks excessively in a longitudinal direction, and results in warping of the lumber.

Dense wood shrinks more in a radial aid tangential direction than less dense wood within a species, and any effect growth rate has on density also influences the amount of shrinkage. Increased density due to extractive content, however, may result in lower shrinkage values.

Wood with low specific gravity probably dries faster than denser wood within a species. No references, however, were found on this aspect.

In summary, much of the work on growth rate was done without considering the quality aspects. Furthermore, numerous contradictions occur in the literature on some aspects of this characteristic, and much work remains to be done in clarifying and correlating environmental influences with ring width.

As pointed out, this discussion is limited to only one aspect of timber quality. The literature on other quality factors should be reviewed, especially on those factors that influence the processing and end-use requirements. Such information will aid in coordinating future studies on tree and wood characteristics. In other words, analysis of past work will disclose missing information, emphasize needed data, and indicate study priorities.

SUMMARY AND DISCUSSION

Two aspects should be considered in timber quality research. One is the recognition and evaluation of the tree and wood characteristics as they affect end uses, and the other is growing trees for these products. Grades are necessary to evaluate and segregate the tree or its parts for specific uses and into various classes of each use (7, 48, 91). Economics and market demand determine the value of a particular grade under a given set of circumstances, but the wood characteristics alone determine the grades. It is of little consequence to consider the price aspects if the grades are improperly made.

One phase of the problem is ascertaining the end-use requirements of the various products and determining which tree and wood characteristics affect these requirements. Another aspect is recognizing these characteristics in the various stages of processing and in the product. The third aspect is how these can be evaluated and incorporated into meaningful grades. Some characteristics, such as knots and size of the material, are easily recognized and evaluated, but such others as tension wood or compression wood are difficult or impossible to evaluate at the present time. A long and sustained effort will be needed merely to inventory the natural variation that occurs within a species.

Examples are given for the end-use requirements of various classes of products showing the relationship of these requirements to tree and wood characteristics. The requirements that may be desirable in processing are also shown.

Species differences are important in the use of wood for various products, and it is recognized that some species are more desirable for certain uses than others. This timber quality analysis, however, is not concerned with species differences. The main emphasis is on what constitutes desirable characteristics within a species insofar as these affect the requirements of the end use. The choice of species is a decision for the forest manager, who knows which species grow best in his region as well as having some idea of market conditions for his timber. No attempt is made, moreover, to predict the future demand of various products, which is the task is the market specialists. The requirements of forseeable uses appear little different from those of today, and it is

assumed that future use requirements will be basically the same.

The outlook for products from chemical conversion of the wood, bark, or extractives is promising. Such chemical products probably wilt be obtained from residue material rather than from trees specifically grown for this purpose. Other than species differences, almost any form of wood probably will be suitable. New gluing, treating, machining, and other processes and use systems are in the offing, but from all indications these will have little effect in changing the concept of timber quality as known presently. On the other hand, more emphasis will be laid on growing quality trees and in better segregation of the material for the intended use. Increased use of wood for chemical and particle products will increase the market for residue and otherwise cull material.

Actually, there are relatively few characteristics of a species that govern use requirements for most products (35, 53). The most, important ones are:

1. Growth rate. A uniform growth rate of 6 to 10 rings per inch has been found to be most desirable (67), but a closer look should he made as to the suitability of wood with wider rings for present users.

2. Uniformity in size and shape of the tree as well as in growth rate will become more important as automation increases (29). A straight, concentric log with little taper will lend itself more readily. to harvesting or processing regardless of the end use.

3. Specific gravity. Structurally speaking, the quality of clear wood is almost synonymous with its density. High-density wood also is desirable in most pulpwoods because of higher fiber yields. Low-density wood seems to be preferable for particle board (29), but this might be obtained from such low-density species as aspen or buckeye. Information is lacking, however, as to whether low-density wood from aspen, for example, is preferable to that of wood with a higher density within the species.

