EFFECTS OF PRUNING ON WOOD DENSITY AND TRACHEID LENGTH IN YOUNG DOUGLAS-FIR

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ABSTRACT

To study whether pruning young Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) hastens the transition from juvenile to mature wood, we investigated the effects on wood properties in an intensively managed young plantation in the Coast Range of Oregon. Ten years after trees were pruned to a fixed height (3.4 or 5.5 m), we investigated the effects on wood density (in 12 trees per pruning treatment, two or three treatments per age class, three age classes, and two heights for a total of 168 cores) and tracheid length (in four trees per treatment, one height and age class only, for 12 trees total). The trees were 13, 16, and 18 years old when pruned in 1988. Removal of 50% of the live crown in young trees caused a small one-year decline in growth ring width at breast height, but removal of 30% of the live crown did not. In partial contrast, pruning caused no detectable effect on wood density at breast height, presumably because the branches were in the lower crown, and were not contributing much to the growth of the bole. Pruning caused a small increase in wood density at the upper height (5.3 m) in the youngest age class (for which this 5.5 m pruning would be removing vigorous live branches at this height) but not in the medium age class (for which the pruning would be removing lower live crown at this height) or in the oldest age class (for which there would have been no live branches at 5.5-m). Pruning the youngest trees caused a 3–4 year increase in tracheid length at breast height. In summary, pruning had very small or no effect on growth ring width, density, or tracheid length; but the effects that it had were the ones expected if pruning accelerated the transition from juvenile to mature wood. The larger benefit of pruning, especially if done early in rotation, is to shorten branch healing time and provide for a longer period of clear wood production.

Keywords: Pruning, wood density, tracheid length, Douglas-fir, juvenile wood, mature wood.

INTRODUCTION

Pruning has been identified as a possible approach for improving wood quality attributes of second-growth Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) (O'Hara 1991; Fight et al. 1995). In New Zealand, where Douglas-fir has been introduced, the wood quality of extremely fast-grown trees has been improved by intensive pruning treatments or careful spacing treatments (Reutebuch 1995). Traditionally, pruning studies have concentrated on the growth and yield of trees following pruning treatments (O'Hara 1991). Research is lack-

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ing on changes in wood properties as a result of pruning (Maguire and Petruncio 1995). Review of Douglas-fir pruning studies in the Pacific Northwest indicates that pruning the lower one-third of the live crown will not impact diameter or height growth significantly (O'Hara 1991). In addition, pruning trees to be retained in long rotations has been shown to be economically feasible, especially when performed early in the rotation (Fight et al. 1995).

The presence, location, angle, frequency, and size of branches are important wood quality considerations (Zobel and van Buijtenen 1989) because of their impact on the log grades (Northwest Log Rules Advisory Group 1998), lumber (Western Wood Products Association 1998), and veneer (Ernst and Fahey 1986, Fahey et al. 1991). Branch characteristics are especially important for a species like Douglas-fir that has persistent branches. In young natural unmanaged stands, a minimum of 77 years is required for natural pruning of the basal 4.9-m log (Bransford and Munger 1939; Kachin 1939; Paul 1947; Kotok 1951). This issue is particularly crucial because the current trend for its management is moving towards wider spacing (Oliver et al. 1986; Reukema and Smith 1987; Scott et al. 1998; Newton and Cole 1999), resulting in relatively large and persistent knots compared to dense natural stands.

The largest effect of pruning on the bole is likely to be seen somewhere within the mid-to-lower portion of the former live crown. This is because removal of the very lowest live branches often has no significant effect on stem form, presumably because the lowest branches were not contributing net photosynthate to the bole (e.g., Reukema 1959; Sprugel et al. 1991). Removal of the lowest of the vigorous branches, in contrast, will decrease growth of the bole near their attachment. Typically, these lowest vigorous branches will not be at the base of the crown, but up somewhat in the canopy (reviewed in O'Hara 1991).

