

A DISCUSSION OF WOOD QUALITY ATTRIBUTES AND THEIR PRACTICAL IMPLICATIONS

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L.A. Jozsa and G.R. Middleton

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Special Publication No. SP-34

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COVER: 95-year old lodgepole pine stand at 1900 stems/ha, located on a good site in the Montane Spruce Biogeoclimatic Zone. Maximum tree diameter was 24.8 cm at breast height.

ILLUSTRATIONS by Les Jozsa

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ABSTRACT

Wood quality is defined as the suitability of wood for a particular end-use. Wood anatomy and tree growth are discussed in terms of macroscopic and microscopic features of a tree examined in cross section. End-use requirements are described in terms of lumber grading. The following wood quality attributes are introduced, defined and discussed in terms of their practical implications for wood processing and wood products: wood density, density variation, juvenile wood/mature wood distribution, proportion of heartwood/sapwood, fibre length, fibril angle, compression wood, knots, grain and extractives. The potential for influencing tree growth characteristics (eg. wood density, branch size) and wood quality (structural and appearance lumber grades) through stand stocking control is discussed. Foresters are asked to consider the wood quality implications of site-specific silvicultural operations.

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TABLE OF CONTENTS

ABSTRACTii

ACKNOWLEDGEMENTSii

LIST OF FIGURESv

LIST OF PLATESvi

1.0 INTRODUCTION1

2.0 TREE GROWTH AND WOOD ANATOMY2

3.0 WOOD QUALITY ATTRIBUTES DEFINED
BY END-USE REQUIREMENTS7

 3.1 Wood Density8

 3.2 Density Variation8

 3.3 Juvenile Wood/Mature Wood Distribution12

 3.4 Proportion of Heartwood/Sapwood16

 3.5 Fibre Length16

 3.6 Fibril Angle18

 3.7 Compression Wood20

 3.8 Knots21

 3.9 Grain25

 3.10 Extractives31

4.0 POTENTIAL FOR INFLUENCING WOOD QUALITY 32

 4.1 Stocking Density32

 4.2 Intensive Silviculture37

 4.3 Site39

5.0 CONCLUSION42

LIST OF FIGURES

- Figure 1. Major tissue types in a tree cross section, and the principle driving forces of tree growth and annual ring formation.
- Figure 2. Morphology of earlywood and latewood.
- Figure 3. Stem juvenile-/mature-wood distribution.
- Figure 4. Wood density variation within growth rings.
- Figure 5. Intra-ring density profiles plotted according to real ring width (a) and standardized ring width (b).
- Figure 6. Average ring density trend from pith-to-bark in some second-growth woods.
- Figure 7. Edge-loaded lumber showing internal compression, shear, and tension stresses.
- Figure 8. Fibre length as a function of age.
- Figure 9. Anisotropic nature of wood and fibril orientation in normal, juvenile and compression wood.
- Figure 10. Some alternative sawing strategies.
- Figure 11. Maximum knot sizes allowed on the edge and on the centre-line of 2x4, 2x8 and 2x12 lumber.
- Figure 12. Select Structural grade yields for different widths of dimension lumber from logs sorted by knot size.
- Figure 13. Valid and invalid relative density and ring width comparisons.
- Figure 14. Average ring density and ring width versus rings from the pith by sampling height for 60 Douglas-fir trees.
- Figure 15. Log diagramming.
- Figure 16. Effect of stocking density on crown development.
- Figure 17. Lumber recovery factors for mill-run logs.
- Figure 18. Lumber dimension yields by log top diameter class.
- Figure 19. Log quality zones and product value.
- Figure 20. Average knot size related to d.b.h. for several lodgepole pine stands.
- Figure 21. Comparison of average tree wood density for five lodgepole pine sites.

LIST OF PLATES

- PLATE I. Juvenile wood (first 20 years of growth) marked on 50 year-old Douglas-fir log ends and visible on lumber ends.
- PLATE II. Open grown lodgepole pine on a poor site in the B.C. Chilcotin region.

A Discussion of Wood Quality Attributes and Their Practical Implications

by L.A. Jozsa and G.R. Middleton¹

INTRODUCTION

A comprehensive knowledge of the characteristics of any material is essential to its best utilization. This is especially true for wood because of its cellular nature and its complex cell wall structure. One of the greatest architects of our time, Frank Lloyd Wright, put it best in 1928: “We may use wood with intelligence only if we understand wood”. Resource managers and foresters, who wish to maximize forest values, need to understand not only the principles of tree growth, but also some of the macroscopic and microscopic features that determine wood quality.

Quality is a subjective term and must be defined in every context. We define wood quality in terms of attributes that make it valuable for a given end use. Certain wood characteristics are desirable in one product, but not in another. For example, it is the low relative density of red cedar and the thermal insulation it provides that makes a clear western red cedar bench comfortable to sit on in a sauna (knotwood or other high-density wood would be too hot to touch). Wood used in the floor joists of your dining room must be strong and stiff (so the china will not rattle as one walks across the room). We have quiet china because wood with strength and stiffness attributes of high density, small knots and straight grain is available from such species as Douglas-fir and western larch. Wood used for making disposable medical lab coats, on the other hand, should have low density and uniform grain, with long fibres to pulp like western red cedar; which yields collapsible thin-walled fibres, excellent bonding, low porosity and high strength. The high-value, clear yellow-cypress heartwood in a Japanese prayer post will have dimensional stability, straight grain, uniform density, little figure, uniform light colour, and natural durability. Notice that in these widely divergent examples one recurring theme is wood density, an attribute which has a direct influence on solid wood properties (thermal conductivity, strength, shrinkage, machinability, etc.) and on pulp yields. Notice also that attributes valuable in one use can be less valuable or detrimental in others. Our focus is on conifers, also known as evergreens or softwoods.

Wood quality characteristics can be inherent to particular species, but are also influenced by tree growing conditions. This connection to tree growth gives forest managers both an opportunity and an obligation to manage judiciously for value on every site be it only through choice of rotation length, species selection, and initial spacing and stocking control on some sites, to fertilization, thinning and pruning on others.

Many wood quality attributes are heritable, and differences in tree-to-tree quality within species can be traced to genetic differences. Forest managers rely on tree improvement programs to ensure that genetics are considered prior to regeneration and planting. Once an appropriate species is selected, its genetic code will govern tree form, tree growth and inherent wood quality. Through stocking control and other silvicultural treatments, however, the forest

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manager will embark on live crown management, which will determine growth rate, base of live crown, branch size, stem taper, heartwood/sapwood distribution, and juvenile/mature wood content.

Presently, stand managers may feel reasonably confident that they know the relative outcome of management decisions in terms of stand volume, tree size and perhaps even knot size, but they often have scant knowledge as to what effect their decisions will have on future wood quality and value. Likewise, the woodlands manager responsible for timber production will be at a disadvantage in terms of log allocation efficiency without some knowledge of the quality differences that exist in the current resource. It is their need for decision support information that provides the impetus for research into the practical implications of wood quality, some of which are known, and are discussed here.

TREE GROWTH AND WOOD ANATOMY

A stem in cross-section reveals the secrets of tree growth and wood anatomy (Figure 1). Readily visible are various layers of tissue, the most obvious being the wood portion with concentric annual rings. Equally obvious is the bark which is composed of two layers, the inner living bark comprised of conducting and storage cells (for photosynthates) and the outer dead bark, a collection of dead cells. The principal function of the dead bark is to prevent the living tissues from drying out.

Perhaps the least obvious but most important layer of tissue in the cross section is the cambium. It is a thin single cell layer of tissue between the inner bark and the wood, as shown in Figure 1. This is where tracheids (wood fibres) are produced by the tree through cell division, using energy derived from the products of photosynthesis. After cambial division each successive cell undergoes enlargement, wall thickening, and lignification. The rate of cell division and final size are both thought to be largely influenced by growth regulating hormones (auxins). Wood fibres are formed in an aqueous environment and exist in a living tree in the “green” or maximum swollen state.

Annual rings seen in the cross section are a chart of yearly growing activity. Active cambial division begins at the time of flushing, usually in mid-May to mid-June, when buds break their scales and reveal their green needles. In general, low density earlywood is produced from this time until about mid-July, when the cessation of leader growth and the maturation of new needles takes place. After mid-July new foliage ceases to be a net sink of photosynthate and becomes an exporter. Concurrently, there is a reduction in cambial division. Thus, more material becomes available for cell wall thickening. Also, reduced crown activity limits auxin production, which helps trigger the formation of high density latewood. Generally darker in appearance, latewood continues to be produced to the end of the active growing season which, depending on the region, lasts about four months until late September, when the lower temperatures and a reduced photoperiod bring on tree dormancy.

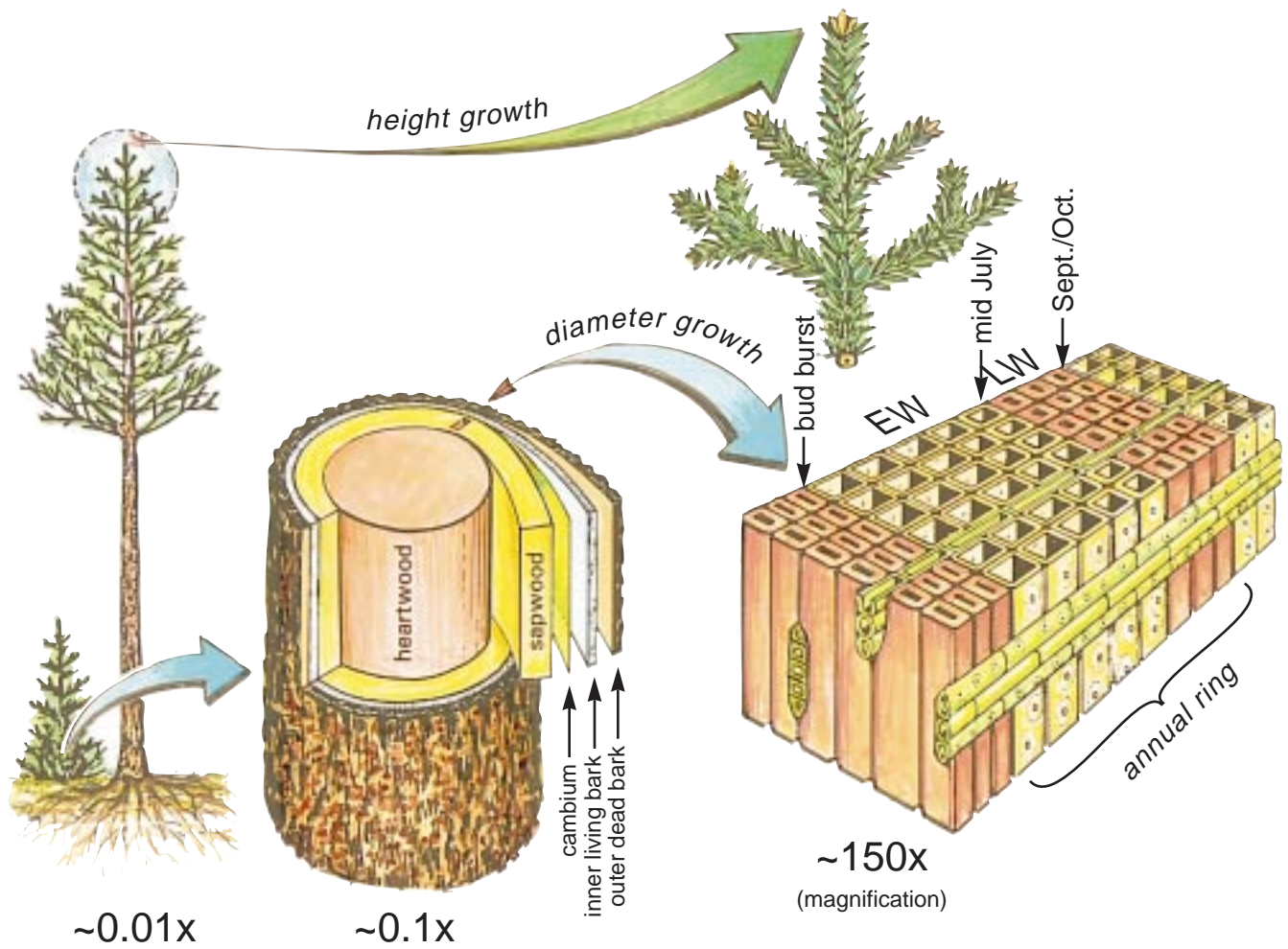


Figure 1. Major tissue types in a tree cross section, and the principal driving forces of tree growth and annual ring formation

Often visible in a stem cross section is the different colouration of two broader divisions, sapwood and heartwood. The sapwood portion of the tree is physiologically active and is in continuous communication with the cambium and the inner living bark. The sapwood acts as a food and water storage reservoir and provides the function of sap conduction. Heartwood can be found usually at the centre lower portion of mature stems. At one time heartwood was sapwood, but it no longer functions physiologically, its cells are dead. Heartwood is usually darker in colour than the sapwood because of organic deposits (extractives).

Least visible in the stem cross section are the wood fibres. The growing tree forms large diameter, thin-walled fibres in the early part of the growing season, and smaller diameter thick-walled fibres during the latter part. Figure 2 shows that many bordered pits can be found on the radial faces of earlywood fibres. Latewood fibres have smaller and a lot fewer bordered pits (or none at all). The more frequent pitting, including ray-cross-field pits, in earlywood fibres is due to the greater degree of physiological activity during their formation. Note that the tangential faces have very few pits. When pulped to individual fibres, thin-walled earlywood fibres are much more flexible than the thick-walled latewood fibres. Earlywood fibres collapse to a ribbon and tend to lie on their radial face, while latewood fibres remain tubular, stiff and rigid.

Radial growth begins first near the top of the tree and proceeds gradually downward in the stem, resulting in more earlywood and wider rings near the pith in the upper crown region. Transition to latewood occurs first near the base, farthest from the source of auxin supply, and proceeds upwards. Therefore, the density of an individual wood fibre is determined by its position relative to the region of the active live crown, and by the time of its formation.

Not visible in our stem cross-section is an important pith-to-bark gradient in wood density that is unique for each species. The fact that a relatively pronounced change in density often occurs during the first 15 to 30 years of growth gave rise to the term “juvenile wood”. This term can foster confusion, because this wood is found not just in young (juvenile) trees, but near the pith in every tree, including “old growth”. It is sometimes more accurately referred to as “pith associated wood” or as “crown wood”, that part of the stem which was formed under the influence of the live crown. Juvenile wood is an important wood quality attribute because, depending on species, it can have lower density and always has shorter fibres, larger fibril angle, and slightly lower cellulose content than mature wood. Wood juvenility can be established by examining a number of different physical or chemical properties. The measurements are usually made year-by-year, or in 5-10 mm-wide increments from pith-to-bark.

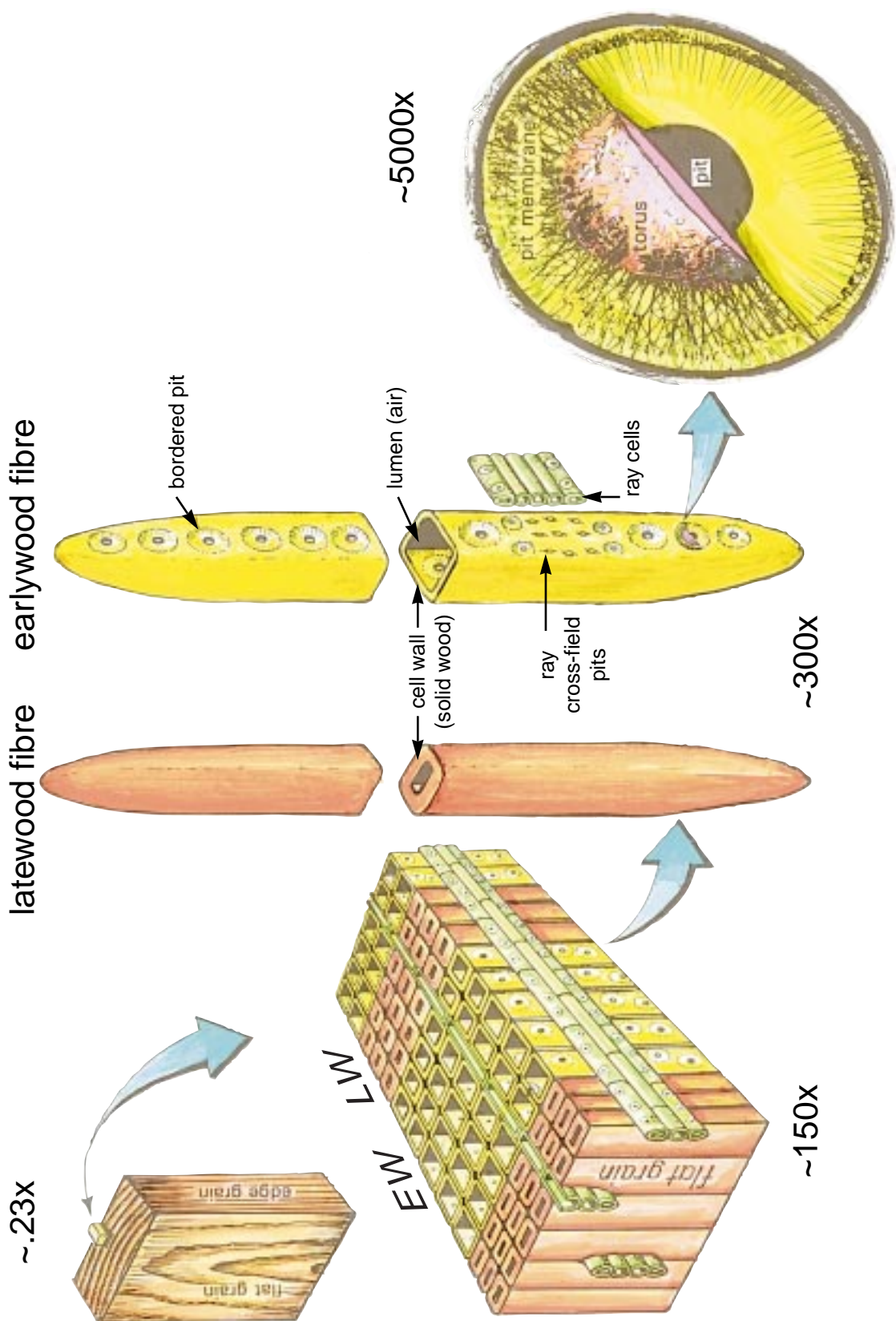


Figure 2. Morphology of earlywood and latewood.

In addition to varying by species, the extent of the juvenile-wood core depends on tree age, and on the extent and vigour of the live crown (which is dependent on stocking density). Generally, for a given diameter, faster-grown trees have a greater proportion of juvenile wood than trees that have not retained their live crown. Therefore, a 15-year old Douglas-fir Christmas tree, with live branches to the ground, would have 100% juvenile wood in its stem. If this tree were to grow for another 50 years in a 500 to 600 stems/ha environment, on a medium-to-good site on the B.C. coast, its merchantable stem would contain about 50% juvenile wood by volume. The lower portion of the stem would have a shell of mature wood below the live crown and, around the juvenile core, while the top portion would be all juvenile wood. This example of juvenile wood distribution is illustrated in Figure 3.

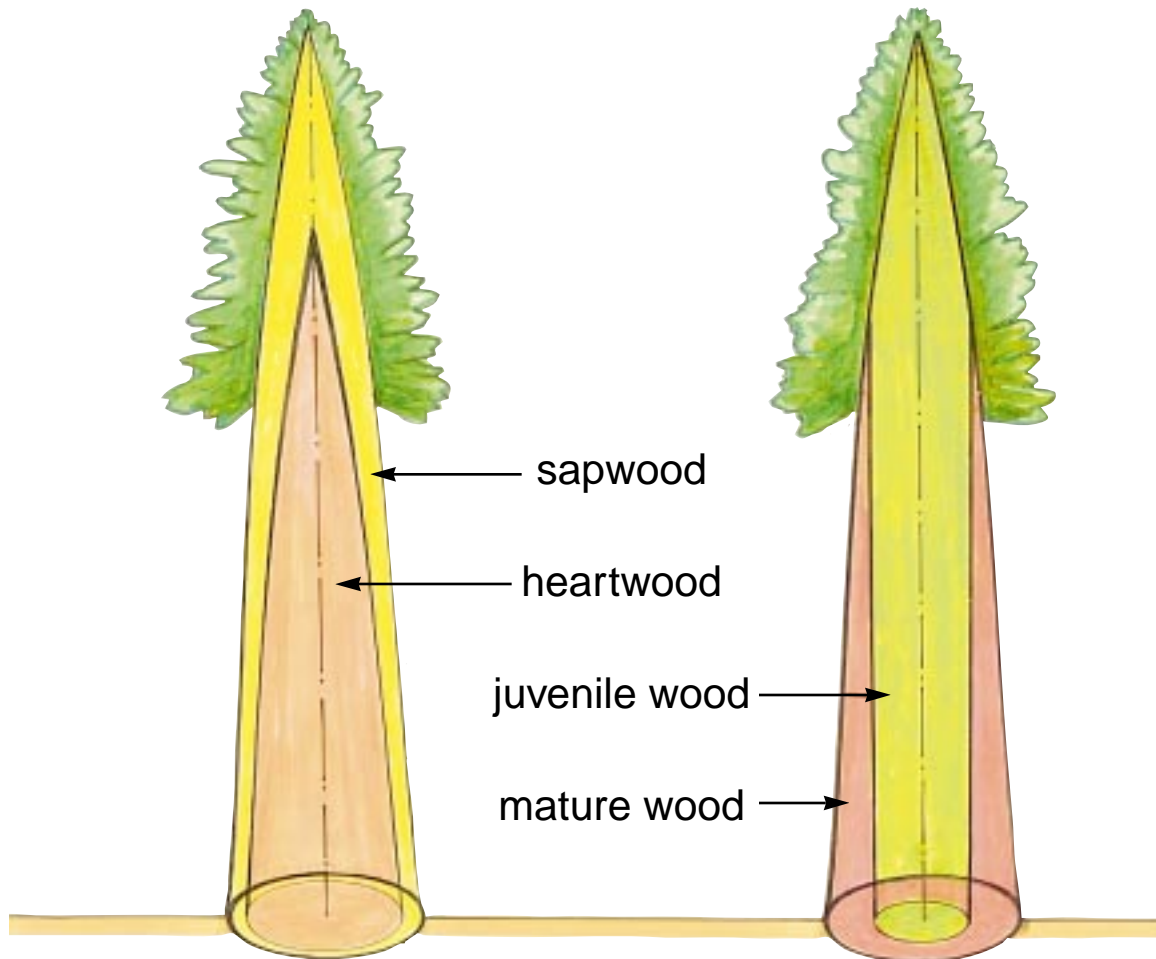


Figure 3. Stem juvenile-/mature-wood distribution.

WOOD QUALITY ATTRIBUTES DEFINED BY END-USE REQUIREMENTS

Grading rules were developed to segregate solid-wood products according to quality requirements in specific end uses. Lumber grading can be defined as the visual analysis of lumber for characteristics which will affect end-use. A lumber grade groups pieces, all different within defined limits, such that they are all suitable for the end use for which the grade is intended. Standardized rules and practices ensure that the same grade will represent the same value, and can be used for the same purpose, regardless of the log source or the sawmill from which it is produced.

There are many product categories each with their own set of quality prerequisites. Following are some of them:

- Clears - items such as Finish, Casing, Base, Ceiling, and Panelling. These are appearance grades, therefore **ATTRACTIVE VISUAL FEATURES** of the wood are most important.
- Vertical Grain Clears - such as Flooring, Decking, Stepping, and Door and Window Parts for which **WEARING FEATURES AND DIMENSIONAL STABILITY** become the predominant consideration.
- Boards and Shiplap - these are used mainly in sheathing and concrete forms where **BRACING STRENGTH** and **TIGHT CONSTRUCTION** are the main considerations.
- Millwork/European Joinery Grades - these are tight-knotted materials which can be used “as is”, or be remanufactured into components for items such as windows, doors, furniture, and cabinets, where **APPEARANCE** and **DIMENSIONAL STABILITY** are important.
- Structural Light Framing, Light Framing, Structural Joists and Planks, Beams and Stringers, Posts and Timbers - in these lumber products **STRENGTH** and **STIFFNESS** are the governing factors.

Grade-setting characteristics can be classified into three groups: Natural (developed within the tree), Manufacturing (caused by men or machines during manufacturing and handling), and Seasoning (caused by drying). Often the manufacturing and drying characteristics that impact on grade are a function both of each wood’s natural characteristics and of our inability to match processing and handling methods to take best advantage of them, or to ameliorate problems. For example, when we dry three species together, a common practice, we compromise the optimum drying of any one of them. Over the years, however, research has helped to define a number of quality attributes which determine how various woods behave. These attributes can be used to assess the suitability of a given wood for a specific end use.

3.1 Wood Density

Wood is a porous material, consisting of a matrix of fibre walls and air spaces. The air spaces exist mostly in the form of fibre cavities (lumens) and to a much lesser extent as voids within fibre walls. The solid-wood substance (fibre wall) has three major constituents, cellulose, hemicellulose and lignin. Since the density (weight per unit volume) of these is identical (about 1.5 g/cm³, oven dry basis) the solid-wood substance is considered to be constant for all wood species. It follows that wood density provides a simple measure of the total amount of solid-wood substance in a piece of wood. For this reason, wood density provides an excellent means of predicting end-use characteristics of wood such as strength, stiffness, hardness, heating value, machinability, pulp yield and paper making quality.

It is worth reviewing what is meant by density. The Canadian Standards Association (Metric Editorial Handbook, 1980) decreed that the term specific gravity was obsolete and should be replaced by relative density (not to be abbreviated). In a statement of relative densities the comparative substance for solids is assumed to be water. In the technical literature, relative density is quoted in various ways. In experiments dealing with tree and wood samples relative density is usually expressed on an oven dry (o.d.) weight and green volume basis. This is known as basic relative density. In the lumber and plywood sector relative density is often expressed on an “as is” basis; air dry weight and volume, or oven dry weight and air dry volume. Such measures are used for comparisons within an experiment and are known as air dry density. Oven dry relative density is obtained when both the weight and the volume of wood are measured in the oven dry state; this definition is most commonly used in engineering applications.

Wood is hygroscopic (tends to absorb moisture from the air) and it changes in both weight and volume with loss or gain of moisture content. It is therefore very important that the moisture content at which both weight and volume were determined be clearly stated when the term relative density is used in reference to wood. In this discussion, the terms wood density and density are used interchangeably and, unless otherwise noted, always refer to basic relative density.

3.2 Density Variation

Density variation can be as important as mean density as a measure of a wood's suitability for some end uses. For example, it is density uniformity that makes yellow-cypress, white pine, western hemlock and lodgepole pine such excellent carving and turning stocks. Veneer peeling and slicing is another end-use where a high degree of uniformity is very beneficial. Wood density variation is the greatest within the annual ring, from earlywood to latewood. This determines the evenness of grain. X-ray densitometric techniques “slice” the wood into 0.1-mm thick segments, and provide intra-ring density profiles. Depending on species and the cambial age of wood, within-ring minimum density values range from 0.25 to 0.40, while maximums are in the 0.6 to 0.9 range (o.d. weight, green volume). Figure 4 shows wood

density variation within the growth rings of Douglas-fir and yellow-cypress. Greater density variation in Douglas-fir is apparent in the contrast between the dark latewood bands and light coloured earlywood. The yellow-cypress cross section shows a more uniform grain.

Figure 5 shows species and cambial age-related differences in intra-ring density profiles. Four different second-growth tree species are compared during their juvenile wood phase (summary of rings 5-9) and during their mature wood phase (summary of rings 45-49). Figure 5a shows intra-ring density profiles according to their average ring width. It can be seen that the average ring width in the juvenile phase is about twice as wide as in the mature phase for Douglas-fir, western larch, and lodgepole pine while yellow cypress is an exception. Density distribution is more homogeneous in the juvenile wood mainly through lower latewood density and lower latewood percentage by width. Figure 5b shows the same data, but with a standardized ring width. These tree rings were standardized to the same width to facilitate comparisons between minimum/maximum density, earlywood/latewood percentage by width, rate of density change from earlywood to latewood, and juvenile-/mature-wood.

The variability in wood density of major softwood species in North America became a concern in the 1960's and 1970's because of questions regarding the properties of structural timbers and plywood produced from various species combinations and smaller second-growth timber. Large scale wood density surveys were carried out in U.S.A. and Canada at that time and are well documented. The U.S. Forest Service measured about 25,000 trees in their western survey alone.

Unfortunately, very little information can be gleaned from these efforts in terms of relative density differences between old-growth/second-growth, juvenile-/mature-wood, pith-to-bark and base-to-top density trends. For this reason, and the persistence of anecdotal evidence "that second-growth wood is inferior, when compared with old-growth wood", Forintek has examined second-growth woods in terms of wood relative density distribution and dimensional stability (through longitudinal shrinkage measurements). It is encouraging to know that examples of successful harvesting and processing of natural second-growth stands occur throughout British Columbia. The significance of these stands is that they are being harvested at well below old-growth rotation age with satisfactory financial returns (45-50 years on the Coast and 60-80 years in the Interior). It follows that managed stands, with more uniform trees and higher yields, could achieve even better results.

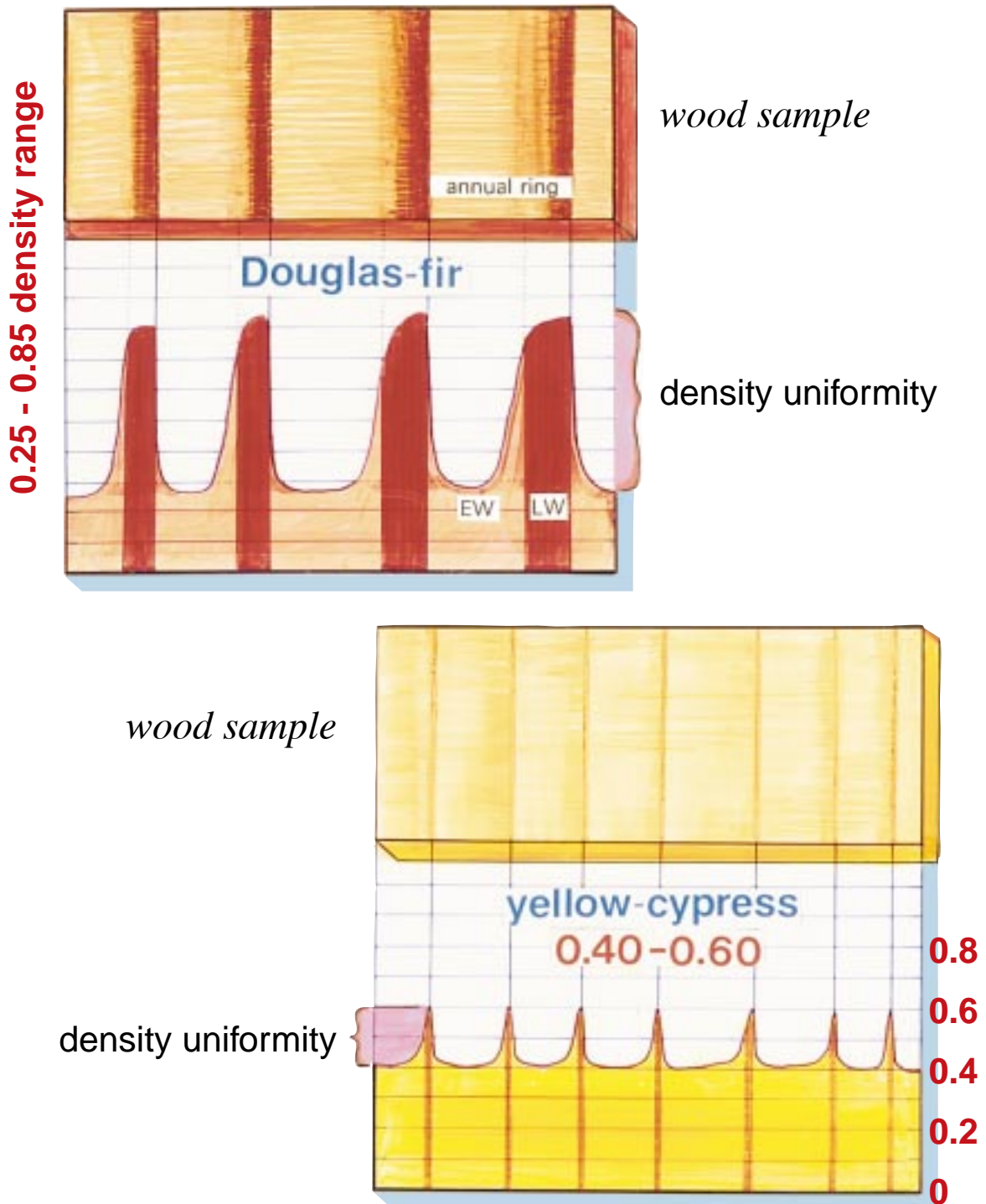


Figure 4. Wood density variation within growth rings.

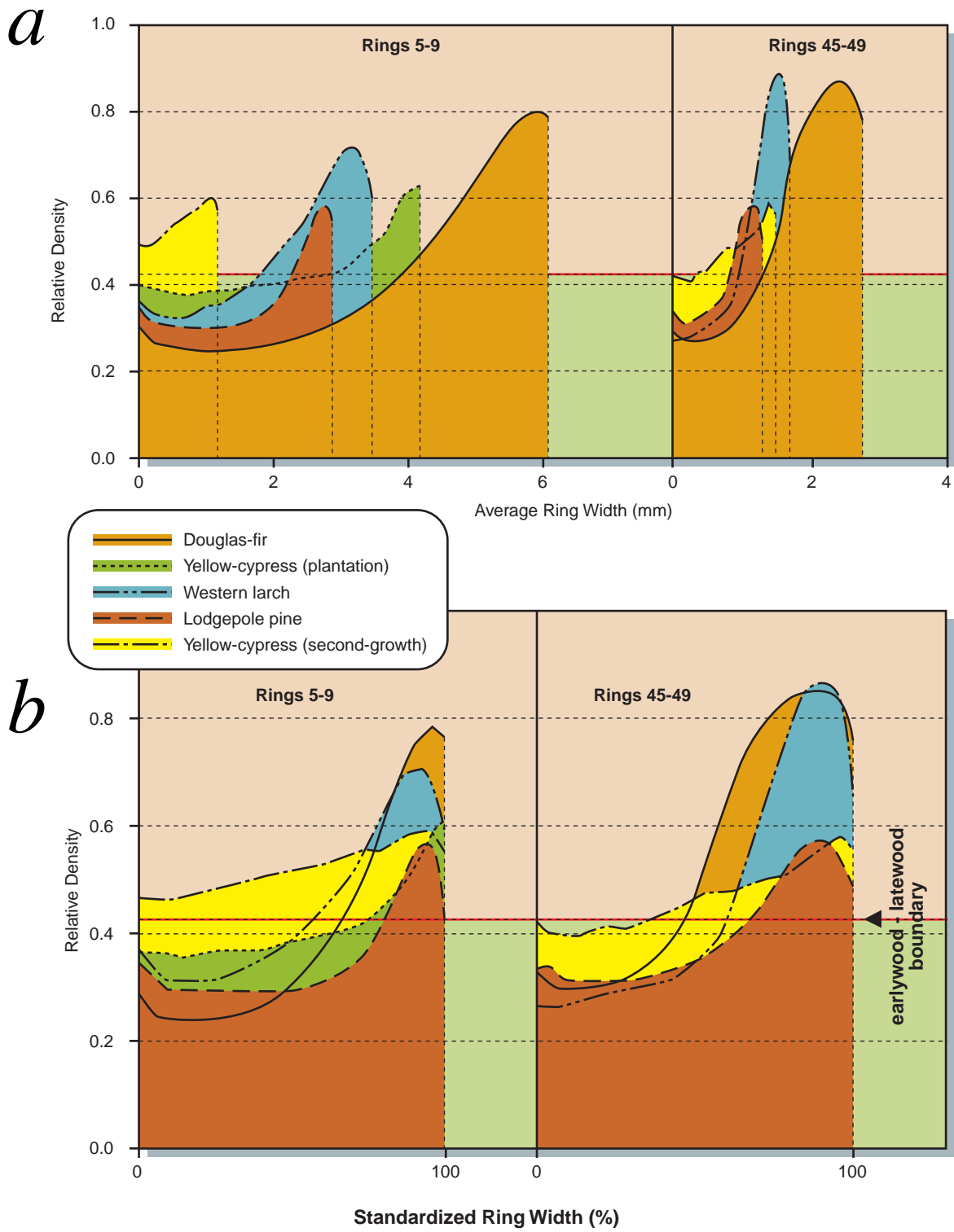


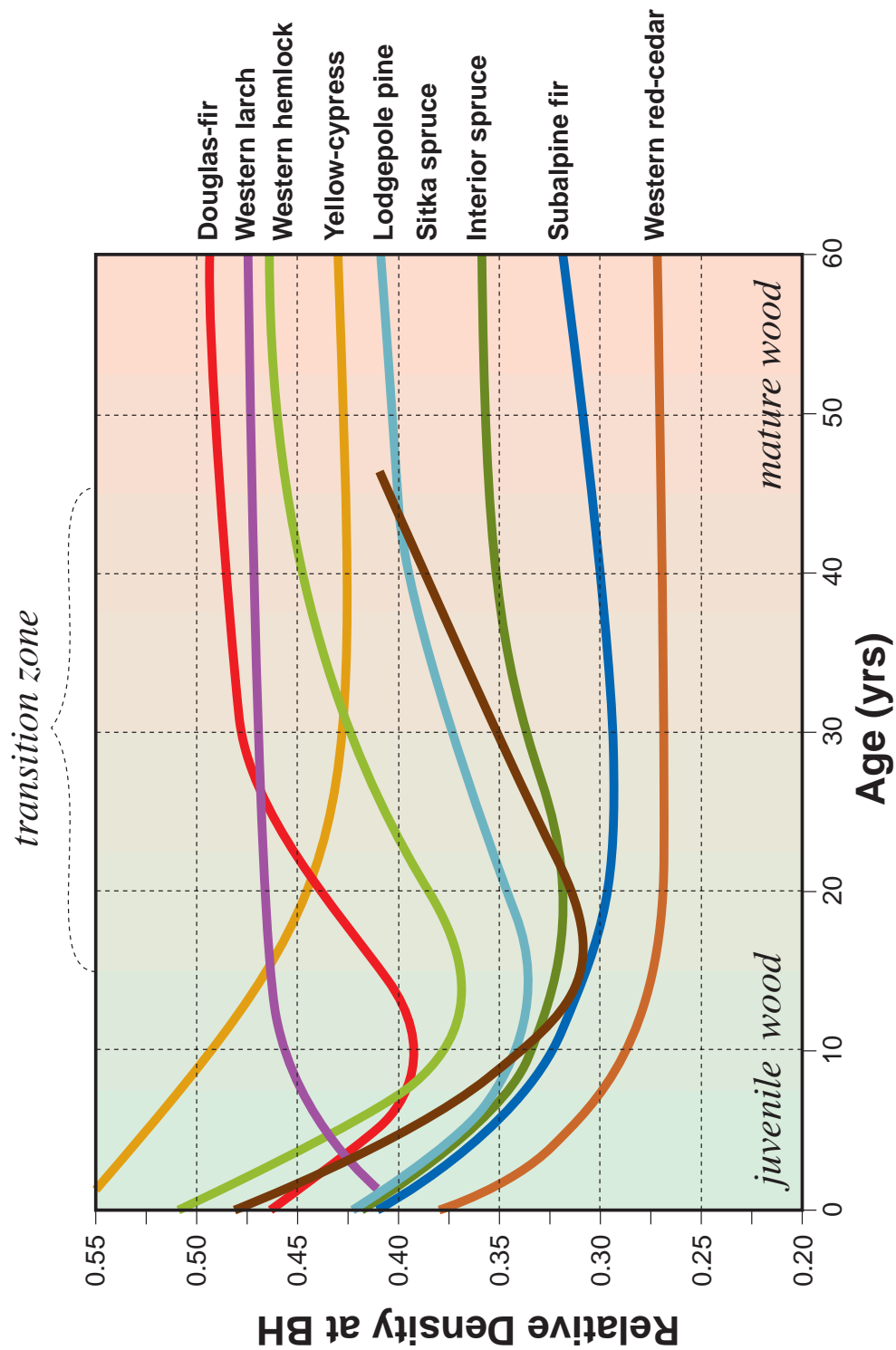
Figure 5. Intra-ring density profiles plotted according to real ring width (a) and standardized ring width (b).

3.3 Juvenile Wood/Mature Wood Distribution

The transition from harvesting old-growth, first to natural, then to extensively managed second-growth, and ultimately to silviculturally manipulated stands, will result in changes not only to timber size but also to timber characteristics. One important change will be the increased proportion of juvenile wood relative to mature wood. This has implications for previously established standards of comparison. Wood density surveys through the last 50 years have established industry standards for all commercially important tree species. For example, we can find the following average basic relative density values for Douglas-fir (0.45), western larch (0.45), western hemlock (0.42), yellow-cypress (0.42), lodgepole pine (0.41), interior spruce (Engelmann and White) (0.36), Sitka spruce (0.35), western-red-cedar (0.33), and subalpine fir (0.33). Because of the time of these determinations, and the nature of the sample material, these values are essentially old-growth reference values which are becoming increasingly less applicable.

Figure 6 shows a comparison between average ring density trends at breast height (BH) from pith-to-bark of some rapidly grown second-growth woods. Wood juvenility can be determined through examining a number of different variables (fibre length, fibril angle, longitudinal shrinkage, lignin/cellulose ratio) but here average ring density was used. *It is important to note that not all species have low density juvenile wood (usually the first 20-30 years of growth).* In yellow-cypress, white/Engelmann spruce, western-red-cedar and subalpine fir the inner juvenile wood is of comparatively higher density than the outer mature wood. Forintek has reported on the extent and distribution of low-density juvenile wood in second-growth Douglas-fir and lodgepole pine. Although lodgepole pine has a longer period of juvenility than Douglas-fir, the difference between low-density inner wood and high-density outer wood is about one half of that in Douglas-fir and western hemlock. The Sitka spruce trend line is the only one that had not flattened out from the steady increase from age 15 to 45. Western hemlock's trend line shows a relatively long low density juvenile wood period, possibly the result of its shade tolerance (crown persistence). *It is important to remember that these examples represent the most vigorous forest-grown trees we could find.* The rationale was that if there were no problems with rapid growth then regular growth would pose no problems either.

The increased proportion of juvenile wood relative to mature wood in second-growth has quality implications for lumber production. Juvenile wood in all tree species can present unusual warping problems. It can shrink excessively along the grain because of large fibril angles, or twist because of spiral grain. In species where the difference in density between juvenile wood and mature wood is relatively large, a higher proportion of juvenile wood can result in reduced lumber strength, *but there may be ways in which sawing patterns can be designed to mitigate the impact.* It would make little sense, for example, to saw 2x4's for structural uses from the centre cant of rapidly grown, large, second-growth Douglas-fir. We do not grow big trees to make small products.



N.B.: Average trend lines are based on examinations and summaries of various numbers of trees as follows: Douglas-fir - 60 trees; Lodgepole pine - 60 trees; Sitka spruce - 20 trees; Subalpine fir - 15 trees; Western hemlock - 26 trees; Western larch - 15 trees; Western red cedar - 10 trees; White/Engelmann spruce - 20 trees.

Figure 6. Average ring density trend from pith-to-bark in some second-growth woods.

A wide lumber piece that straddles a juvenile core may perform well in service, stressed in compression (top edge) and tension (bottom edge), as occurs in joists, beams and similar pieces of lumber (Figure 7). Its performance may be much the same as that of engineered I-beams which are manufactured with deliberate recognition that the strength of the edges is more critical than that of the centre. (Grading rules use rate-of-growth as a proxy for strength and require that an *average* rate-of-growth be determined on piece ends, specifying that the average be taken over a 3-inch line at a right angle to the growth rings.) Alternatively, narrower lumber pieces can be machine-stress-rated (MSR), a method of assigning more specific strength values. Because all juvenile wood is not created equal (genetics), a range of ratings will be obtained and pieces that contain juvenile wood can be marketed to their best advantage. Even with some reduction in strength, lumber from higher average density species such as Douglas-fir, may be as strong with juvenile wood as lumber of other species and could be sold in new species groups of MSR (eg. in combination with spruce-pine-fir, S-P-F). The sawmill manager must know what he has in terms of wood quality and must direct each log to its highest value breakdown. Marketing people must be prepared to find the highest market value for a wider array of products.

Increased proportions of juvenile wood have implications from the pulp and paper industry's perspective. A study² of second-growth Douglas-fir found that *the use of low density juvenile wood in the production of bleachable-grade kraft pulps resulted in reduced yields*. Pulping yields are a reflection of the weight of wood in the digester in relation to its fixed volumetric capacity. In general, juvenile wood contains about 3 percent more lignin (and correspondingly less cellulose) than mature wood, and this *also contributes to lower yields of chemical pulps*.

2. J.V. Hatton and K. Hunt. 1989. *Unbleached Kraft Pulps*. In *Second growth Douglas-fir: Its management and conversion for value*. Compiled and edited by R.M. Kellogg. SP-32. Forintek Canada Corp. Vancouver B.C.

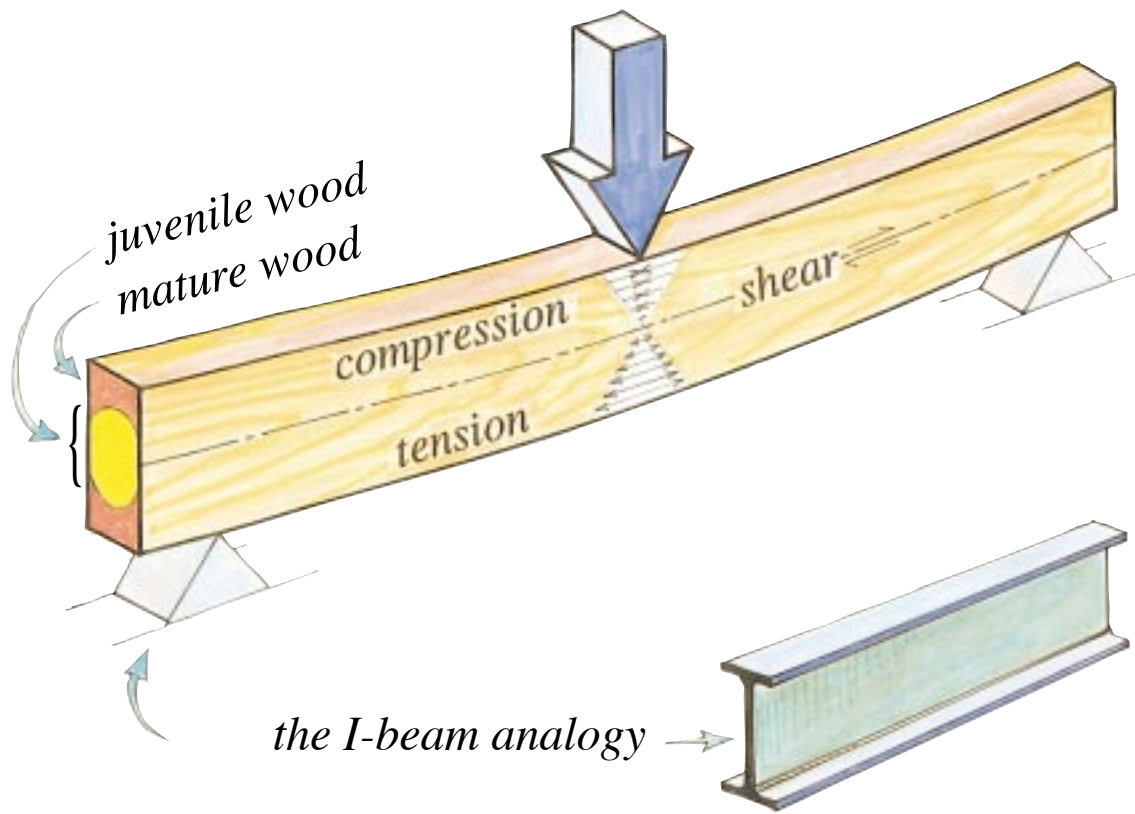


Figure 7. Edge-loaded lumber showing internal compression, shear, and tension stresses.

3.4 Proportion of Heartwood/Sapwood

The proportion of heartwood/sapwood is a wood quality descriptor important to both the solid wood and the pulp and paper sectors. For example, in lumber drying the difference between sapwood and heartwood is quite important. Usually sapwood contains much more water than heartwood (on average 120% and 40% moisture content, respectively). Nonetheless, it is normally more difficult to remove water from the heartwood than from the sapwood. The slower drying rates observed for heartwood are usually due to aspirated bordered pits and to the presence of extractives, both of which block up the passages for water flow. Preservative uptake in pressure treating (to improve decay resistance), cooking liquor penetration in pulping, and stain/paint penetration are more difficult to achieve in heartwood than in sapwood because of this permeability difference.

3.5 Fibre Length

Fibre length is a wood quality attribute important to the pulp and paper industry but easily overlooked from the solid-wood products perspective. The pulp and the solid-wood products sectors in B.C. are closely linked, however, because 80% of pulpmill furnish comes from sawmill waste. The other 20% comes from low-quality pulplogs.

Fibre length is one of a number of wood properties that can be used to determine wood juvenility. Based on work done to date, it is likely that in all B.C. softwoods fibre length is shortest next to the pith at all height positions in the stem, and it increases radially outward with age. In the species studied, material taken from inner portions of logs averaged at least 1mm shorter in fibre length than material taken from the outer zone (at least 20 rings from the pith). This means that sawmill chips taken from tree tops, thinnings, and from peeler cores will yield shorter fibres (by at least 1mm) than chips taken from the outer parts of the logs like sawmill slabs and edgings.

Figure 8 shows fibre length as a function of age at five height levels in 50-year-old Douglas-fir trees (Forintek's Douglas-fir Task Force). Fibre length was measured for each 5-year interval for the first 15 years, and in 10-year increments thereafter. A rapid increase in fibre length is evident for the first 25 years of growth at all height levels, this levels off gradually, as shown in Figure 8. At comparable ring numbers from the pith, average fibre length is shorter near the base of the stem, at breast height, than at upper heights. For example, at age 25, fibre length is approximately 15% shorter at breast height than at 20, 40, and 60% heights.

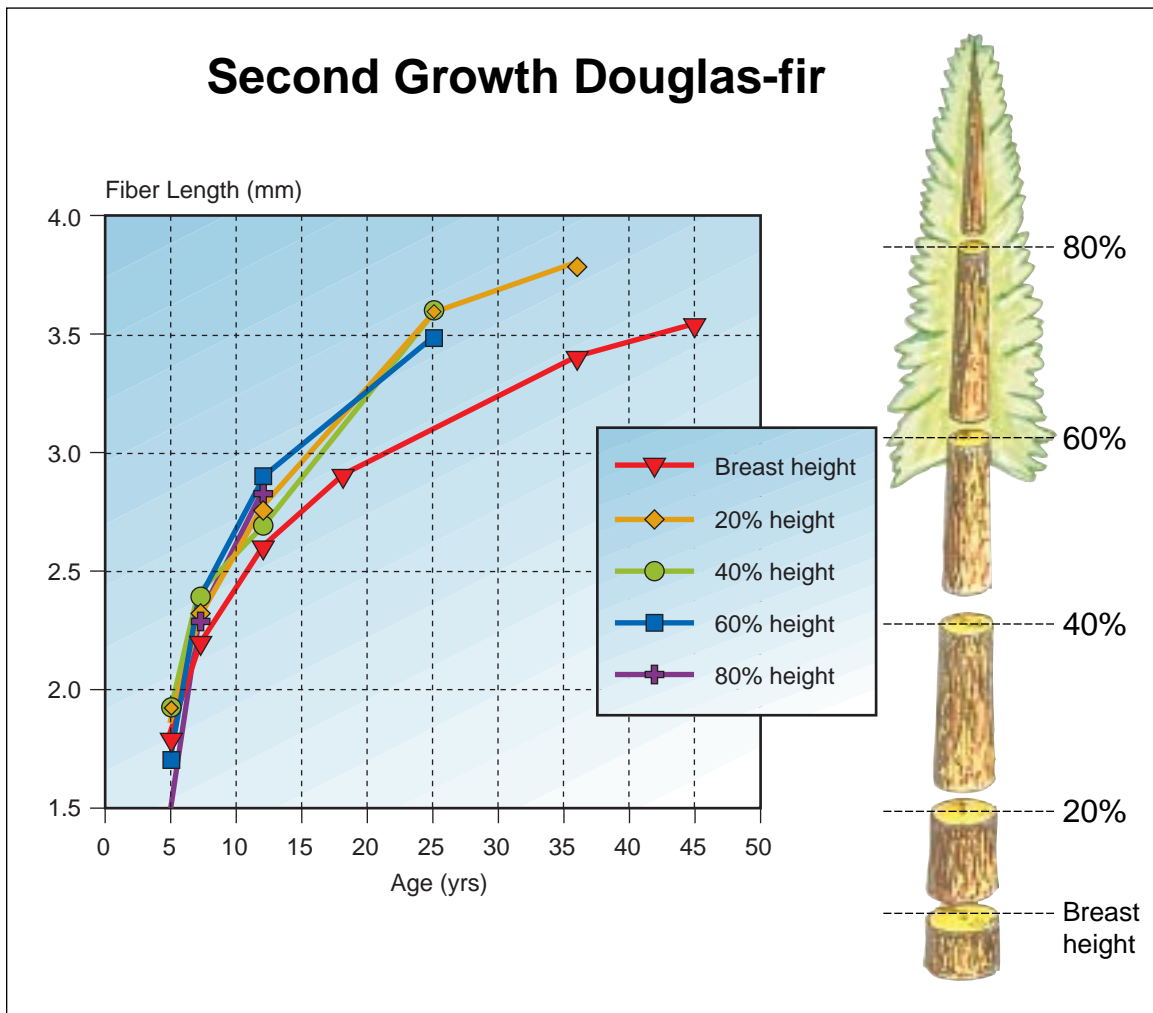


Figure 8. Fibre length as a function of age.

A direct connection between the strength properties of wood and fibre length has not been established, however, longer fibres will make stronger paper sheets. This is an important consideration when good-quality longer fibres are needed as reinforcement to carry poorer-quality fibres through the paper machine. In addition to fibre length, fibre coarseness (weight per unit length) is another quality descriptor. For this reason the low-density (and short fibred) juvenile wood of Douglas-fir yields lower fibre coarseness than mature wood. Finer fibres tend to form better quality paper sheets, for most end uses, than coarser fibres which are typical of the mature wood of this species.

Other researchers³ have reported a close correlation between fibre length and fibril angle linking increased fibril angle with shorter fibres contributing to the lower strength and stiffness of juvenile wood.

3.6 Fibril Angle

Wood fibres are comprised of organic building blocks (cellulose, hemicellulose and lignin) precisely arranged in the fibre wall. Figure 9 shows at high magnification the layered structure of the fibre wall. Included here is the lignin-rich middle lamella (ML), the surrounding “glue” that holds individual fibres together in a piece of wood. (This “glue” is the target of the chemical pulping process – dissolving the ML causes the wood to separate into its individual fibre elements forming pulp.) The primary wall (P) is made up of a loose and random weaving of cellulosic microfibrils, intermixed with lignin. In the secondary wall, made up of S1, S2, and S3 layers, these cellulosic microfibrils are closely packed. The S2 layer is the thickest of the three (from 3 to 15 times thicker, in earlywood to late wood, than the S1 and S3 layers combined) and, as a result, has the greatest impact on how the fibre will perform in strength tests, and in shrinking or swelling. Particularly important is the orientation or angle of the microfibrils in this S2 layer. Microfibril angle refers to the mean helical (spiral) angle that the fibrils of the S2 layer of the fibre wall make with the longitudinal axis of the fibre.

Microfibril angle has macro implications due to the anisotropic (has physical properties which depend on direction) nature of wood. As wood absorbs or releases water it swells and shrinks more in the tangential direction than radially. Shrinkage of the fibre wall, and therefore of the whole wood, occurs as bound-water molecules escape from spaces between cellulose molecules allowing these cellulose molecules to move closer together. The amount of shrinkage that occurs is generally proportional to the amount of water that is removed from the wood and the orientation of microfibrils in the cell wall. Swelling is simply the reverse of this process.

3. Tsoumis, G. 1991. *Science and technology of wood*. Van Nostrand Reinhold, N.Y. 494p.

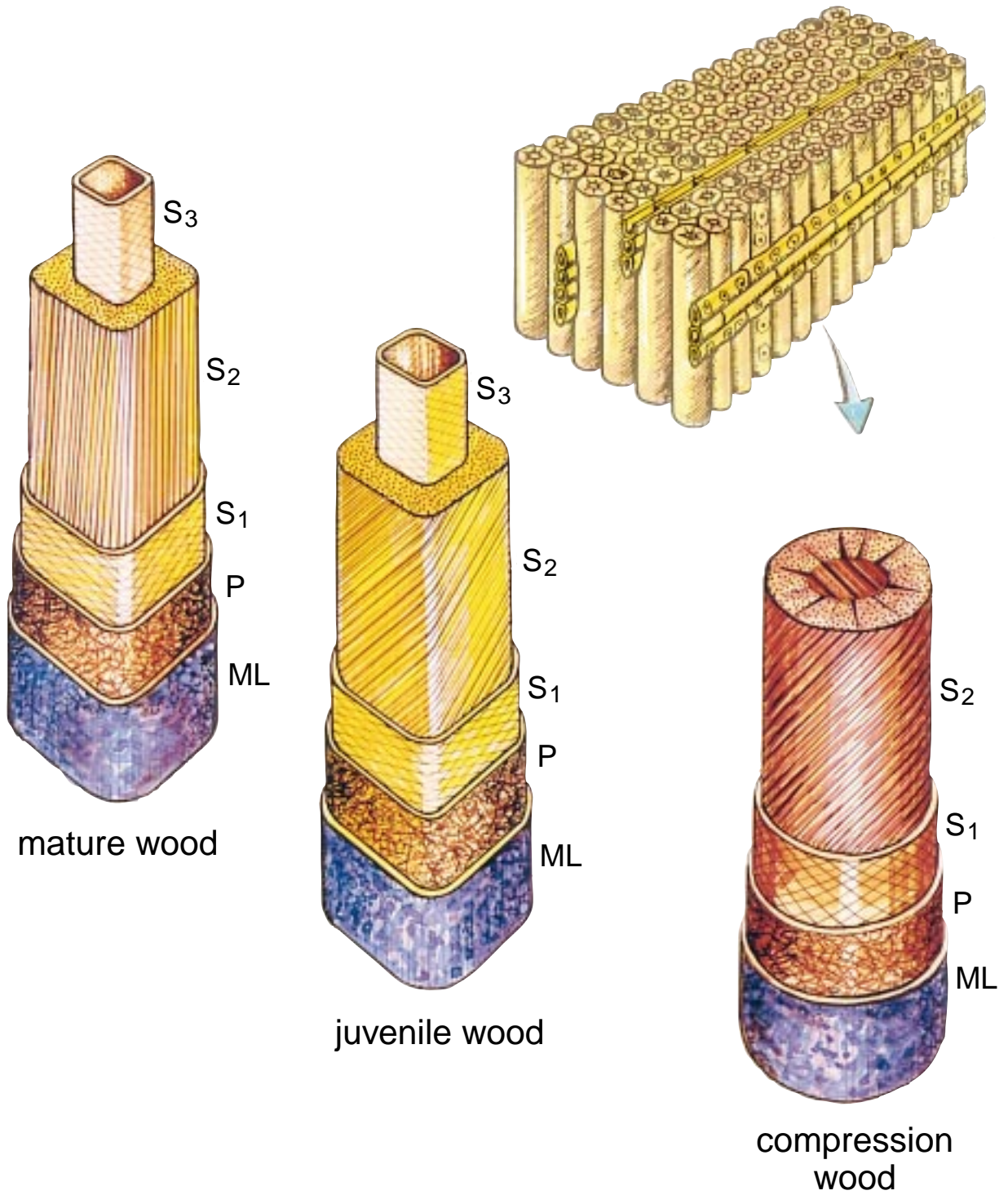


Figure 9. Anisotropic nature of wood and fibril orientation in normal, juvenile and compression wood.

Figure 9 shows the fibril orientation for normal mature wood, juvenile wood, and compression wood. The longitudinal shrinkage of normal mature wood is negligible for most practical purposes. Here microfibril orientation is about 7 degrees or less off the cell axis. Usually, some longitudinal shrinkage does occur in drying from green to oven-dry condition, but this is only 0.1 - 0.2 percent for most species and rarely exceeds 0.4 percent. As an example, a 2x4-in. stud 8 ft long, for the wall of a house, would shrink 0.1 - 0.2 in. (2-5 mm) in length when drying from green (>30% M.C.) to oven-dry condition (if it were cut from normal wood). If this stud were cut from compression wood or juvenile wood, where microfibril orientation could be up to 45 degrees, then the longitudinal shrinkage can be as much as ten-fold (1.0 - 2.0 in, or 2.5 - 5.0 cm) as a result. Troublesome warping results when longitudinal shrinkage potential varies within a piece of wood due to the presence of normal mature wood in combination with juvenile wood or compression wood. Bow and crook are commonly traceable to such variable longitudinal shrinkage.

Wood juvenility was established for a number of softwood species from pith-to-bark through microfibril orientation and longitudinal shrinkage measurements. The results showed microfibril orientation near the pith $>35^\circ$ with a gradual decrease as a function of age. By age 20 microfibril orientation was $<10^\circ$. Pith-to-bark longitudinal shrinkage measurements showed similar trends; excessive shrinkage (1-2%) near the pith and $<0.3\%$ by age 20. These large fibril angles in juvenile wood have been correlated to lower strength and stiffness in lumber products where these lower values could not be attributed to appreciable differences in density.

3.7 Compression Wood

Compression wood is a term applied to abnormal wood formed in softwood tree stems and branches that have grown out of the vertical position. As a rule, compression wood is formed in softwoods on the underside (or compression side) of leaning stems. This name refers only to the position where compression wood is formed and does not imply that it forms as a result of compression stress. Instead, two factors have been isolated, gravity and auxins, as the most likely triggers of compression wood formation.

Compression wood is relatively easy to identify visually, especially on smooth surfaces. A stem cross section containing significant amounts of compression wood will have much wider rings (and darker wood) than normal wood, resulting in an eccentric shape with the pith offset toward the upper side of the leaning stem. A reddish-brown colour makes it conspicuous, especially in species not having dark coloured heartwood or little contrast between earlywood and latewood (like true firs, spruces and yellow-cypress). There can be various degrees of severity, but in pronounced compression wood the annual rings seem to be composed entirely of latewood. In mild cases, recognition can be difficult. In such cases thin cross sections are sawn, about 3-4 mm thick, and are illuminated with transmitted light (or held to the sun) to reveal the opaque nature of compression wood. Normal wood appears transparent with a honey-like glow.

The two main disadvantages of compression wood to the wood worker are its deleterious effects on strength and shrinkage. In structural uses where load bearing capability is vital, failures in loaded wooden members may often be traced to the presence of compression wood. Investigations of fatalities resulting from the sudden breaking of ladder rails, for example, have pinpointed undetected compression wood as the cause. Excessive warping can often be traced to compression wood because it shrinks 10 to 20 times more than normal wood. Compression wood also presents problems to the pulp and paper sector. Its high lignin content reduces yield and results in undercooked chips, its abnormal microfibril orientation lowers strength, and its dense stiff fibres do not bond well to one another.

At the microscopic level more differences become evident between compression wood and normal wood (Figure 9). In cross section compression wood fibres are rounded, leaving voids where the fibres come together. An examination of the fibre wall reveals that the S-3 layer is missing and the slope of the microfibrils in the S-2 layer is about 45 degrees from vertical. In addition, deep helical checks extend from the fibre cavity through the S-2 layer. It must be emphasized that in microscopic examination these are not drying checks; they exist in the living tree. No doubt this feature contributes to the opaque appearance of compression wood in transmitted light; the helical checks refract light, while normal wood fibres transmit light readily, acting much like “optical fibres”.

What triggers auxin production from tipped tree stems and how these hormones move to specific locations in the stem are not known. However, it has been shown by researchers that the system is sensitive and compression wood formation can start in 24 hours after tipping a stem. The amount of compression wood formed is directly related to tree vigour and the angle of the lean. Studies have shown compression wood formation with stem displacements as small as two degrees in fast growing trees; yet in senescent 720-year-old Engelmann spruce, a 30 degree lean did not produce compression wood. Furthermore, in perfectly upright trees compression wood was blamed on prevailing winds and uneven crown distribution.

From the forester’s point of view, it should be noted that the formation of compression wood may be controlled, within limits, through silvicultural measures that protect the trees from becoming displaced from the vertical. Such measures include proper spacing of plantations, establishing wind barriers, and timely thinnings of proper intensity in order to avoid abrupt exposure of tall and slender trees. Such trees have been observed to lean under their own weight, or due to wind action or snow loads, and they will continue to produce poor quality compression wood until harvested.

3.8 Knots

A knot is a branch that is included in the wood of a tree stem by growth around its base. With time, some of the branches die, decay, fall off and become overgrown (in most B.C. softwoods at about 100 years of age). These knots will be visible only when the tree is sawn

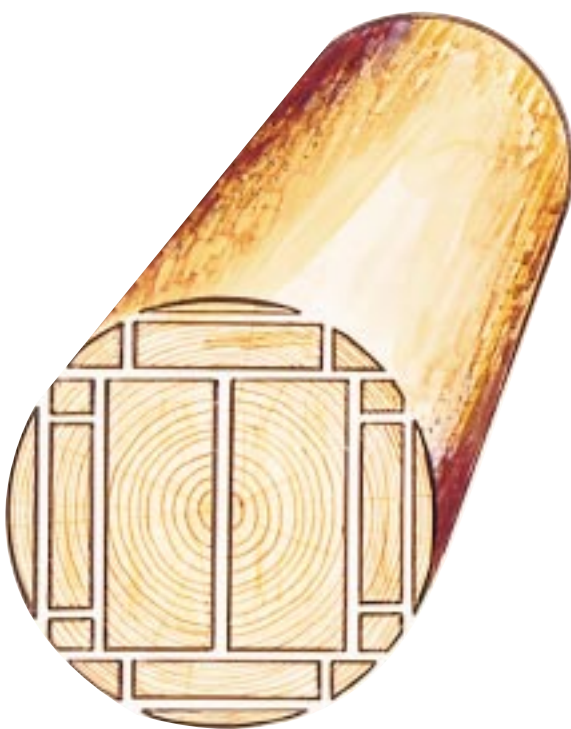
or split. As long as a branch is alive its cambium is continuous with the stem. This results in a tight or intergrown knot. In a dead branch the continuity in the cambium is broken and the knot produced is encased or loose.

Knots are termed defects in structural lumber because of the strength-reducing effect caused by grain deviation around them. The appearance of a knot on the surface of a piece of lumber depends on the direction of cut through the branch stub. Figure 10 illustrates some different sawing strategies. Cant sawing is typical of small-log mills cutting structural lumber, where much of the lumber will be flat-sawn and knots will appear slightly oval. When the cut is made along the axis of the branch (as in quarter-sawn or edge grained lumber) the knot will appear somewhat triangular and is called a spiked knot. Also shown is cant sawing with a centred sawline, “green split”, used in Scandinavia to eliminate the pith in the production of joinery (a further centred cross-cut, made on the two flitches that contain what remains of the pith places the pith on one corner of each resulting piece where it can be machined off with little loss of wood). These two small-log cant sawing methods are compared to sawing around which is used in large-log mills to maximize clear wood production.

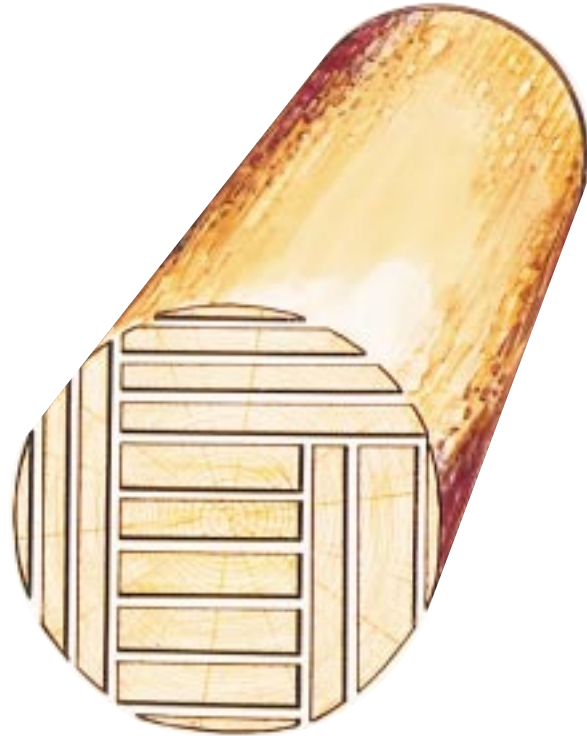
In Structural Joists and Planks, where the top grade is “Select Structural”, the maximum knot size allowed for lumber depends on the width of the piece (ratio of clear wood face to knot diameter) and the position of the knot. If the knot is positioned on the centre-line of the wide face of a Select Structural piece, then its maximum diameter can be approximately 36% of the width. Therefore a 2x4, 2x8, and a 2x12 could accommodate approximately a 2.2, 5.7, and a 7.6 cm diameter knot, respectively. If the knot is positioned on the edge of the board, however, then the maximum knot size allowed is 20% of the width for Select Structural grade (Figure 11). In many stress grades no distinction is made between intergrown knots, knots that are not firmly fixed, or holes, the latter two defects having no more impact on strength than the first.

For joinery grades, knots are judged both for size, frequency, and appearance. Live knots can be prone to undesirable seasoning checks, but dead knots are a more serious defect because they detract from appearance and can become loose and fall out in machining. The number of knots permitted in a piece is based on 5 lineal feet (unit size). Joinery grade lumber products are high quality knotty grades for natural finish. That is, the wood is exposed as in doors, windows, furniture and panelling. Top grades will have partially clear wood with infrequent intergrown knots, and even smaller dead (black) knots (that are about half the size of the live knots). Therefore, it is common for a piece of lumber to make the top joinery grade on knot size and quality, but fail on account of knot frequency. (Edges are very important as well, and they must be of high standard with respect to edge knots and wane because this is an appearance grade.)

cant sawing



cant sawing
(centered saw-line)



sawing around

Figure 10. Some alternative sawing strategies.

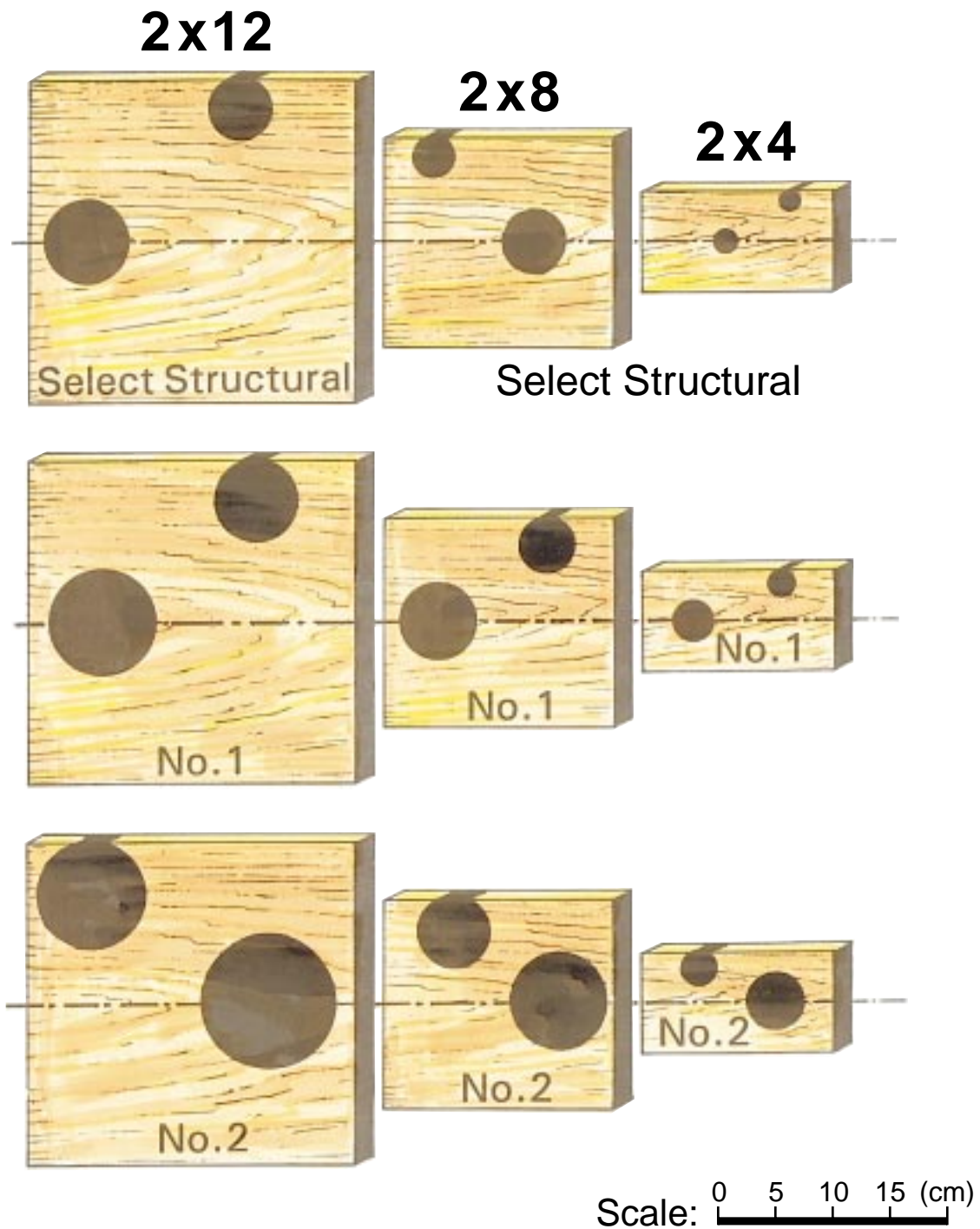


Figure 11. Maximum knot sizes allowed on the edge and on the centre-line of 2x4, 2x8 and 2x12 lumber

Some foresters are concerned that encouraging more rapidly grown trees by decreasing stand density will result in larger knots that will degrade product values. Knots will be larger but the impact on lumber grade will be mitigated by the fact that larger trees allow the production of wider lumber widths which permit larger knots. This mitigating effect is illustrated in Figure 12 in which percentage of Select Structural lumber yield is related by dimension to log classes defined by the average of the four largest knots measured on the log. It shows that the percentage of Select Structural 2x8's is unaffected as average knot size increases while the percentage of Select Structural 2x4's declines as expected. Just as it is a mistake to cut 2x4's from the juvenile core of large rapidly grown Douglas-fir, it would be equally unrewarding to produce only 2x4's from rapidly grown (larger knot) trees.