4. Freedom from reaction wood. Tension wood in hardwoods or compression wood in conifers should be avoided (19, 39).

3. Concentricity. Trees with the pith off center to any great degree are likely to contain reaction wood, and are undesirable for cutting rotary veneer.

6. Freedom from knots. Knots are not desirable for most uses, and should be avoided insofar as possible.

7. Bole form. Crook, fork, lean, large taper, etc., not only reduce the usability of the tree but add to conversion costs.

8. Freedom from decay. Decay is undesirable for most all uses, including pulpwood (34), and should be eliminated as early as possible in the tree or any of its parts (36).

9. Freedom from insect attack. Insect galleries reduce the strength and appearance, but they may not influence the pulping qualities.

10. Freedom from spiral grain. Spiral and sloping grain not only reduce the strength of the material (97), but also result in poor machining. From tests and observations, poor planing results are directly correlated with grain deviation and the presence of tension wood in hardwoods. Sharp tools, the recommended number of cuts per inch, moisture content, and knife angle, however, will help to overcome grain subnormalities.

11. Freedom from blemishes is important for appearance. Bird peck, pith flecks and mineral streak are causes for degrade in hardwoods for some uses. Detailed information is lacking on the relationship of these with wood quality.

12. High extractive content is desirable if decay and insect resistance is sought in durable species. This appears, also to reduce shrinkage, although more work is needed to show this relationship in American species. High extractive content of some species, however, may cause difficulty in some pulping processes and may cause discoloration in the use of some species for siding. More information is needed in order to recognize and segregate durable from nondurable wood.

13. Compression failures, which result from forces imposed on the stem without complete failures (52), seriously reduce the strength of the wood. They are regarded as quality indicators (54), and more work is needed to recognize their presence more readily and evaluate their effect on various products.

14. Figured wood usually demands a premium price, and foresters should not overlook the possibility of increased production of such wood. This inherited charateristic; (6) might also be propagated by vegetative cuttings (25), or by grafting such cuttings to wild stock in the forests. In fact, more research on methods and results of grafting cuttings from superior trees to wild stock

already established in cutover areas apparently would be fruitful. Furthermore, some hardwood trees may have poor form desirable for most uses, but they may be highly desirable and command premium prices for specialized uses.

15. Size of tree may be an important quality indicator Cor some products. It has been shown that the wood from the center of the tree, or what would be the entire tree when small, has shorter fibers, a larger fibril angle, more longitudinal shrinkage, and lower density than the outer wood. Thus, if long fibers or high specific gravity are desirable in pulpwood, for example, the outer wood of larger trees makes better pulpwood than does the wood of small trees. The same also applies to products where high strength or stability are required.

16. Predictability of quality. Trees or logs guaranteed to have uniform quality are superior to those of unknown quality even though both have the required characteristics for the end use.

Although technological advances aid in extending the utility of otherwise low-grade wood, a demand for material traditionally considered high quality will always exist. This is emphasized innumerous articles which refute the idea that future requirements will be met by reconstructed wood particles. Indications are that the wood characteristics which affect suitability for important end uses today will continue to affect them for many years.

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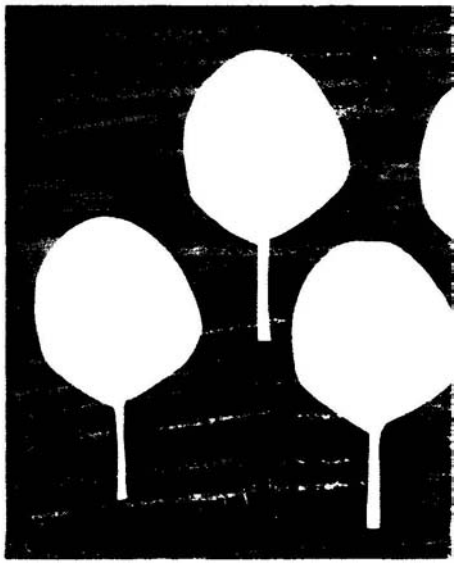

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