It is often assumed that pruning will accelerate the transition from juvenile to mature wood, following Larson's reviews (e.g., Larson 1963) that juvenile wood is made in the vicinity of the crown and mature wood is made below the crown. However, few studies have investigated the effects of pruning on wood properties. Live branch pruning may cause an immediate increase in wood density and has been shown to decrease stem taper (O'Hara 1991). However, some researchers argue that a permanent shift to mature wood does not occur simply because wood density changes after pruning. Briggs (1995) asserts that pruning can be proven to cause a true transition to mature wood only if "length, microfibril angle, chemistry, and other characteristics of tracheids suddenly shifted to mature wood norms." The purpose of this study was to determine whether there were changes in wood density or tracheid length following pruning in young Douglas-fir trees. If there were any changes, we expected them to be most pronounced on the trees in which we sampled within the zone that had been pruned in the previous decade. The study is intended to mimic management that occurs in intensively managed plantations.

MATERIALS AND METHODS

Site description

The study site is located 5 km south of Philomath, Oregon (44° 29′ N, 123° 22′ W, elevation 125 m). Mean annual precipitation is about 120 cm, mean annual temperature is 13°C, and the mean frost-free season is 165–200 days (Zedaker 1981). Estimated site index at 50 years (SI50) is 38 m. The property was farmed from the mid-1860s until the early 1960s when it was converted to Christmas tree plantations of Douglas-fir. The stand was extremely homogeneous: soils and slope were very similar throughout the stand, there was intense vegetation control for the first five years, and the resulting trees had extremely similar diameters (coefficient of variation $<12\%$) and heights to one another before pruning was undertaken.

Experimental design and treatments

The study has a randomized complete block design with three age classes of trees. Two-year-old trees were planted in 1976 (age class 1), 1973 (age class 2), and 1971 (age class 3) for Christmas trees. Ages throughout this paper are the years since planting 2-year-old bare root seedlings. Plantations were thinned to 741 trees/ha when trees were 7 years old, then commercially thinned to 494 trees/ha when trees were 20 years old (age classes 1 and 2) or 22 years old (age class 3). The commercial thinning, largely from below, removed small saw logs that were mostly poorly formed. Nine plots (405 m^2) were established in age class 1, and six plots were established in each of age classes 2 and 3.

During winter 1988–89 when trees were 13–18 years old (Table 1), plots were randomly assigned to a treatment. Ten healthy dominant or co-dominant trees were selected for treatment per pruning treatment per plot. Thus there were 250 treated trees/ha selected from the 741 tree/ha plots. At this time, the 13-year-old trees had crown all the way to the ground, most of the 16-year-old trees had their lowest live branch at about 3.7 m above ground, and most of the 18-year-old trees had their lowest live branch between 5.5 and 6.1 m. In the older two age classes, branches in the lower two whorls were severely suppressed.

In age class 1, three plots were pruned to 5.5 m (the one-lift treatment), three plots were pruned to 3.4 m, and three plots were left untreated. These treatments resulted in crown reductions of about 50% and 30% for the 5.5-m and 3.4-m treatments, respectively (Table 1). In fall of 1990, the trees pruned to 3.4 m received a second lift to 5.5 m (the two-lift treatment), resulting in an 18% crown reduction (Table 1). For age classes 2 and 3, three plots were pruned to 5.5 m (the one-lift treatment) and three plots were left unpruned. Pruning was accomplished manually with a pole-type branch-pruning saw.

We sampled the plots in late 1998 when trees were 23–28 years old, and the breast-height disk was 19–24 years old (Table 1). For each age class, trees were divided into four size classes based on diameter at breast height. From each plot, four trees were selected randomly for sampling. In addition, from each age class, three trees were selected randomly from each treatment and size class to ensure that the treatment and control groups were comparable and covered a range of diameters. This sampling provided a total of 12 trees from each treatment group, for a total of 36 trees in age class 1, 24 in age class 2, and 24 in age class 3.

Wood density determination

We took one 5-mm-diameter increment core per tree from each treatment for wood density and growth ring width analysis (84 trees total) at each of two heights: breast height (1.4 m), and the top of the first log, 5.3 m (assuming a 16-foot log, with a 1-foot stump and 0.3-foot trim allowance). The cores were air-dried and then cut to a slab about 1.5 mm thick (in the direction of the grain). The cut samples were extracted to remove materials that could alter the attenuation of X-rays. We submerged samples in a near boiling 2:1 mixture of 95% ethyl alcohol and toluene for eight hours, with the liquid replaced every two hours. Cores were then spread and weighted (to avoid warp) in the X-ray room to equilibrate to ambient moisture content (about 12% mc).

