Time and Distance to Clear Wood in Pruned Red Alder Saplings

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Abstract

Pruning trials in young alder stands were sampled to evaluate response to pruning. Effects of pruning (1) live branches on different dates, and (2) dead branches with or without damaging the branch collar were assessed on trees pruned in 3- and 6-year-old plantations, respectively. Six years after pruning, stem sections were collected and dissected in the longitudinal-radial plane to expose the center of the stem and branch stub. Ring counts and linear measurements were made for various boundaries or points, including time of pruning, stub length, defect, and beginning of clear wood formation. Pruning during the growing season and, to a lesser extent, late in the growing season when leaf abscission was beginning, resulted in shorter times and distances to formation of clear wood (2.1 years, 14.5 mm) than pruning in the dormant season or just prior to the beginning of the growing season (2.6 years, 18.6 mm). Cutting the branch collar on dead branches led to shorter times and distances to clear wood (2.8 years, 21.9 mm) than intentionally avoiding such wounding (3.5 years, 24.8 mm); these differences were associated with shorter branch stubs as there were no differences in the amount of defect. Epicormic branching was minimal in the two pruning studies, averaging less than one branch per tree in the date of pruning test and only two branches per tree in the branch collar wounding study. Assessments for comparable unpruned trees indicated that times to form clear wood after branch death would be markedly greater and that epicormic branching was equal to or greater than that determined for pruned trees. Although statistically significant differences occurred among different pruning dates and with branch collar wounding, the decision to prune or not prune is of much greater practical importance, regardless of when (date) or how it is done. Such pruning decisions can be made by using this information on time and distance to clear wood in economic analyses developed with available data on tree growth, log volume, lumber recovery, pruning costs, and price differentials for clear vs. knotty wood.

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Introduction

Red alder (*Alnus rubra* Bong.) is an important hardwood in the coastal forests of Oregon, Washington, and British Columbia (Harrington 1990). For decades it was considered primarily a weed species that provided unwanted competition to conifers in these forests, but red alder is now recognized for some highly valued ecological and economic contributions. Rapid early growth and ability to fix atmospheric nitrogen make it a very desirable species for restoring and enhancing productivity of forest sites after natural and human-caused disturbances (Tarrant and Trappe 1971). Its wood is desired for fuel, fiber, and solid wood products; as with other hardwood species, clear wood has the highest value and is used in furniture, cabinetry, and paneling. Red alder grows rapidly at young ages and recent silvicultural research has indicated that alder sawlogs can be produced in plantations on short rotations (30 years or less) with wide spacings (c.f., DeBell and Harrington 2002, Hibbs and DeBell 1994). Wide spacings, however, also lead to large, long-lived branches on the lower bole that can reduce log grade and value of lumber recovered. Such branching can be reduced by growing the trees at denser spacing to facilitate natural pruning (Hibbs and DeBell 1994) but diameter growth will be reduced. Another alternative is to grow the trees at wide spacing and manually prune the lower branches as is done to produce clear wood in other species throughout the world (Hanley et al. 1995, Haygreen and Bowyer 1996).

Although there is a long history of pruning hardwood species in other regions, there is little research or experience with regard to pruning red alder. Berntsen (1961) examined stem sections of 43-year-old alder that had been pruned 22 years before. He found that stubs of pruned limbs were sometimes grown over within two years; decay was present in every dead or pruned stub but it rarely extended beyond the knot and it did not hinder the increment of clear wood. Berntsen (1961) also found that epicormic branches frequently originated, singly and in clusters, where other branches had been naturally or artificially pruned; these were apparently of such size and number to negate any gains in wood quality from pruning. Such branches, more common in hardwoods than conifers, form from suppressed buds located throughout the stem that are released (or sprout) following stand or tree disturbance. If the epicormic branches are abundant, persist and grow to large size, the resulting knots may reduce quality and value of the logs at harvest below that of unpruned trees. Berntsen (1961) therefore concluded that the desirability of pruning was questionable until more was learned about the cause and control of epicormic branching.

Our research was conducted in young, rapidly growing red alder plantations. We investigated how the trees responded to pruning in terms of how long it took to form clear wood and also the degree to which epicormic branches were formed. Existing pruning trials (Brodie and Harrington 2006) offered the opportunity to assess: (1) effects of date (season) of pruning live branches, and (2) the nature of the cut for dead branch pruning (e.g., does it make a difference whether live tissue around the branch collar is wounded in the operation?). For some hardwood species, substantial differences in wound occlusion and subsequent decay may exist among seasons or dates of pruning (i.e., McQuilkin 1950). If such differences occur in red alder, pruning operations will need to be scheduled accordingly. If differences are negligible, however, pruning can be scheduled with greater flexibility. The study of pruning dead branches resulted from observations that some dead branches that broke off naturally did not occlude quickly. Also dead branches sometimes would break off inside the stem and leave a pocket or hole that filled in rather slowly. We hypothesized that wounding the branch collar would *rejuvenate* the tissues around the branch collar resulting in faster occlusion; in addition, making the pruning cut through the branch collar (closer to the stem) would also reduce stub length). We examined correlations between time and distance to clear wood formation and stem size (radius), stem (cambial) age, branch diameter, branch angle, and radial growth rate after pruning. We also evaluated epicormic branching on the pruned study trees and on comparable unpruned trees in the surrounding plantation.

Figure 1—Young red alder plantation near Lacey, Washington.

Methods

Origin and Nature of Sample Trees

Stem samples for our investigation originated and represent subsamples from two trials of pruning methods (Brodie and Harrington 2006) that were superimposed on selected portions of research plantations of young red alder (fig. 1) at the Washington State Department of Natural Resources' Meridian Seed Orchard, 12 km east of Olympia and near Lacey, Washington (47° 00 ‘ N, 122° 45 ‘ W). Detailed descriptions of the site, design and establishment of the research plantations, and early growth and stand development were reported in DeBell et al. (1990) and Hurd and DeBell (2001). Early results of the pruning trials are

Table 1—Size of trees at pruning and at time of sampling (6 years later)[1].

Measure and time		Study 1-date of pruning			Study 2-branch collar wounding		
		Mean	Min	Max	Mean	Min	Max
DBH (cm):	At pruning	6.7	4.7	9.1	11.0	7.8	13.4
	At sampling	12.4	8.2	18.9	19.2	15.3	24.7
Height (m):	At pruning	7.0	5.6	8.2	9.4	8.3	10.1
	At sampling	13.2	9.1	16.5	17.1	15.8	19.4

[1] Number of observations is 60 trees for study 1 and 30 trees for study 2.

given in Brodie and Harrington (2006). The soil at the site is a deep, excessively drained loamy fine sand formed in glacial outwashes and trees were irrigated to supplement the low rainfall (15 cm) falling during the May 1 – September 30 period. Climate is mild with an average growing season of 190 frost-free days; mean annual temperature is 10.1°C, mean January minimum temperature is 0.1°C, and mean August maximum temperature is 25.1°C. The plantations were established with 1-year-old seedlings and kept weed-free by tilling, hoeing, and selective application of herbicides.

One pruning trial (date of pruning) subsampled for our study was installed in a 3-year-old plantation (4 years from seed), spaced (after thinning) at 2 m by 2 m or 2500 trees per hectare. