Tree Growth, Forest Management, and Their Implications for Wood Quality

John Punches

Wood has long served as one of our most versatile and heavily used raw materials. From it we derive solid wood for structural and ornamental applications, composite products in the forms of panels and beams, numerous paper products, chemicals, fuel—the list could go on and on. Foresters have worked for many years to increase wood yield from forests, while manufacturers have refined their techniques and become increasingly efficient in turning wood into products. To a large extent, however, each group has worked toward its objectives without understanding the needs and/or constraints of the other.

Wood is the result of a biological process. It grows under a wide range of genetic and environmental influences and has a similarly wide range of properties and characteristics. Understanding the process by which trees grow allows foresters to anticipate the effects of their activities on the products that ultimately will be produced from their trees. Similarly, understanding tree growth processes helps wood products manufacturers comprehend how various wood characteristics develop and what constraints foresters face while guiding the growth process.

This publication provides basic information on tree growth, characteristics that define wood quality, and the implications of common silvicultural (tree tending) activities on wood quality. It is at best a summary—tree growth is an immensely complex process, and not all aspects of wood formation are fully understood. Most of the relationships discussed in this publication apply to trees in general; however, some items apply more specifically to a species group. These limitations are noted in the text.

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The Biological Process of Tree Growth

Trees, like most plants, grow taller over time. What distinguishes trees from other plants is their ability to extend growth over long periods and to add successive layers of growth in both height and in diameter. The process is magnificently orchestrated, and while science cannot claim to understand it completely, the basics certainly are within grasp.

A tree increases in height through the activity of ***apical meristems***, growth regions at the tips of its branches and stem (Figure 1). Diameter growth, also called secondary thickening, occurs via a ***lateral meristem*** called the ***cambium***, a layer of living cells between a tree's bark and its woody core (Figure 2).

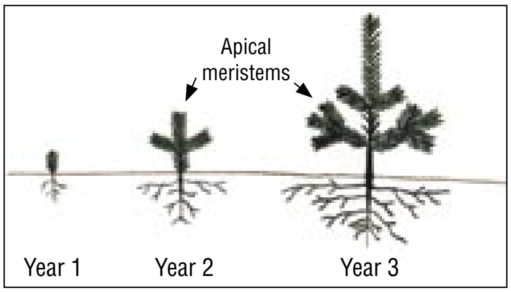

Figure 1.—Height growth.

In the Pacific Northwest, trees typically lie dormant during the cold, wet, winter months, then renew growth in the spring. Growth begins with activation of the apical meristems. Buds burst, and new foliage appears. All height growth and branch elongation results from activity at, rather than between, apical meristems, so a branch located a foot off the ground will remain at that location even though the tree may grow considerably taller.

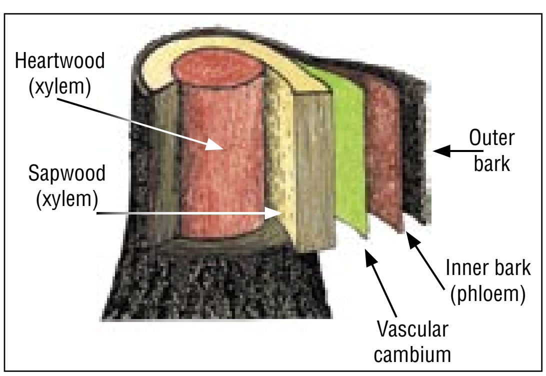

Figure 2.—Stem cut-away showing tissue layers.

Growth hormones are produced near apical meristems and are transported through the tree's vascular system. As they spread, they activate the cambium, and secondary thickening (diameter growth) occurs. Since hormones must spread from the ***crown*** (the region of living branches and the stem to which they are attached) down the stem, secondary thickening does not begin all at once. The cambium is activated first in the crown and then progressively down the stem, responding to a concentration gradient of hormones.

Once activated, the cambium produces both wood and bark cells. Inner bark cells, known as ***phloem***, are produced in a narrow layer just outside the cambium (Figure 2). They are the mechanism by which carbohydrates (sugars produced in the tree's crown during photosynthesis) are transported throughout the tree in any direction needed and are made available to feed the cambium's activity. Growth hormones also are transported through the inner bark.

As new layers of bark form, older layers are progressively crushed and forced outward. Within these layers are specialized ***cork cambiums*** in some species, forming corklike cells that further thicken the bark to form a protective outer shell around the tree's vital inner tissues. The fissured bark of Douglas-fir and ponderosa pine results from this process.

Wood cells, known as ***xylem***, are produced to the inside of the cambium layer and typically form a new ring of wood each season (Figure 3). Wood cells formed early in the growth season are known as ***earlywood*** or ***springwood***. Once mature, they are relatively long and hollow and have thin cell walls. They are primarily conduits for moving water and minerals from the root system to the crown. In conifers, earlywood production coincides with the tree's period of height growth.

When apical meristems terminate their activity (typically in late spring), height growth stops and hormone production

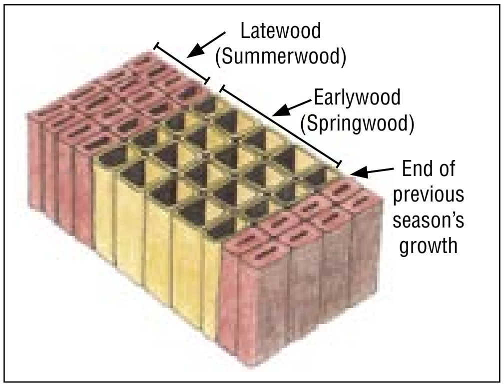

Figure 3.—Earlywood and latewood cells in a conifer.

decreases. As hormone levels in the cambium fall, the tree begins to produce thick-walled cells called ***latewood*** or ***summerwood***. Latewood production begins at the points farthest from the crown (i.e., the places where hormone levels are lowest) and gradually works its way up the stem. Latewood cells serve the tree primarily as mechanical support; their thick walls make them considerably stronger than their earlywood counterparts. Latewood production is facilitated by the fact that the now-mature foliage in the crown is producing a surplus of carbohydrates that can be distributed to regions of active growth. Since it has considerably more wood material within its cells, latewood is often noticeably darker in color than its neighboring earlywood.

The process just described results in the yearly addition of a new sheath of wood within a tree's stem, branches, and roots, stretching from just behind the root tips to just below the buds at the branch and leader tips. The sheath consists of earlywood and latewood and lies just beneath the cambium layer. Each new layer of wood is added on top of the previous year's layer. These ***growth rings*** or ***annual rings*** are readily observed on a cross section of a tree stem (Figure 4). Healthy trees with abundant water and little competition generally produce wide rings; those facing intense competition, drought, or disease produce narrower rings.

In temperate regions, tree age can be estimated by counting growth rings, but use this technique cautiously. Trees may take several years to reach the height at which the rings are being observed, so the resulting ring count would underestimate total age. (For example, if a tree took 5 years to reach 8 feet in height, it always will have five more rings at its base than at the point 8 feet above ground.) Trees also can add ***false rings*** when conditions encourage them to stop and then resume growth during a single season. A dry summer followed by early, warm rains makes this phenomenon fairly common in the Pacific Northwest. Finally, when faced with particularly stressful conditions, some trees may produce no visible ring whatsoever, making them older than a simple count of rings would suggest.

Xylem cells, both the earlywood and latewood varieties, can be further categorized as mature wood, juvenile wood, or reaction wood.

In a cross section of a tree's stem, wood formed first (at that point in the stem) will be found at the core. ***Core wood*** is formed in close proximity to the tree's living crown and often is called ***crown-formed wood***. It tends to have a high proportion of earlywood, which makes sense given the factors discussed above. However, core wood cells differ from those

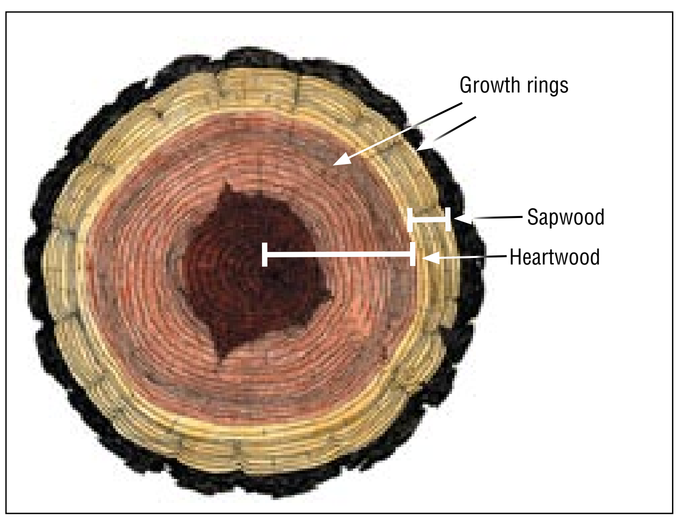

Figure 4.—Tree stem cross section.

in wood formed farther from the core at the same height, and this has some distinct implications for wood quality. Core wood, or ***juvenile wood***, cells are prone to high longitudinal shrinkage during drying, and they tend to be weaker than the ***mature wood*** cells found beyond the core (which formed farther away from the crown and later in the tree's life). In general, juvenile wood is less dense than mature wood. However, in many conifer species, wood closest to the pith (tree center) will have relatively high density; density will fall rapidly in the next few rings and then will increase over subsequent rings as the wood production transitions from juvenile to mature. The more uniform, generally stronger, and more stable mature wood is considered to have superior characteristics for solid wood applications, and trees that have higher proportions of mature wood generally are considered to be of higher quality.

Trees develop yet another form of wood cell, called ***reaction wood***, to straighten leaning stems or support branches. Conifers form a type of reaction wood called ***compression wood***, while broadleaved trees form ***tension wood***. As implied by the names, compression wood forms on the side of a stem or branch under mechanical compression, while tension wood is found where the stem or branch is under tension (Figure 5). Reaction wood, while serving a necessary function within the tree, reduces wood quality in most applications. It tends to be weaker and more prone to shrinkage than mature wood, often has a different color, may machine poorly, and can be difficult to finish.

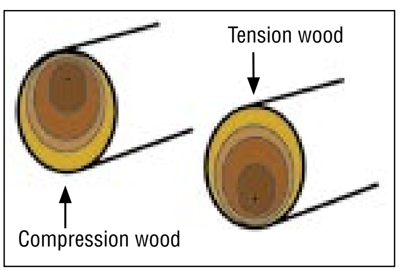

Figure 5.—Types of reaction wood.

New wood produced by the vascular cambium is known as ***sapwood***. It comprises both earlywood and latewood and might contain mature wood, juvenile wood, or reaction wood if growing conditions favor their formation. Fully developed sapwood consists primarily of dead, hollow cells that serve as conduits for transporting water from roots to the crown. Roughly 5 to 10 percent of sapwood consists of specialized living cells that help transport and store food products, produce defensive chemicals, and transport waste byproducts. Sapwood is generally light in color, but as it ages its few remaining living cells die, and a region of dead wood, known as ***heartwood***, accumulates at the center of the stem (Figures 2 and 4, pages 2 and 3, respectively). Heartwood is often darker in color than the surrounding sapwood. The color change might be attributed to chemical changes in cells as they die and to the accumulation of chemical byproducts produced during the tree's growth process. These chemicals, known as ***extractives***, are deposited in the older xylem cells at the tree's center. The heartwood of trees with high extractive content often is resistant to decay. Redwood, western juniper, and western redcedar are good examples of species with high extractive content.

Crown Effects

Since the crown is the tree's source of wood-building carbohydrates, larger crowns can be expected to support higher levels of wood production. Numerous forest management activities seek to increase crown vigor and thereby increase tree growth rate. It should be apparent by now, however, that a tree's crown has a tremendous impact not only on growth rate but on the type of wood produced within the tree's stem. Crown-formed wood tends to be mostly earlywood of the juvenile variety. As such, it tends to be low in density and high in shrinkage, with obvious impacts on wood quality. Mature wood generally appears after the living crown has receded past that point on the stem, and higher density latewood is most prevalent in the portion of the stem farthest from the crown.

Taper is largely a crown effect. Since the cambium activates first within the crown, growth rings tend to be widest here, and maximum diameter growth often occurs near the base of the crown. Thus, trees with large crowns tend to have highly conical stems, while stems of trees whose crowns have receded gradually become more cylindrical (Figure 6). High-taper trees have smaller scaling diameters (because diameter is measured at the log's small end) and thus are of lower value to the grower. When sawn or peeled, they will yield less product and will be more prone to cross grain.

Knot size is directly impacted by crown size. Persistent, live crowns give branches more time to grow, and knot size increases. Receding crowns limit branch size, thus limiting knot size. Clear wood can develop only after branches have been removed (either by natural or manual pruning) and the branch stubs have been covered with new layers of wood.

Defining Wood Quality

Wood quality is defined by many characteristics and is properly assessed only as related to a specific application. Wood intended for structural applications may be judged by its strength, stiffness, and dimensional stability, while wood for architectural millwork may require specific grain patterns or color. In the pulp and paper industry, wood quality may be based on fiber length and relative proportions of cellulose and lignin (two of wood's basic, chemical building blocks).

Several wood characteristics serve as predictors of wood quality across applications. The most common are density, density variation, ring width or ring count, and knot size, type, and placement.

Density is mass per unit of volume. In wood, it simply means that more wood fiber is packed into a given volume. Wood density often directly correlates with its utility as a raw material. Dense wood tends to be stronger, stiffer, better able to hold fasteners, and more wear resistant and impact absorbent. In any given volume, it will have more wood material and less void space than a less dense sample and will yield more wood fiber for paper products.

Density is rarely uniform across any given growth ring; this phenomenon is known as ***density variation***. It is caused by the inherent differences between earlywood and its neighboring, higher density, latewood. Wood with considerable density variation can give rise to uneven machining characteristics or might wear differently under use. For example, when wood with a high degree of density variation is used as flooring, ridges of high-density latewood may appear as the lower density earlywood is crushed or worn away.

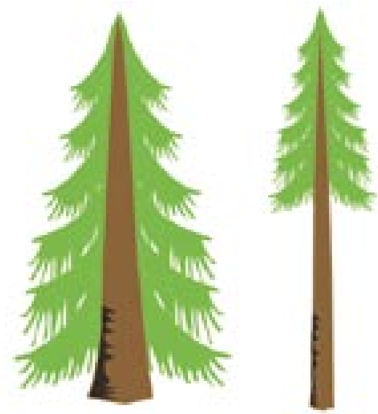

Figure 6.—Crown effect on taper.

Ring width and ***ring count*** (rings per inch) are used in various grading rules as indicators for a number of wood quality factors. Wide rings, which equate to a low ring count, have long been employed as a predictor of low density. This is somewhat unfortunate, because density actually is not related to ring width but to the proportions of earlywood and latewood within the rings. At the time the rules were developed, however, most timber had grown slowly under relatively high competition, and the observation was largely valid. Wide rings also make density variation problems more likely. A tree's widest rings are formed within its crown, and the wide rings near a tree's pith almost always will be composed of juvenile wood.

Branches affect wood quality by showing up as knots in sawn and peeled wood products. Knot size and placement are important wood-quality factors and are reflected in log and lumber grading rules. Knots come in two varieties (Figure 7). Where a living branch intersects the stem, a ***tight knot*** or ***intergrown knot*** forms.

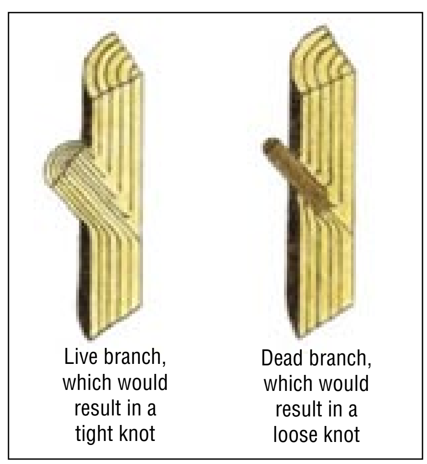

Figure 7.—Branch type dictates knot type.

Figure 8.—Stem and crown forms vary among trees.

The wood grain is distorted at this point, but the knot is attached physically to surrounding wood. Dead branches form ***loose knots*** or ***black knots***. They have no physical connection to the surrounding wood and interrupt the grain. While any knot reduces wood strength to some extent, loose knots do so to a far greater extent. Lumber and log grades often designate maximum acceptable knot sizes and numbers, and lumber grades place additional emphasis on their placement (since a knot at the edge of a board will have a greater negative impact on its strength than if at the board's center).

Influencing Wood Quality

What can forest managers do to influence wood quality? Here are some common answers to this question—and reasons why they may or may not work.

Use genetically improved planting stock

Most improved planting stock is selected based on growth rate; crown, stem, and branch form; and disease resistance. While not specifically developed for enhancing wood quality, many of these characteristics do lend themselves to production of high-quality wood. Tree genetics is only one of several factors affecting tree growth, so it cannot by itself ensure high-quality wood.

Favor superior trees during thinning

On any given site, some trees will produce higher quality wood than others (Figure 8). Concentrating the site's growth potential in these trees (by thinning) might increase production of quality wood. This strategy is particularly applicable when the controlling factor in wood quality is genetics. It is less successful, and may even be counterproductive, when site conditions have been the controlling factor. Thinning modifies site conditions and can increase wood quality if production of clear wood with acceptable characteristics is enhanced. It can decrease wood quality if the crown persists and knot size increases or ring width becomes too great.

Enhance nutrition

Fertilization is used to increase growth rate and, to some extent, tree health. Its primary function is to increase the volume of living crown on the tree. Its effects on wood quality are difficult to predict. Some studies show increased quality, while others show declines. Fertilizing should not be dismissed, however, particularly when combined with other activities.

Control crown extent

Crown extent (length) can exert greater influence on wood quality than all other factors combined. A large crown produces more carbohydrates, thus supporting faster and more extensive growth. However, crown-formed wood tends to be mostly earlywood and may have a high proportion of juvenile wood. Production of latewood and (to some extent) of mature wood is favored by increasing distance from the crown. Crown persistence directly relates to knot size, and clear wood will form only after the crown has receded past that point on the stem.

Controlling crown extent should be a primary goal when managing for wood quality.

Concentrate on the butt log

A tree's bottom (butt) log often contains more volume than other logs in the tree and has the greatest potential for quality. It has the greatest proportion of mature wood relative to juvenile wood, is most likely to be free of branches, and can be pruned most easily. Pick a butt log length appropriate for anticipated market conditions and manage to maximize its value.

Impacts of Common Silvicultural Activities

With this background in tree growth processes and wood quality factors, now we should be able to see the implications of a number of common silvicultural practices.

Figure 9.—The effect of planting at a low density.

Low planting density delays competition between trees and forestalls stand closure (Figure 9). Trees are encouraged to produce full crowns, and, lacking competition for light, they tend to sacrifice height growth. At the end of a rotation, they generally will have larger knotty cores, larger knots, more taper, higher proportions of earlywood, and lower density than they would if grown under higher levels of competition. Juvenile wood impacts are more difficult to anticipate, but it is likely these trees would include a significant proportion of juvenile wood.

High planting density hastens competition between trees and speeds stand closure (Figure 10). Trees concentrate on height growth, and crowns recede relatively rapidly due to shading of lower limbs. Under these conditions, diameter growth is slowed, but wood quality tends to increase. At the end of a rotation, these trees can be expected to have smaller knotty cores, smaller knots, less taper, a higher proportion of latewood, and higher density. Again, juvenile wood content is difficult to predict, but it is likely to be lower than in a low-density planting.

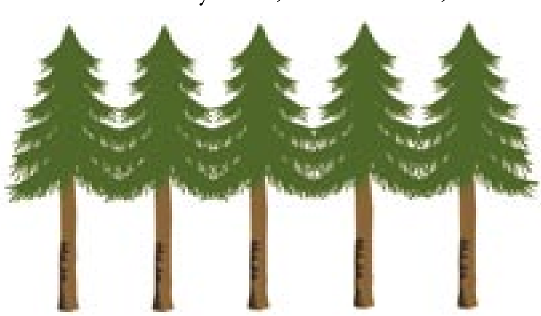

Figure 10.—The effect of planting at a high density..

Thinning reduces competition among trees and delays crown recession (Figure 11). If properly applied, however, it can increase both diameter and height growth. Since it stimulates crown expansion, it generally encourages trees to retain more taper. The larger, more persistent crown will grow larger knots and a greater volume of juvenile wood. Its effects on wood density below the crown or in regions old enough to produce mature wood depend on how far the crown was allowed to recede and the tree's age before thinning. If the trees have little stem length below the crown, wood quality will be highly affected by the crown, and density will suffer. Trees with greater stem length below the crown may have very acceptable latewood components and would add layers of mature wood over their knotty, juvenile cores, both factors that serve to increase wood quality.

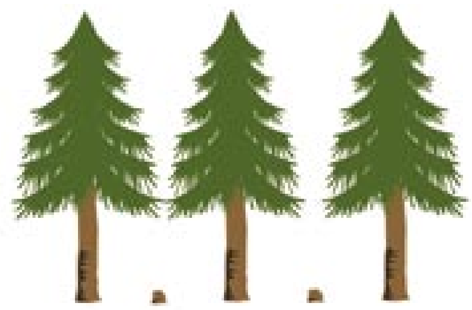

Figure 11.—The effect of thinning.

Pruning directly manipulates crown extent and so has profound implications for wood quality (Figure 12). Forcing the crown up the stem limits knot growth, decreases taper, encourages latewood production, minimizes the size of the knotty core and allows clear wood to develop. In some species, it might reduce juvenile wood production, but evidence of this remains elusive. Aggressive pruning can reduce growth rate (by reducing the amount of food-producing leaf area) and can stimulate

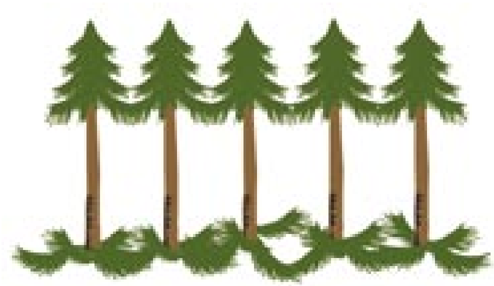

Figure 12.—The effect of pruning.

development of ***epicormic branches*** (branches originating from dormant buds) if done in open stands, but appropriate pruning can minimize these effects.

Fertilization stimulates crown vigor, thereby increasing growth rate (Figure 13). It also encourages the production and retention of sapwood, resulting in greater sapwood depth. Its impact on wood quality is highly dependent on crown position. If the crown covers much of the stem, wood quality is likely to decrease. If the crown has receded, the branch-free stem may produce perfectly acceptable wood at an enhanced rate. Fertilization can even impact relative earlywood and latewood proportions. If fertilization increases the period of height growth, earlywood production will be prolonged and latewood production delayed. If, however, the height growth period is unaffected but late-season growth is extended, latewood production could be enhanced. There is some evidence that adding certain micronutrients can extend the period of latewood production, thereby increasing latewood proportion and wood density, but the jury is still out on the specifics of this interaction.

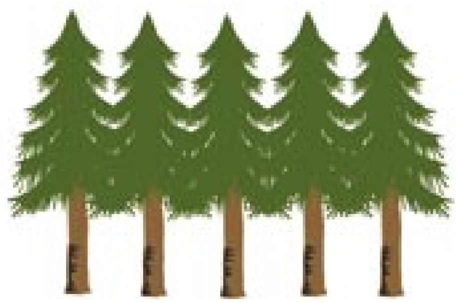

Figure 13.—The effect of fertilizing.

Some Parting Thoughts

In the forest, tree growth and wood formation are dictated by a complex interaction of site, climate, genetics, and competition. Forest managers seldom can control these factors completely, but they can influence forest conditions using basic silvicultural tools. Silviculture impacts wood quality primarily through its effect on crown extent. Stand density management (both at planting and, later, in stand development), pruning, and fertilization each has distinct and fairly predictable impacts on crown condition. Understanding tree growth processes and crown implications allows foresters to seriously consider wood quality as one of their management objectives. It also helps manufacturers understand the limitation of their wood raw materials.

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