NOTE

Wood density of western hemlock: effect of ring width[1]

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Wood density of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) was determined by X-ray densitometry of strips from breast-height samples consisting of rings 20–24 from the pith. Ring parameters were averaged over the 5 years for each strip. Wood density was negatively correlated with radial growth rate. Average wood density dropped from 0.47 to 0.37 g/cm^3 as average ring width increased from 2 to 8 mm. Wood density decreased at higher growth rates primarily because earlywood width increased while latewood width remained the same; as a result, percentage of latewood decreased. Earlywood density decreased slightly at higher growth rates, but latewood density was not significantly related to growth rate.

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La densité du bois de la pruche de l'Ouest (*Tsuga heterophylla* (Raf.) Sarg.) a été mesurée par densitométrie aux rayons-X sur des échantillons en forme de bandes prélevés à hauteur de poitrine et constitués des cernes annuels 20–24 à partir du coeur. La moyenne des paramètres de 5 cernes annuels a été calculée pour chaque bande. La densité du bois était négativement corrélée avec le taux de croissance radiale. La densité moyenne du bois est passée de 0,47 à 0,37 g/cm^3 lorsque la largeur moyenne des cernes annuels augmentait de 2 à 8 mm. La densité du bois a diminué aux taux de croissance plus élevés principalement parce que la largeur du bois de printemps augmentait alors que la largeur du bois d'été restait la même; ce qui entraînait une diminution du pourcentage de bois d'été. La densité du bois de printemps diminuait légèrement aux plus hauts taux de croissance mais la densité du bois d'été n'était pas significativement reliée au taux de croissance.

[Traduit par la rédaction]

Introduction

Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) is an important commercial species in coastal forests of the western United States and Canada. Currently, management practices are aimed at promoting faster growth rates; given the increasing attention paid to wood quality, the effect of this faster growth on wood density in western hemlock is of interest.

Density is one of the most important wood characteristics; wood strength and stiffness, pulp yield, and caloric content are all closely correlated with wood density (Haygreen and Bowyer 1989). The relationship between growth rate and wood density in conifers has been much debated. In species with a rapid transition from earlywood to latewood, such as the hard pines and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), wood density and growth rate are reported to be unrelated (Megraw 1985). In contrast, growth rate has an important influence on density in spruces, in which the transition from earlywood to latewood is gradual (Hale 1924; Brazier 1970).

In western hemlock, the transition from earlywood to latewood is "more or less gradual" (Panshin and deZeeuw 1980). In the few available studies of hemlock, rapid growth resulted in reduced wood density (Wellwood 1960; Krahmer 1966) and reduced percentage of latewood (Smith 1980). Wellwood (1960) made his measurements on wedge-shaped pieces cut from disks taken at three heights in 39 western hemlock trees from 60-year-old stands. Krahmer (1966) measured specific gravity of samples obtained by subdividing radial strips cut from disks. The disks had been cut at 2.4-m intervals from 12 western hemlock trees, ranging in age from 34 to 243 years. These samples included a range of ring ages, but were all outside the high-density zone surrounding the pith. Smith (1980) measured latewood width in rings 3–15, using breast-height increment cores from 29 western hemlock trees in a 20-year-old spacing trial.

X-ray densitometry (Hoag and McKimmy 1988) allows detailed measurement of ring density and width, including widths and densities of both earlywood and latewood. In this study, we used X-ray densitometry to conduct a detailed analysis of the effect of ring width on wood density in western hemlock.

Methods

Study sites

Samples for this study were collected in July 1989 at two precommercial thinning trials of western hemlock. One trial is on the Cascade Head Experimental Forest, near Lincoln City, Oregon. The other is near Clallam Bay, Washington. Both locations are described in detail by Hoyer and Swanzy (1986).

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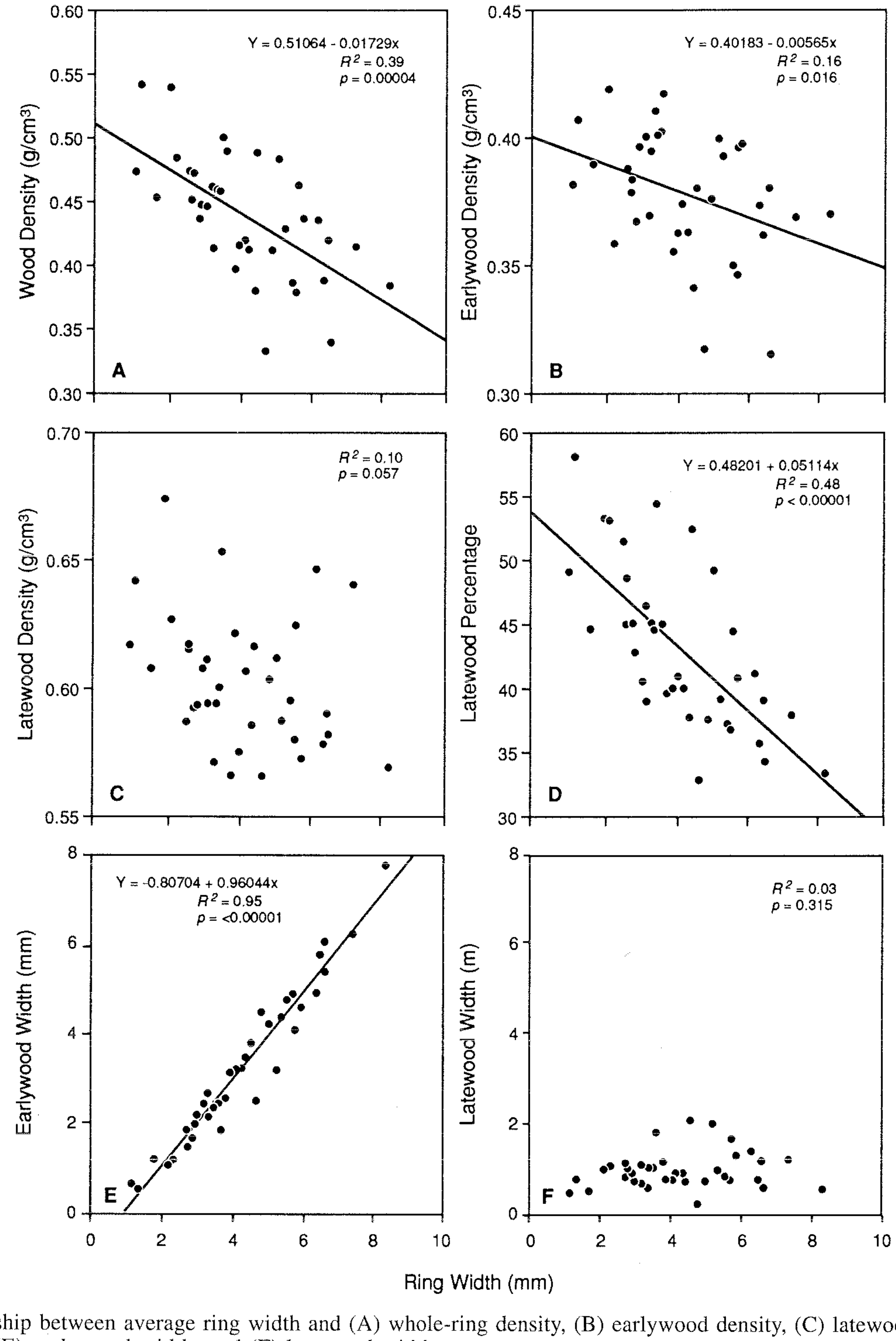

FIG. 1. Relationship between average ring width and (A) whole-ring density, (B) earlywood density, (C) latewood density, (D) latewood percentage, (E) earlywood width, and (F) latewood width.

The Cascade Head site was thinned at age 12 years and was 38 years old in 1989; spacings were 2.4, 3.6, 4.9, and 6.1 m. The Clallam Bay site was thinned at age 11 years and was 29 years old in 1989; spacings were 1.2, 2.2, 2.8, 5.4, and 6.6 m. At both locations, there were two replicates of each spacing.

Both trials were established by early thinning of dense, naturally regenerated stands, so the actual growing space around individual trees varied widely, even within the same plot. Because diameter growth of trees is strongly affected by growing space, the growth rates of individual trees on the same plot varied widely as well. For this reason, we used the trials primarily as a source of wood samples grown at different rates, rather than attempting to assess the effects of a particular spacing on wood density.

At each location, three trees (small, medium, and large diameter) from each plot were sampled. The resulting sample included a wide range of growth rates, with a large amount of overlap in growth rates between plots. A total of 27 trees at Cascade Head and 30 trees at Clallam Bay were sampled.

Core measurements

A 5 mm diameter increment core, from pith to bark, was extracted at breast height from each sample tree; orientation of the core was random.

In the laboratory, each core was sawed from pith to bark to

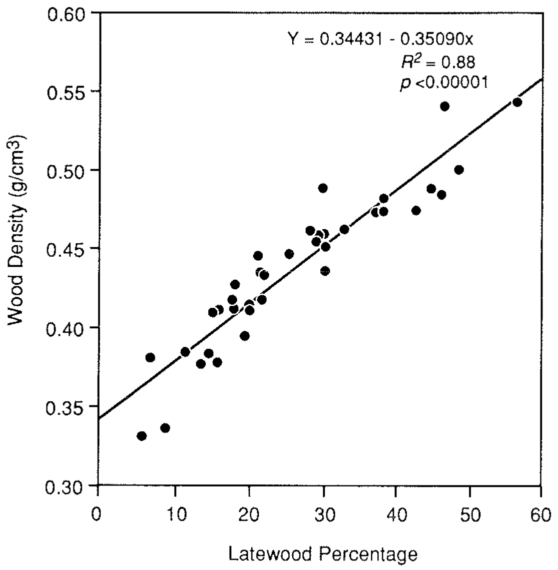

FIG. 2. Relationship between latewood percentage and wood density.

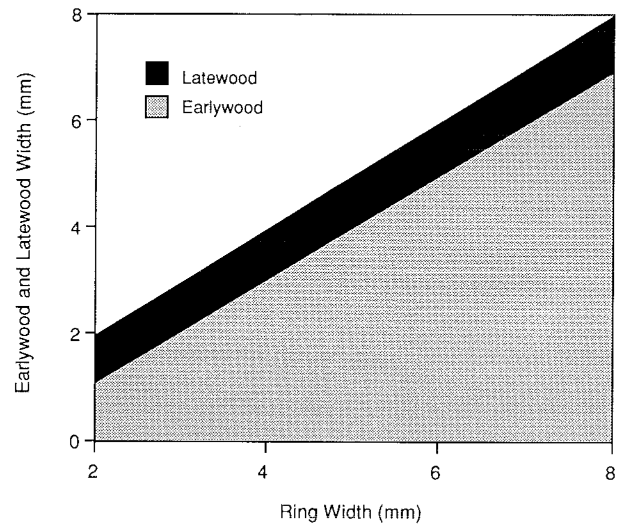

FIG. 3. Predicted widths of earlywood and latewood produced over a range of ring widths.

produce a strip 1.5 mm thick (along the grain) and 5 mm wide. Western hemlock is reported to contain extractives that could affect density measurements by X-ray densitometry (Parker et al. 1974), so extractives were removed by using toluene and ethanol in a Soxhlet apparatus (DeBell 1992). After extraction, the strips were air-dried to an equilibrium moisture content of 9%.

Density of the strips was determined by X-ray densitometry as described by Hoag and McKimmy (1988). The densitometer was calibrated for western hemlock by adjusting the attenuation coefficient so that X-ray density equaled gravimetric density on selected samples (Hoag and Krahmer 1991). For each ring scanned, earlywood width and density, latewood width and density, total ring width and density, and latewood percentage were calculated. The density used to delineate earlywood and latewood was 0.5 g/cm^3. The choice of the density to use for this delineation is somewhat subjective (Parker and Kennedy 1973). However, Cown and Parker (1978) found that 0.5 g/cm^3 was adequate for the 15 conifers that they examined, which included western hemlock. After examining intraring density profiles from our samples, we concluded that this was an appropriate value to use.

Cores from some trees were discarded because of irregularities in the core or breakage during sawing. The final sample consisted of 17 cores from Cascade Head and 20 cores from Clallam Bay. For Cascade Head, the final numbers of cores at each spacing were three at 2.4 m, six at 3.6 m, five at 4.9 m, and three at 6.1 m. For Clallam Bay, the numbers were four at 1.2 m, six at 2.2 m, three at 2.8 m, five at 5.4 m, and four at 6.6 m.

Because many of the cores did not include the pith, ring age was estimated by counting back from the current year's ring, which could be identified with certainty. Breast-height ages of the stands were known from Hoyer and Swanzy (1986).

Rings 20–24 were selected for analysis for two reasons: (*i*) older rings were not available from Clallam Bay, as these trees were in the 25th growing season at breast height when the cores were extracted, and (*ii*) the range of ring widths was greater in these rings than in the younger rings.