The samples were scanned with a direct reading X-ray densitometer (Gartner et al. 2002) with data collected every 0.1 mm along the length of each sample. The density values were imported into DendroScan 4.5 (Varem-Sanders and Campbell 1996) to locate boundaries between growth rings (the steepest point in the density vs. distance curve between the latewood density of one year and the earlywood density of the next year) and between earlywood and latewood (the mean of the lowest earlywood value and the highest latewood value per growth ring). All units of wood density are expressed as basic density using dry mass and green volume. The following tree-ring variables were generated: ring width, earlywood width, latewood width, latewood proportion, average ring density, earlywood density, and latewood density.

Tracheid length determination

We took one 8-mm-diameter core for measurement of tracheid lengths in age class 1 (the youngest trees) from each of four randomly chosen trees from both pruning treatments and from the unpruned controls (for a total of 12 cores). From each core, every growth ring from 1987 to 1998 was divided into earlywood and latewood. Samples were macerated by heating them at 85°C in a 10% solution of 1:1 nitric acid and hydrogen peroxide in water. Samples were rinsed and then stained with aqueous safranin. The macerated fibers were mounted on slides, with three random selections from each sample on each of three separate slides. Fifty entire earlywood and latewood tracheids per ring were measured using the image-analysis system. Given that the average tracheid length was 4 mm or less, and that the samples came from an 8-mm core, it was necessary to look carefully at both ends of each tracheid to tell if tracheids were entire. The images of the slides were captured through a CCD video camera attached to a stereo-microscope. Tracheid length was captured and analyzed using the public-domain software program NIH Image, v. 1.47 (Rasband 1992). We calculated the average tracheid length for each growth ring and tree in both the earlywood and the latewood, then applied a weighting factor of proportion latewood to estimate mean tracheid length for the ring.

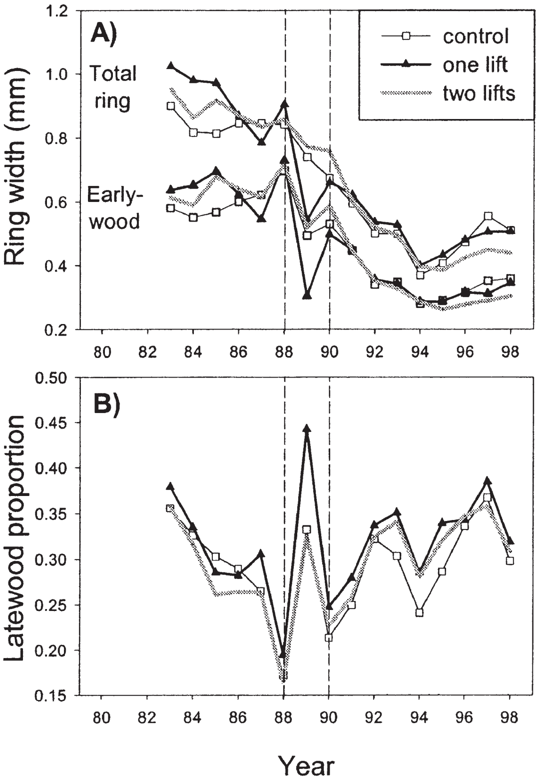

FIG. 1. Radial patterns of growth-ring width by pruning treatment at breast height (1.37 m) for age class 1 (mean ± s.e., n=12 trees for each data point). A) Total growth-ring width and earlywood growth ring width. B) Latewood proportion. The dashed lines show when trees were pruned.

Data analysis

Because individual trees and not plots were pruned, individual trees were treated as randomly chosen experimental units. We assumed that radial changes due to climate would affect all the treatment groups alike. Therefore, there would not be a treatment and climate interaction. The response variables were graphed for visual inspection. Variables with visible treatment differences were further evaluated with analysis of variance or t-tests where appropriate.

RESULTS

Growth-ring width

Growth-ring widths were examined at breast height for age class 1. During the years studied, the general trend was a decrease in ring width, driven by earlywood width (Fig. 1A). The one-lift pruning (pruned to 5.5 m) caused a small one-year decrease in growth ring width at breast height (see 1989, Fig. 1A). Most of the reduction was in the earlywood (Fig. 1A, B). This pruning would have removed live branches from breast height, but they would have been in the lower live crown.

Under the two-lift pruning system, neither the first lift (to 3.4-m) nor the second lift (to 5.5-m two years later) caused a decrease in growth-ring width or latewood proportion at breast height (see 1989 and 1991, Fig. 1A, B). The first lift removed all lower live crown branches below 3.3 m; hence all branches removed in the second lift were from 3.3–5.5 m (Table 1).

TABLE 1. *Age of trees when pruned, breast-height age of trees when sampled, proportion of crown removed, height of pruning, approximate location of lowest live branch when trees were pruned, and assessment of whether live branches had been removed from the bole at each of two sampling heights.*

	Tree age when pruned (yrs)	Tree age when sampled (yrs)	BH age when sampled (yrs)	Crown removed	Pruning ht (m)	Lowest live branch ht when pruned (m)	Were live branches removed at 1.4 m?	Were live branches removed at 5.3m?
One-lift system								
Age class 1	13	23	19	50%	5.5	0	yes	yes
Age class 2	16	26	22	15%	5.5	3.7	some	yes
Age class 3	18	28	24	10%	5.5	5.5–6.1	no	very few
Two-lift system								
Age class 1	13, 15	23	19	30%, 18%	3.4, 5.5	0, >5.5	yes, no	yes, some

Wood density

Wood density tended to increase from the pith toward the bark in the years studied in all three age classes and at both heights (Fig. 2). Within this trend, there was considerable year-to-year variability not related to treatment. At breast height, there were no treatment-related differences in density that began at the time of pruning (Fig. 2A, B, C). This result is in spite of the increase in latewood proportion in 1989 after the one-lift pruning reported above, and also in spite of the fact that for the one-lift trees and the first lift of the two-lift trees, there had been lower live crown branches at breast height when pruning occurred (Table 1).

At the upper height, the only age class that exhibited a significant change in wood density after pruning was age class 1 (Fig. 2D). For this age class, in 1988 there were no significant density differences between treatments (P-value = 0.50), but in 1989 the density in the one-lift treatment was higher than in the unpruned control (one-sided p-value = 0.0044, t-test). From 1988 to 1989, density increased by 9% for control, 18% for one-lift, and 6% for two-lift. The increase in the one-lift treatment was due to a larger increase in latewood proportion and a slight increase in earlywood density (data not shown). Both age classes 1 and 2 had live branches at the upper height at the time of pruning (Table 1); they would have been in the mid-crown for age class 1, and the lower crown for age class 2.

Tracheid length

The first lift in both the one-lift and the two-lift systems caused increases in the mean, earlywood, and latewood tracheid lengths in the trees of age class 1 at breast height (see 1989, Fig. 3). Both of these treatments removed live branches from breast height during their first lifts (Table 1). By 1992, four years after the first lift, there was relatively little difference in tracheid lengths between treatments, which had the same live crown length by then (data not shown). The second lift did not cause any further increase in tracheid length at breast height. Apart from age-dependent trends in each age group, there was little year-to-year variation.

DISCUSSION

The results of this study are not conclusive about whether pruning accelerates the transition from juvenile to mature wood, but it is clear that if such a transition is accelerated, its effect on wood properties is small. Pruning had no important effect on wood density at breast height for any of the pruning treatments. This result was in spite of removing 10 to 50% of the live crown, and, in age class 1 (the youngest trees), pruning to below breast height in both the one-lift system and in the first lift of the two-lift system. This result implies that the oldest, lowest branches in these trees do not have a strong effect on wood density.

However, in age class 1, pruning appeared to cause a several-year increase in wood density at