3.9 Grain

The term grain is often used in a loose and confusing manner to describe wood quality. Its specific meaning depends on the context in which it is used. For example, in softwood lumber grading, grain is used to describe two different concepts: (i.) the direction of wood fibres and annual rings, i.e., vertical grain, flat grain, and cross grain, and (ii.) the growth rate or the relative width of growth rings, i.e., coarse grain, medium grain, and close grain. In wood anatomy studies and in wood-working circles, the connotations of coarse, fine, and medium grain refer to the relative size of wood fibres as seen with the naked eye or under magnification. Large-diameter fibres produce a coarse grain (like Douglas-fir), while small-diameter fibres form fine-grained woods (like yellow-cypress and yew). Some fast-grown tree species, such as radiata pine, often produce very coarse wood. Even or uneven grain refers to the contrast between earlywood and latewood within the annual ring.

The practical implications of grain in the anatomical sense include its influence on how well wood takes paint and on how wood dries. More precisely, paint sticks better to the radial surface of wood (edge grain) than to the tangential surface (flat grain), because paint is better able to penetrate wood through the bordered pit apertures. Thus, paint adhesion is not very good in the latewood zone where pits are smaller and infrequent. Interestingly, wood drying takes place faster on the flat grain than on the edge grain. This apparent contradiction results from the fact that paint penetration is very shallow while moisture movement that occurs during drying comes from deep within the piece and depends on ray cells which act as conduits.

Rapid growth rate (coarse grain) has been frequently blamed for lower strength and stiffness and higher warp. Many of the problems thought to be related to wide rings were really due to the age of wood formation. In other words, juvenile versus mature wood. The misconception arose with Douglas-fir when wide-ringed, low-density wood at the centre of the tree (which is juvenile wood) was compared with the narrower-ringed, higher-density wood near the bark (which is mature wood). Because the wide juvenile rings produced low- and the narrower mature rings produced higher-density wood, it was incorrectly concluded that rapid growth *per se* resulted in low-density wood.

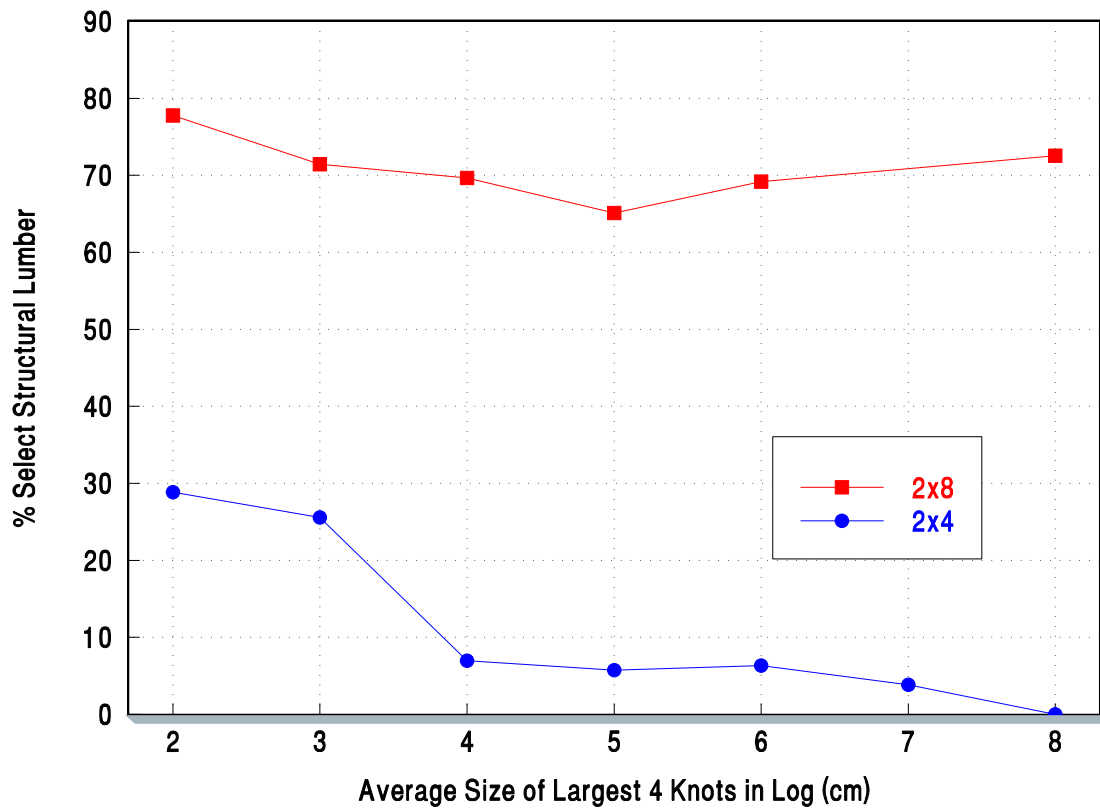


Figure 12. Select Structural grade yields for different widths of dimension lumber from logs sorted by knot size

The “true” effect of growth rate on wood density (and other properties as well) can only be made on *rings of the same age*. At Forintek, we have found that when each annual ring is segregated according to its age from the pith, only a weak relationship is found between relative density and ring width in Douglas-fir, Sitka spruce, yellow-cypress and lodgepole pine (other species are being investigated). Figure 13 illustrates the difference between valid and invalid comparisons of relative density and ring width. The invalid comparison confounds ring width (growth rate) with ring number (age).

As mentioned earlier, in some National Lumber Grades Authority (NLGA) stress grades, such as Structural Joists and Planks, rate-of-growth requirements are specified for Douglas-fir and western larch because of strength considerations. The top three grades require “Medium Grain”, which means 4 or more rings per inch, however, fewer than four rings per inch are acceptable if the rings contain >33% latewood. Four rings per inch (or medium grain) means that the average ring width is 6.35 mm, measured on a line at a right angle to the rings. Again, if piece size permits, this measuring line should be 3 in. long. For the 60 trees measured intensively in Forintek’s Douglas-fir Task Force, rings >6.35 mm wide were formed between age 3-12 at BH, 20, and 40% tree heights (in the lower half of the stem). This interval is within the 20-year juvenile wood core, and it encompasses the lowest density wood as well (Figure 14). Because of the exponential growth trend in these trees, ring width drops to 4.5-5.0 mm by age 20 and 3.5-4.0 mm by age 25. From age 30 to 50 average ring width is less than 3.5 mm in these second-growth Douglas-fir trees whose average stocking density was 530 stems/ha. Therefore, in this context the growth rate requirement for Douglas-fir stress grades is justifiable, because it acts as a surrogate to eliminate some juvenile wood.

In the current NLGA grading rules, rate-of-growth requirements are specified also for reasons of appearance in certain end-uses. In Export R-List Grading and Dressing Rules the top grades of Rough Green Clears, Shop, Fitches, and Window Stock require Close Grain, which means 6 or more rings per inch (mean ring width less than 4.23 mm). Figure 14 illustrates that this limit is reached at about age 20-25 in Douglas-fir. The top grade in vertical grain (VG) Door Stock requires at least 8 rings per inch (average ring width less than 3.16 mm).

The terms spiral grain and fibril angle may be confusing. They refer to totally different concepts in wood structure. While spiral grain is a macroscopic feature (easily seen with the naked eye on living and dead trees, telephone poles, and fence posts), fibril angle is visible only microscopically. In straight-grained wood fibril angle can vary from less than five degrees (in mature wood) to 45 degrees or more (in juvenile wood and compression wood).

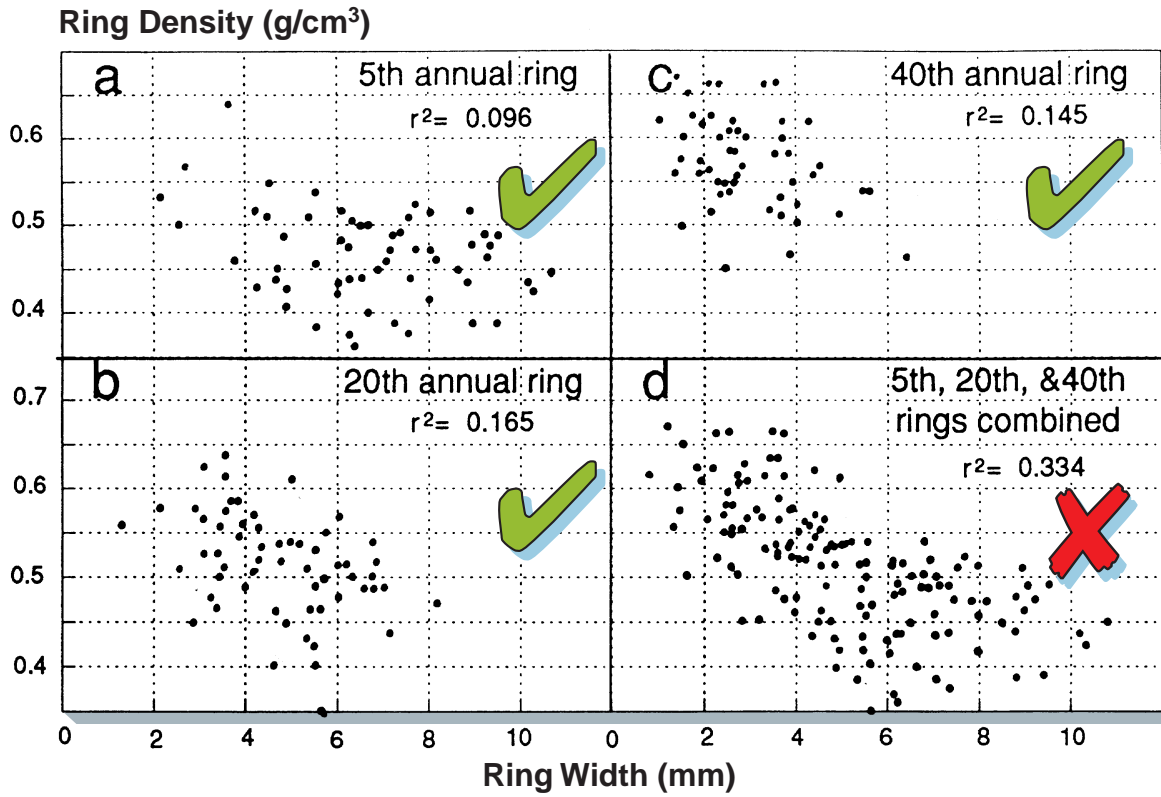


Figure 13. Valid and invalid relative density and ring width comparisons

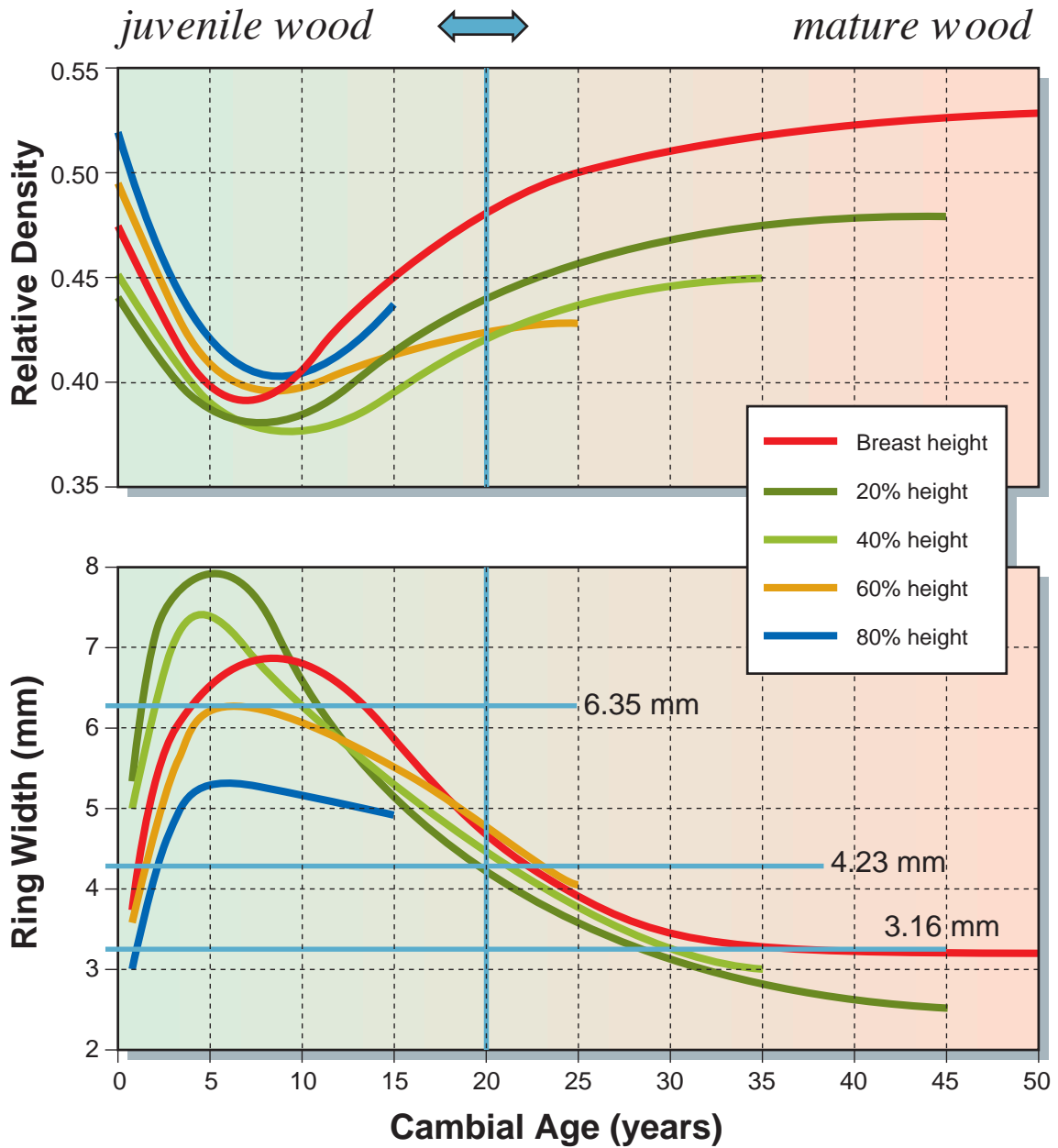


Figure 14. Average ring density and ring width versus rings from the pith by sampling height for 60 Douglas-fir trees

Most importantly, from the solid wood products perspective, *grain orientation* in a piece of wood is determined by the alignment of wood fibres. Ideally, the long axis of the wood fibres is parallel to the board length. In a standing tree which has straight-grained wood the fibres will be oriented parallel to the long axis of the stem. With little exception, fibre arrangement is at some angle, however small, to the stem axis rather than precisely parallel to it. At times this deviation is large, resulting in an obvious spiralling grain pattern. This kind of grain orientation can significantly affect wood properties. Lumber sawn from such logs is characterized by slope of grain which causes low strength and stiffness and a tendency to twist as it dries. Planing such lumber to a high-quality finish may also be difficult. Excessive spiral grain (about 35 degrees) can severely impact log quality. In a documented case a 3m diameter old-growth Douglas-fir log was chipped because it was totally unacceptable for manufacturing into solid wood products or veneer. Grain orientation that is not parallel to the long axis of a log also adversely affects machining properties and the nature of moisture-induced dimensional changes. Fortunately, excessive spiral grain is not a problem in most second-growth stands in B.C.

Problems associated with spiral grain and excessive fibril angle are perhaps most apparent when lumber is kiln dried. Lumber drying is an integral part of forest products manufacturing. It largely prevents dimensional change in service, increases strength, reduces shipping weight and provides protection against stain, mould and fungi (if the final moisture content is less than 19%). Drying, if done properly, adds value to lumber, but lumber drying accentuates problems with wood quality which contribute to drying degrade. In New Zealand radiata pine, for example, the first 10 years of growth from the pith presents a special warping problem, as lumber tends to twist because of excessive spiral grain in combination with large fibril angles.

Because wood is anisotropic, shrinkage is unequal in the three axial directions: along the grain (longitudinal), edge grain (radial), and flat grain (tangential). In normal wood longitudinal shrinkage is quite small (less than 0.4%) but radial and tangential shrinkage is appreciable (on average 4% and 8%, respectively). This behaviour arises from the structure and organization of cellulosic microfibrils in the fibre walls, the elongated shape of individual fibres, infrequent pitting on the tangential surfaces of fibres, numerous pitting on the radial surfaces, and the reinforcing effect of the rays on the radial plane. The last two features tend to retard shrinkage.

Shrinkage starts as moisture content drops below the fibre saturation point, of about 30% moisture content. At this point wood contains only chemically bound water, locked onto the OH groups of cellulose, hemicellulose, and lignin molecules. As water molecules vacate microfibrillar spaces, shrinkage occurs, reaching maximum levels in the oven-dry (moisture-free) condition. As lumber is dried below the fibre saturation point, it will shrink in width or thickness about 1% for each 4% reduction in moisture content.

3.10 Extractives

Extractives are substances deposited in wood in association with the transition from sapwood to heartwood. They often impart significant colour and decay resistance to the wood. To the woodworker, the most significant aspect of heartwood extractives is colour. The dark distinctive colours we associate with various woods (western red cedar, rosewood, etc.) are the result of extractable compounds that are dark in colour. In some woods there is no difference in colour between heartwood and sapwood. This does not mean that there is no heartwood in these species, but simply there are no dark-coloured extractives in these woods (like spruces and true firs).

The sapwood of all species tends to be light in colour and low in natural decay resistance because it lacks extractives. Because it is these extractives which are toxic to fungi, fungal resistance is restricted to the heartwood portion of the tree. When woods are naturally resistant to decay and insects, it is because of the toxic and repellant nature of their extractives. This is the case with western red cedar and yellow-cypress. The heartwood of some species does not contain fungus repelling extractives, therefore, such woods do not have any more decay resistance than sapwood.

As a rule there is no difference in the strength of heartwood and sapwood. In one rare example it was reported that considerable amounts of extractives in western red cedar may increase crushing strength of heartwood. This was possible because of the bulking effect of the physical presence of extractives. Another study found that western red cedar heartwood had an unusually low fibre saturation point⁴ of 18% (normal levels are 30%). The explanation given for this anomaly was that extractives occupied some of the sites in the fibre wall which would otherwise attract water.

Extractives are reported to cause problems in only a few woods. In some tropical hardwoods high silica content can cause serious problems in sawing, by rapid dulling of the cutting tool. On the other hand, a high silica content provides good protection against termites. Closer to home, some western red cedar with high extractives content was found to be susceptible to “blows” during particleboard production. (A blow is an internal rupturing of the sheet as the press opens which results from a build-up of internal gas pressure.) Also, western red cedar extractives are very corrosive to digesters used in pulping, and cause excessive dulling in chainsaws and other cutting tools. Extractives in general can cause gluing problems. In pulping, woods with high extractive content are less desirable than “white woods” because their colour increases bleaching requirements.

New uses for extractives in pharmaceuticals have enhanced their reputation. The bark extract *taxol*, obtained from the yew tree (*Taxus*) has proven helpful in treating ovarian cancer.

4. The moisture content at which cell walls are fully saturated with “bound” water, but cell cavities are empty of “free water”.

4.0 POTENTIAL FOR INFLUENCING WOOD QUALITY

Wood quality can be influenced by silvicultural practices. Foresters know how alternative management strategies influence major tree characteristics, but are less sure about the implications for future wood quality and stand value. Lumber conversion studies and strength evaluations have been used to determine these implications. These studies link product quantity, quality and value with timber characteristics that are known to result from given silvicultural practices.

Log diagramming is used to link tree and log characteristics to product potential. The following information is recorded: bottom and top diameter, length, and visible surface characteristics - knot size and distribution, live/dead classification, knot indicators, scars, spiral grain, shake, stain, and decay (Figure 15). By using simple tracking methods such as different colour dyes, it is possible to link individual pieces of lumber to individual logs and trees. By marking the extent of juvenile wood on both log ends it is possible to trace the piece of lumber to its radial position in the log. By not end-trimming the lumber in the sawmill individual boards can be identified and assessed for juvenile wood content (PLATE I), making it possible to relate subsequent drying degrade and strength properties to wood juvenility. As an example, Forintek is examining the impact of final stand density on lumber yield and grades from three 95-year-old lodgepole pine stands in the south east Kootenays: 700, 1100, and 1900 live stems/ha. In all, 220 trees were selected, logged, diagrammed, and processed through a sawmill. All lumber was graded for two product lines: (i.) NLGA Structural Joists and Planks, and (ii.) Joinery Grades. It bears repeating that in both cases knot size and frequency play an important role in determining the grade but for two different reasons. In the first case the emphasis is on STRENGTH, in the second it is on APPEARANCE.

4.1 Stocking Density

The extreme in low stocking density is the completely open-grown tree. Such trees have large branches which remain alive for a long time along the entire stem, from top to bottom (Figure 16a). This means that the auxins produced in swelling buds will be distributed throughout the stem, with less than the usual difference between the onset of diameter growth at the top of the stem and its onset at the base. Therefore, more tapered stems are formed under the influence of the live crown. Stems with a vigorous and persistent live crown can produce 100 percent juvenile wood. Open-grown trees, however, can produce some mature wood at their base when lower branches are much less physiologically active, and being so long and thick, tend to consume most of the growth hormones they produce.

In closed-stand conditions the live crown will be shorter, up at the top of the tree. Here, auxins produced in the spring will move downward through the stem, progressively initiating cambial activity. In large softwoods the cambium in the upper part of the stem may become active as much as 2-6 weeks earlier than cambium at the base. Thus more growth is added near the top than at the bottom each year. A more cylindrical stem will be formed as a result (Figure 16b).



Plate I. Juvenile wood (first 20 years of growth) marked on 50 year-old Douglas-fir log ends and visible on lumber ends.

A DISCUSSION OF WOOD QUALITY ATTRIBUTES...

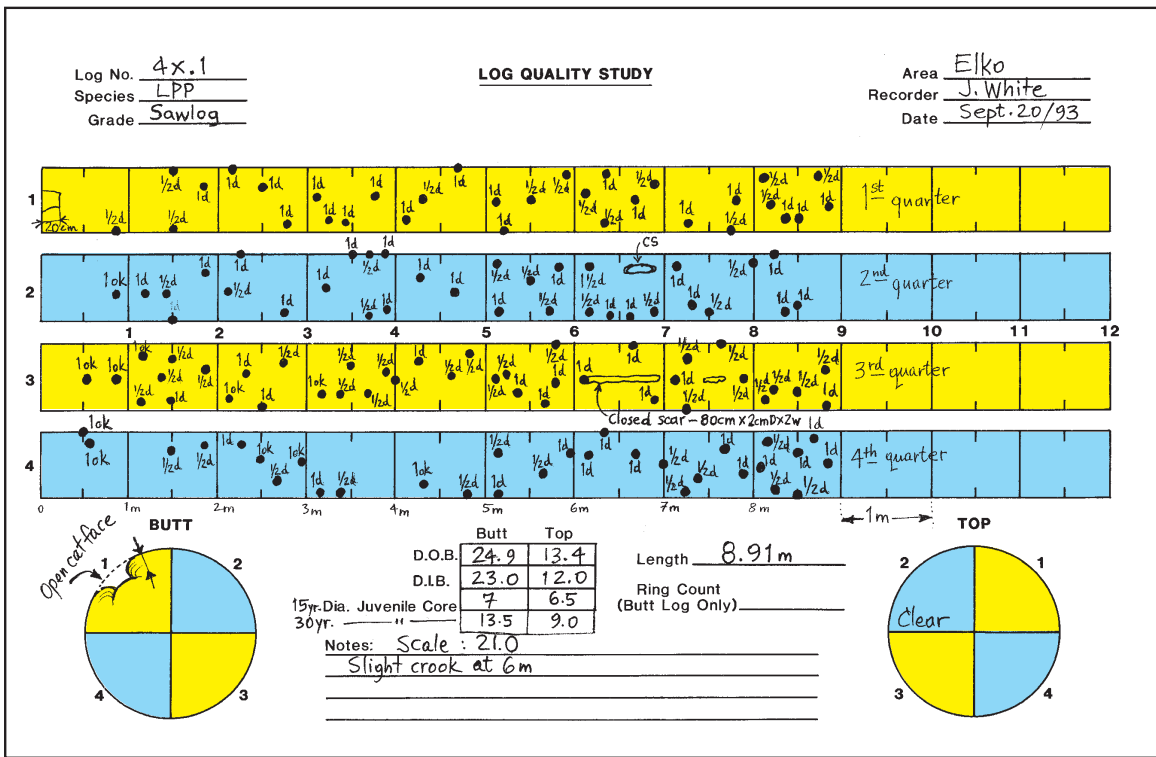
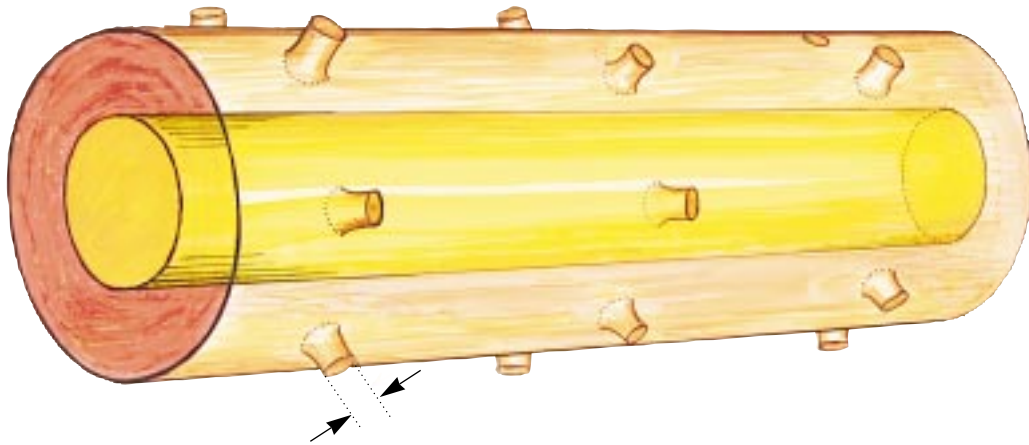


Figure 15. Log diagramming

Just as fully open-grown regimes are not acceptable, neither are overstocked stands where only small stunted trees will grow (Figure 16c). In the absence of other significant quality determining attributes, such as oversized knots or high proportions of low density juvenile wood, tree size serves as a proxy for value. Harvesting (falling, yarding and transporting) is more efficient for larger diameter logs, and lumber conversion is more efficient for large logs. Because sawmills are linearly constrained, it takes as much production time to process a small log as it does a large one. Thus unit production costs are inversely proportional to log size. Moreover, lumber yields per unit log volume (lumber recovery factors) increase with increasing log size (Figure 17), and a premium is paid for wide lumber (10 and 12 in.) which can be produced only from large logs (>30 cm top diameter, Figure 18). Thus, log quality when measured in terms of production and yield becomes largely a function of size (diameter). Log quality declines with the presence in increasing severity of other log characteristics such as poor form (sweep, ovality, taper), large branch size, spiral grain and juvenile wood. An increase in size can mitigate the impact of some of these, the most obvious example being the ability to obtain wider dimensions of lumber that can accommodate larger knots than narrower pieces in the same lumber grades. There is a point, however, where the benefits of increased size achieved by a rapid rate-of-growth may not be sufficient to offset the detrimental effects of increased tree taper, larger branches and higher proportions of juvenile wood.

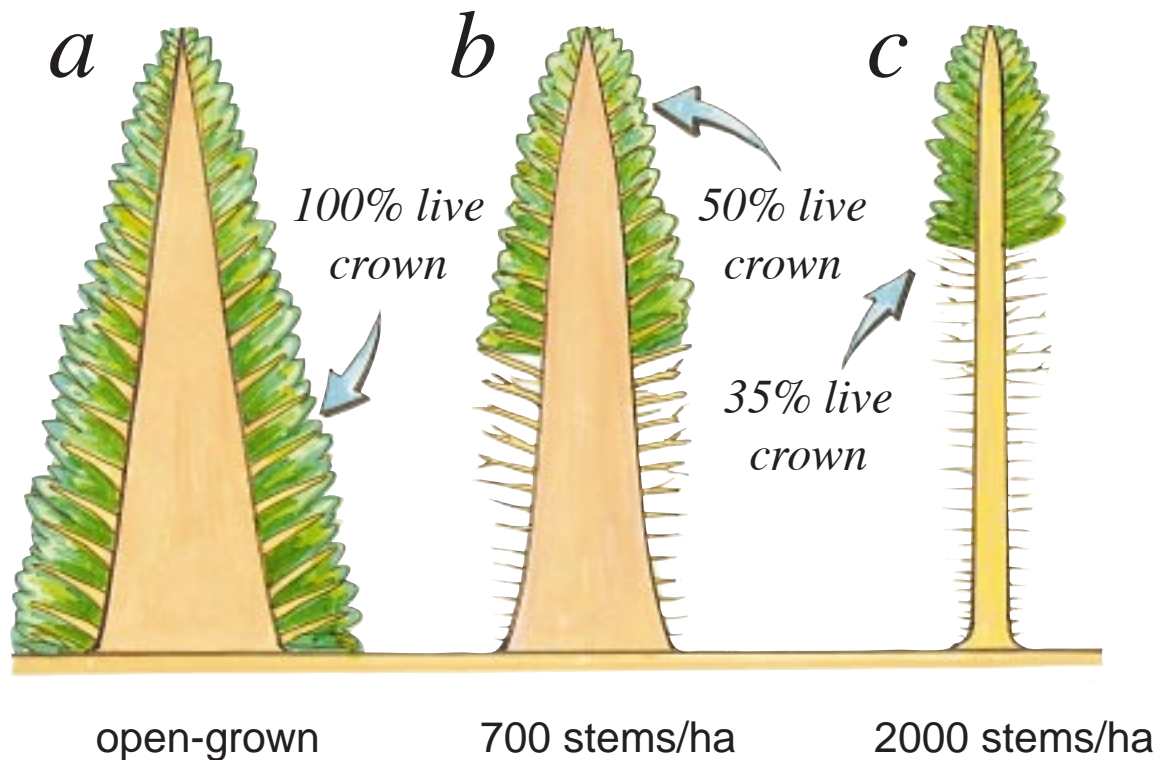


Figure 16. Effect of stocking density on crown development

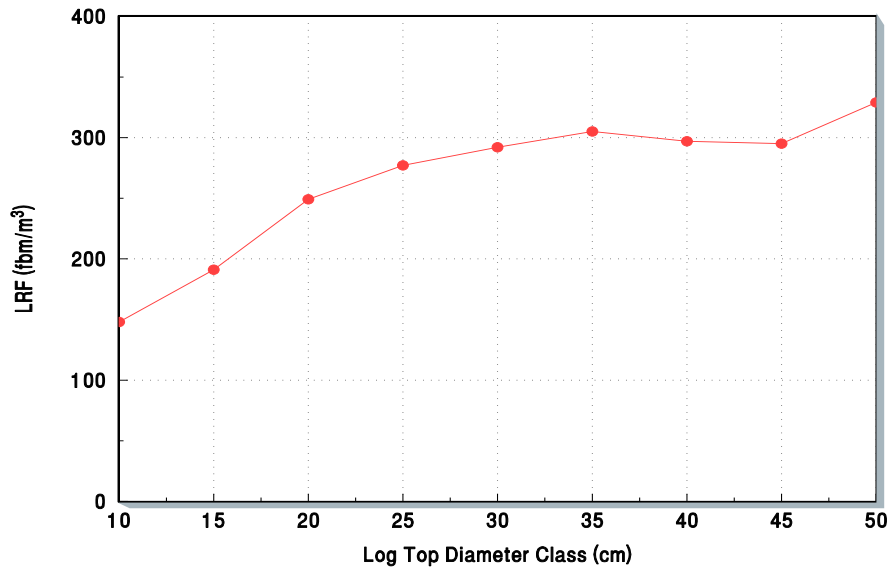


Figure 17. Lumber recovery factors for mill run logs.