Data for all five rings from each core were combined, giving an average value for each tree; this allowed all comparisons to be made on wood approximately the same number of rings from the pith. Earlywood widths, latewood widths, and ring widths were averaged for each tree. We calculated earlywood density, latewood density, and whole-ring density for each tree, using an average of individual ring densities weighted by the corresponding widths. Percentage of latewood was calculated by dividing average latewood width by average ring width.

Average wood density between the Cascade Head and Clallam Bay locations did not differ significantly (α = 0.05), so the density data for the two locations were combined. Relationships of earlywood, latewood, and whole-ring widths to earlywood, latewood, and whole-ring densities were examined by simple linear regression. Relationships of latewood percentage to whole-ring width and whole-ring density were also examined. Significance of the regression models was tested by analysis of variance.

Results and discussion

Wood (whole-ring) density was negatively correlated with ring width (Fig. 1A). The relationship was highly significant (p = 0.000 04) and explained 39% of the variation in wood density. Wood density dropped from 0.47 to 0.37 g/cm^3 as average ring width increased from 2 to 8 mm.

A decrease in whole-ring density must be caused by a decrease in one or more of the following ring characteristics: (*i*) earlywood density, (*ii*) latewood density, and (*iii*) latewood percentage. Earlywood density decreased with ring width (p = 0.016), but the relationship accounted for only 16% of the variation in earlywood density (Fig. 1B). Also, the decrease in earlywood density was only about 0.05 g/cm^3 over the range of ring widths studied, while whole-ring density decreased about 0.15 g/cm^3 over the same range. The relationship between ring width and latewood density was not significant at $p < 0.05$ (Fig. 1C). Thus, changes in earlywood or latewood densities are not the primary cause of the drop in whole-ring density at higher growth rates.

Latewood percentage, however, dropped sharply with increasing ring width (Fig. 1D); ring width explained 48% of the variation in latewood percentage. Whole-ring density was closely tied to latewood percentage (Fig. 2), which explained 88% of the variation in wood density. The decrease in latewood percentage is the primary reason that wood density decreases with increasing ring width.

Latewood percentage decreased because increases in ring width produced wider earlywood without a corresponding increase in latewood width. The relationship between ring width and earlywood width was exceptionally close (Fig. 1E), but latewood width was unrelated to ring width (Fig. 1F). Additionally, the range of variation in latewood width (0.3–2.1 mm) was much less than that of earlywood width

(0.6–7.8 mm) (Figs. 1E and 1F). The result is shown in Fig. 3. The earlywood portion of Fig. 3 is delimited by the regression line from the relationship between earlywood width and ring width in Figure 1E. The latewood component was added as the difference between earlywood width and ring width.

These relationships support the findings of Wellwood (1960) and Krahmer (1966) that wood density decreases with higher rates of growth in western hemlock, and are consistent with Smith's (1980) report that latewood percentage decreases with increasing growth rate. Our study goes a step further in showing why the decreases in both wood density and latewood percentage occur.

Although our samples only included rings 20–24 from the pith, we believe these results may apply in a general sense to western hemlock wood. The relationship of wood density to ring width in our results is very similar to that reported by Krahmer (1960). As stated earlier, Krahmer's samples came from trees as old as 243 years and included a wide range of ring ages.

Because wood density is tied so closely to latewood percentage in western hemlock (Fig. 2), attention to latewood percentage is useful in understanding and possibly learning to manipulate variation in wood density. Latewood percentage might be increased either by minimizing earlywood width or by increasing latewood width. Earlywood width can be minimized by reducing radial growth rate through closer tree spacing, but this is usually considered undesirable because it results in smaller diameter trees at harvest.

If latewood width could be manipulated, wood density could be increased without decreasing radial growth rate. At present, factors controlling latewood width in western hemlock are not understood. In other conifers, several studies have indicated that latewood production is increased when moisture levels in late summer or early fall are increased (Zobel and van Buijtenen 1989). However, moisture level is not usually under the control of the silviculturist in the Pacific Northwest. Genetic selection may be a more promising method of increasing latewood width. High heritabilities have been reported for latewood width in Norway spruce (*Picea abies* (L.) Karst.) (Worrall 1975) and loblolly pine (*Pinus taeda* L.) (Goggans 1964).

Wood density might also be increased without reducing growth rate by increasing the density of earlywood, latewood, or both. Earlywood density is the more important of the two, because rings are composed mostly of earlywood at higher growth rates. While the data do suggest some influence of ring width on earlywood density (Fig. 1B), 84% of the variation is due to some other factor, possibly site or genetics. At present, the effect of these other factors on earlywood density of western hemlock is not well understood.

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