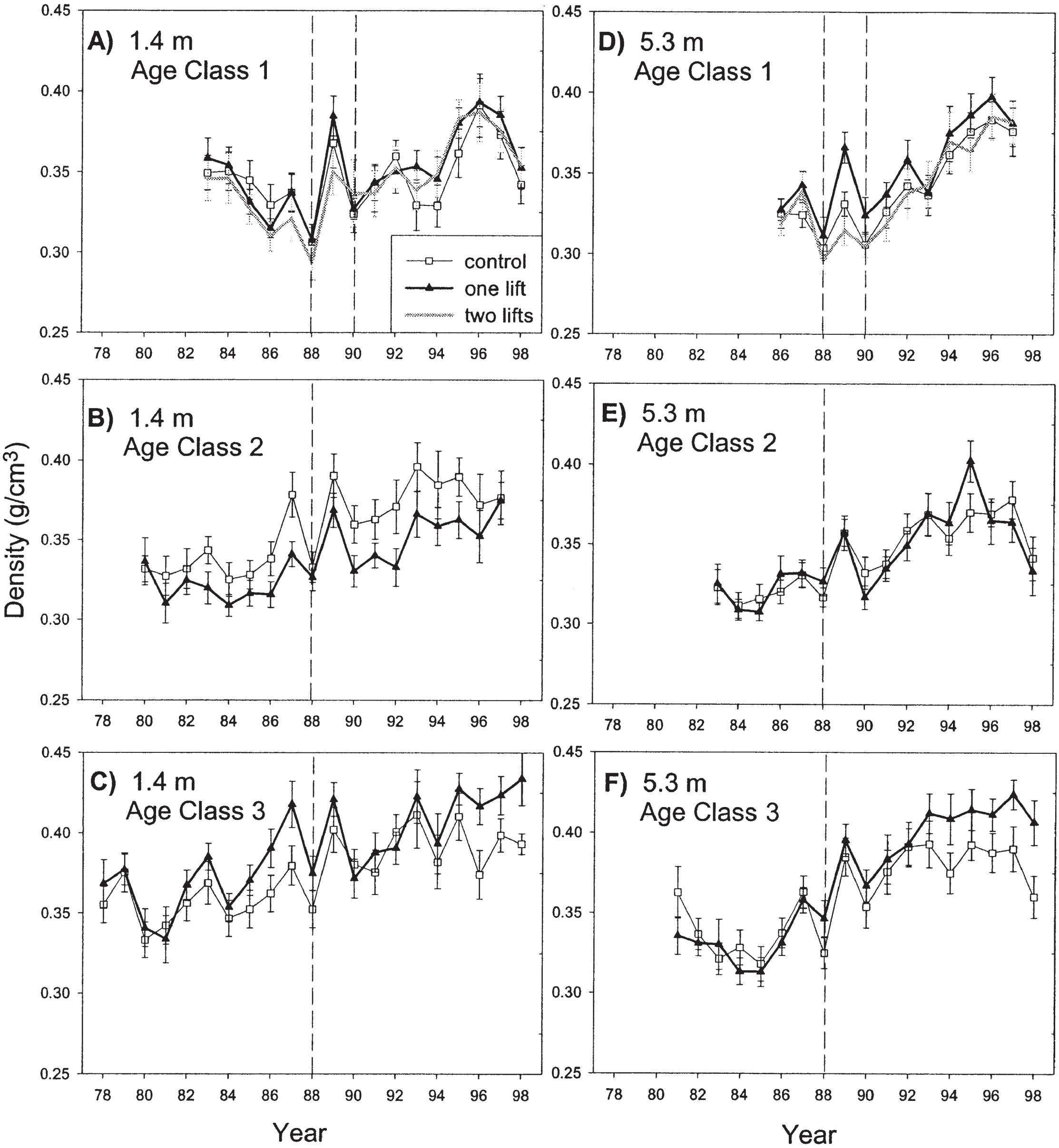

FIG. 2. Radial patterns of wood density by pruning treatment at breast height (1.37 m) and at the upper height (5.3 m) for each of the three age classes (mean ± s.e., n=12 trees for each data point). The dashed lines show when trees were pruned.

the upper height, which would have been a location in the crown from which vigorous branches had been removed. This effect, seen in trees that were 13 years old when pruned to 5.5 m, was not seen in age class 2 or age class 3, the 16- or 18-year-old trees that were also pruned to 5.5 m. In age class 2, the pruning treatment would have removed some live branches, but they would have been near the base of the crown. In age class 3, the pruning treatment would not have removed any live branches from the sampling height, and so no effect would be expected at that height.

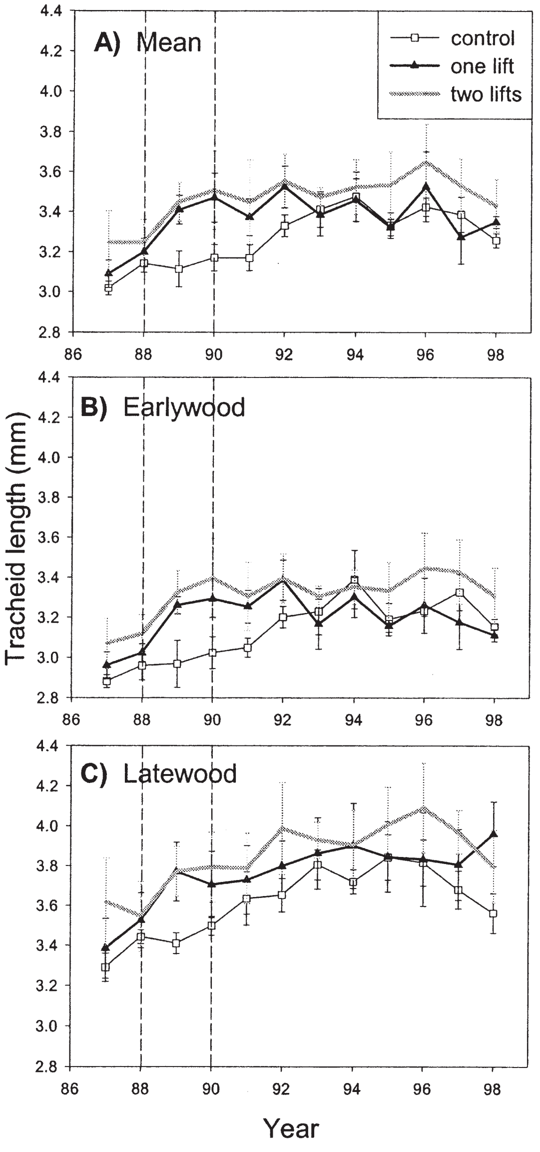

FIG. 3. Radial patterns of A) mean tracheid length, B) earlywood tracheid length, and C) latewood tracheid length at breast height for age class 1 (mean ± s.e., n = 4 trees for each data point). The dashed lines show when trees were pruned.

In summary, our results showed that when pruning removed the very lowest live branches, there was no effect on wood density in that vicinity on the bole, but when pruning removed higher live branches, which were presumably more vigorous, there was a short-lived and small increase in wood density in the vicinity of those branches. Similarly, Polge et al. (1973), studying 8 pruned and 8 unpruned trees, found no important differences in minimum or maximum wood density at breast height following a 50% live crown pruning of 13-year-old Douglas-fir.

Our results are partially consistent with those summarized by O'Hara (1991), that show that removal of one third of the live crown can reduce diameter growth mostly through a decrease in earlywood width. In the current study, we saw such an effect in the one-lift system, but not in the first lift of the two-lift system. The decrease in ring width has been reported to result in an increase in latewood proportion in the lower stem (Marts 1951; Cown 1973). Jozsa (1995), studying 11 pruned 8-year-old Douglas-fir trees, reported a 21% increase in density at breast height for 3 years following a 40% live crown pruning. However, there was only one (unpruned) control tree for comparison. Di Lucca (1989), studying two Douglas-fir trees aged 15 and 21 years, reported an increase in density at breast height and at about 3 m (located at 10% of tree height) following a 30% live crown pruning.

In contrast, Gartner and colleagues (2002) found no effect of the position of the live crown on the density of the outer growth rings in 34-year-old Douglas-fir trees. They compared wood density above and below the live crown, and above and below 2/3 of the live crown, in all cases correcting for cambial age. Fabris (2000) found no important effects of initial tree spacing (and thus, position of the live crown) on latewood proportion or wood density in Douglas-fir trees. He sampled square spacings that ranged from 0.91 m to 4.57 m (3 to 15 ft) representing initial stocking densities of 12,076 to 479 stems/ha. Jozsa (1995) reported on a set of 15-year-old Douglas-fir trees that had had crown all the way to the ground when they were pruned to 4.5 m height. Six years after treatment, disks from control and pruned trees from three heights (stump height, breast height, 4.5 m) showed no significant increases in average ring density from the pruning.