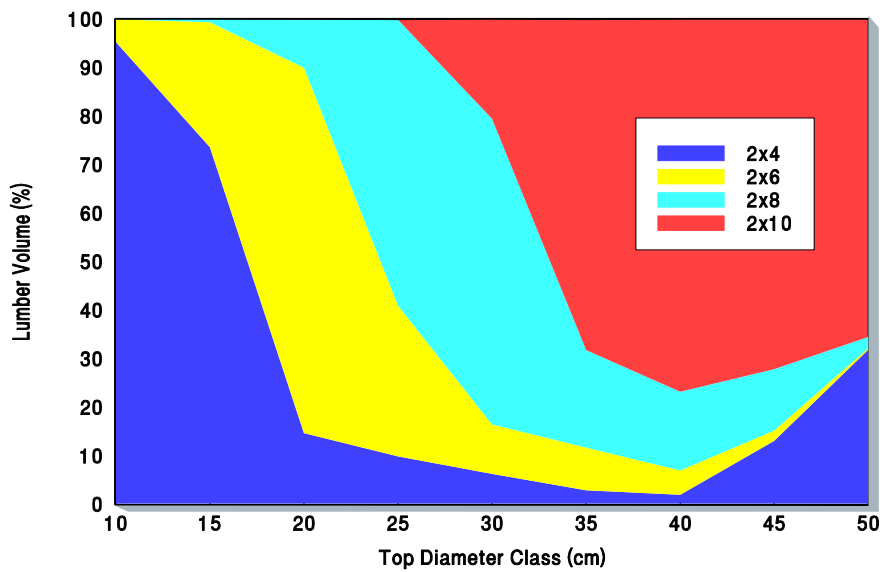


Figure 18. Lumber dimension yields by log top diameter class

4.2 Intensive Silviculture

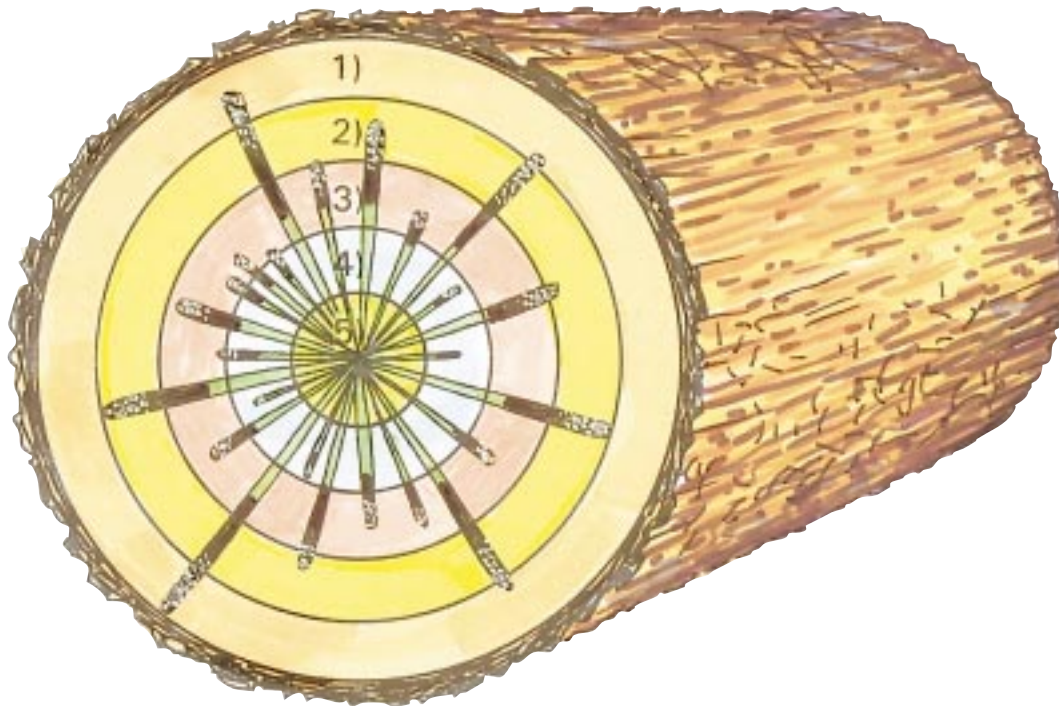
Silvicultural operations affect tree crown and hence wood quality. The objective of silviculture is, in general, to accelerate tree growth and to improve the value of the final crop through reducing competition and increasing nutrition. The following silviculture treatments are the most common ones used today for live-crown management: *Spacing*, *Thinning*, *Fertilization*, and *Pruning*.

Spacing is stocking control at a young age, including the spacing of trees at planting time. The intensity of planting is dependent on a combination of planting costs, estimates of plantation survival and the degree of commitment to follow-up treatments (like juvenile spacing, vegetation and pest control, pruning, fertilization, and commercial thinning). For example, in Brazil a hybrid Caribbean pine is grown on a 26-year rotation and the stand is manipulated eight times. Cheap labour rates make it possible to prune every tree at age four and to space/thin every three years thereafter.

Thinning is also stocking control but it is carried out at a more advanced age than spacing. The purpose is to remove excess and poorer-quality trees from a stand to improve the growth and value of the remaining trees. It may be done to obtain useful pulp or sawlog-sized stems (commercial thinning).

Fertilization promotes tree growth on nutrient deficient sites by stimulating crown and root development. Fertilization can be timed to improve the vigour of crop trees after juvenile spacing or commercial thinning. Yet positive returns have been reported from fertilizing a 100-year-old lodgepole pine stand only 10 years prior to harvesting.

Perhaps the most intensive (and costly) stand manipulation is pruning. *Pruning* is the removal of the lower branches from the stem of a crop tree up to a specified height (pruning lift) to produce clear (knot-free) wood. Like other interventions, the decision to prune must be based on economic efficiency. Nonetheless, pruning is the only way to produce clear wood in rotations of less than 100 years, and calculations should include consideration of the future scarcity of clear wood that will result from the gradual reduction in availability of old growth for commercial use. The potential value of pruning is well illustrated by quality zones that have been developed to describe the value of our present old-growth resource (Figure 19).



(Prices as of January 1995, Madison's Canadian Lumber Reporter)

- 1) Clear: \$1,250 - 4,000/M
- 2) Near Clear: \$600 - 1,000/M
- 3) Appearance Merch: \$450 - 800/M
- 4) Structural Lumber: \$350 - 500/M
- 5) Low Grade: \$200 - 350/M




N.B: The "spokes-in-the-wheel" represent branch stubs. Live branches are shown in outline (), dead portions are shown in black (), and decayed stubs are shown in a mottled tone ().

Figure 19. Old-growth log quality zones and product value.

4.3 Site

We would be remiss if we did not qualify this discussion with some comment about site quality and the limitations imposed by a poor site. We suggested the judicious use of stand manipulation at the outset because the potential benefits are not always realized. For example, decreasing stand density increases both tree size (beneficial) and knot size (detrimental). On a good site the beneficial effect largely overcomes the detrimental as increased tree size keeps pace with knot size by allowing the production of wider lumber for which grade rules permit larger knots. On a poor site wider spacing will be unlikely to achieve the same mitigating result.

Figure 20 illustrates relationships between average knot size and tree d.b.h. measured on tree samples obtained from several lodgepole pine sites of different ages and with different stand densities. Sites 1 and 2 were located in the Sub-Boreal Spruce biogeoclimatic zone on the west shore of Williston Lake near Mackenzie B.C. These were good sites with average tree ages of 165 and 180 years respectively, and stand densities of 700 and 800 live stems/ha. Site 3 was located in the Sub-Boreal Pine-Spruce zone west of the Chilcotin River, a poor site with an average tree age of 145 years and stand density of 780 stems/ha. Sites 4 and 5 were located in the Montane Spruce biogeoclimatic zone in the Willis Creek region south of Princeton. Site 4 was a medium site with an average tree age of 120 years and stand density of 1077 stems/ha. Site 5 was a good site with an average age of 125 years and stand density of 876 stems/ha. The Elkford site was located in the Montane Spruce biogeoclimatic zone. This was a good site where trees averaged 95 years of age and stand density was 700 stems/ha. The knot size information was obtained by detailed diagramming of 60 trees on sites 1,2,4 and 5 and 100 trees on each of Site 3 and Elkford.

Two lines in Figure 20 (Site 3 and Elkford) stand out by virtue of steeper and nearly identical slopes. The lower of these, for which average knot size remains within the range of four other lines up to 32 cm d.b.h., is the relationship observed for the 95 year-old, 700 stem/ha good site. The higher of the two lines (Site 3), and highest of all, is the relationship that was obtained for slightly less open-grown trees (about 780 stems/ha) on the poor Chilcotin site where biogeoclimatic conditions do not support higher stand densities. On this poor site open spacing has resulted in large branches, but without the compensating effect of greater tree size. A sawmill conversion study confirmed that this results in reduced lumber grade yields and lower stand values.

The lower tree height on the poor Chilcotin site (Site 3) also allowed the crowns to persist as illustrated in Plate II. The result was a stand average wood density (based on measurements of wood density in lumber) that was one of the two lowest of five sites studied at that time (Figure 21). By comparison the average wood density of sample trees on the Elkford site was 0.41.

The knot size and tree d.b.h. relationships shown in Figure 20 demonstrate some of the natural variation that occurs in the way basic tree characteristics are related. *It points out the need to be specific with respect to stand density, site, and tree age when drawing conclusions about the wood quality implications of tree characteristics.*

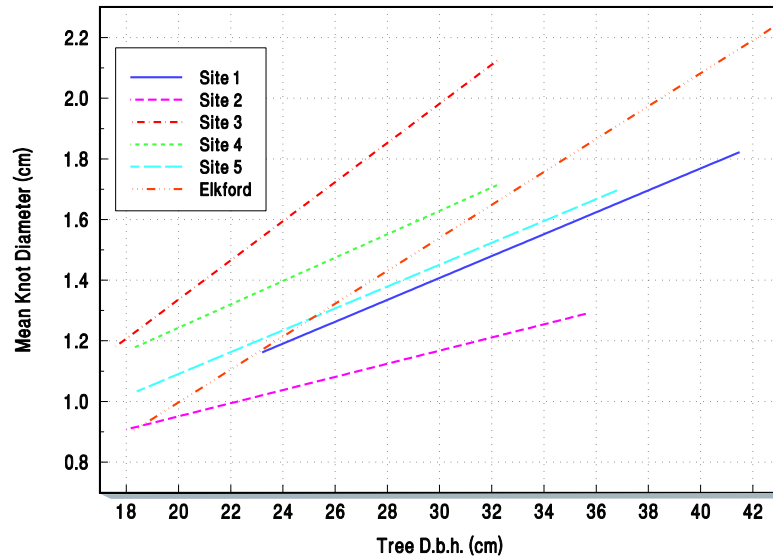


Figure 20. Average knot size related to d.b.h. for several lodgepole pine stands

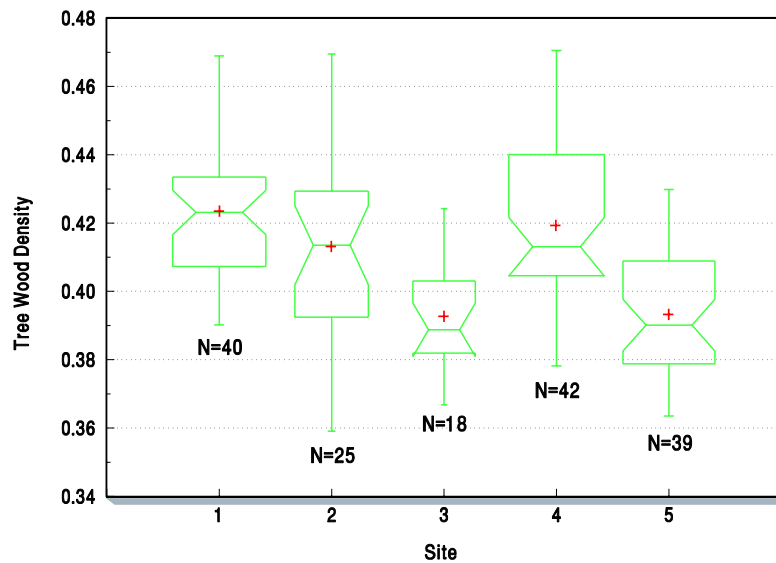


Figure 21. Comparison of average tree wood density for five lodgepole pine sites

Box plots provide a schematic representation of the distribution of a sample. The bottom and top edges of the boxes indicate the 25th and 75th percentiles of the sample respectively. The horizontal line within the box represents the sample median and the “+” sign indicates the sample mean. The vertical lines extending from the box indicate the full range of the data.



Plate II. Open-growth lodgepole pine on a poor site in the B.C. Chilcotin region.

5.0 CONCLUSION

A forester's choice of stand stocking density will significantly impact wood quality and final stand value. Widely spaced trees will grow faster than crowded ones. When this relationship is combined with the knowledge that rapid early growth results in a large core of juvenile wood, larger live crown, larger knots, and higher stem taper, it is easy to see how spacing of trees can affect wood properties. *There is an optimal combination of stocking density and harvest age that will produce the highest value combination of volume and quality for each interaction of species and site. The specific prescription will depend on the desired end product.*

The choice of silvicultural practices is up to the forester. It is hoped that this discussion has helped to ensure that these choices will be made with some understanding of the practical implications for wood quality. We know that every site and species will have unique opportunities, and that no single silvicultural prescription can serve as a general panacea. On each site the objective should be to balance the costs of silviculture against increased future value, and to choose the *economically optimum* rotation age.