With the small sample size used (four trees for each of three treatments), we found that tracheid length increased at breast height for 3–4 years in trees that were pruned at age 13 to either 3.4 or 5.5 m. When the trees were 16 years old, the trees that had originally been pruned to 3.4 m were pruned again, to 5.5 m. This second lift caused no further change in tracheid length at breast height, probably because the crown base was so far from breast height even before the pruning. We have found no other reports of change in tracheid length following pruning in Douglas-fir, although Fabris (2000) reported no important effects of initial tree spacing on tracheid length. Similar to Douglas-fir, *Pinus radiata* that was heavily pruned (leaving one-third of the live crown) at age 9 increased tracheid length for about 3 years (Gerischer and de Villiers 1963). In contrast, another study on *Pinus radiata* found no significant difference in tracheid length between heavily pruned (about 76% of the live crown removed at age 6) and control trees at breast height or at 6.5 m (Cown 1973). It is important in such studies to know the vigor of the removed crown at the sampling height. For example, in the current experiment, larger effects on tracheid length may have occurred higher up the stem where the more vigorous branches were removed.

Although repeated pruning could reduce the size of the juvenile core by reducing annual growth (Gerischer and de Villiers 1963), this practice would also increase the time required to occlude the branch stubs (Petruncio et al. 1996) and would decrease volume recovery. The appropriate management regime for a given type of wood will depend on economic factors as well as biological ones. Riou-Nivert (1989) modeled diameter growth of two stands of different initial spacing, then showed the difference in proportion of juvenile wood and in tree basal area attained comparing the trees when the stands were of equal diameter (the user's viewpoint) and when the stands were of equal age (the grower's viewpoint). When both stands averaged about 18-cm diameter, the widely spaced stand (15 years at breast height) would have 73% juvenile wood and the closely spaced stand (22 years at breast height) would have 40% juvenile wood. In a second set of calculations, Riou-Nivert (1989) showed that at equal age (22 years), the widely spaced trees would have 50% juvenile wood vs. 40% juvenile wood in the closely spaced stand, but two times the basal area. The decision to suppress early growth vs. encourage it is economic, and may be tied to economic issues of pruning for clear wood production.

The stands in which this research was conducted will remain available for continuation of this work, and some of the trees have now been pruned to 8 or 12 m. Re-sampling these stands at a wider range of heights potentially will reconcile difficulties of year-to-year variation and projection of densities and tracheid lengths at log positions most crucial in overall wood quality determination.

CONCLUSIONS

Pruning had at most very small effects on the growth ring width, density, and tracheid lengths of wood in the locations that we sampled. In one of the two pruning treatments on the youngest trees (13 years), pruning the live branches from the ground up to 5.5 m caused a one-year decline in growth ring width; but in the second treatment (in which live branches were removed from the ground to 3.4 m), there was no effect on growth-ring width compared to unpruned controls.

Pruning caused a several-year increase in wood density in only one of the many treatments and sampling heights that we studied. We concluded that there was an increase in wood density along the bole where the most vigorous branches had been removed (as seen at 5.3 m but not at breast height). In contrast, there was no measurable effect on wood density in locations in which the crown was no longer alive (sampling at breast height for the age class 2 and 3 trees), nor in locations in which we had removed the very lowest branches within the crown (sampling of breast height for the age class 1, and sampling at 5.3 m for age classes 2 and 3).

In the trees for which we sampled tracheid length, the age class 1 trees, there was an increase following pruning but only for 3–4 years, and only by about 10% (but note that tree sample size was much smaller for tracheid length than wood density or growth ring width). This increase was observed at both the lower height sampled (where no effect on density had been seen) and at the upper height (where a density effect had been seen).

These pruning effects, when seen, were of a small magnitude and were transitory. For growth ring widths and wood density, more of the variation came from annual fluctuations than from the pruning treatments. Considering even a short a rotation for Douglas-fir (40–60 years), the influence of a temporary change in wood properties has little practical value. The greatest increase in value from pruning is likely to come from the formation of clear wood, which will reduce mechanical and aesthetic degrade associated with knots and distorted grain. Pruning early in the rotation will improve value recovery and wood quality by provision of a longer period of clear wood production, but at short rotations, the amount of clear wood produced over the knot may not be sizeable enough to warrant the pruning.

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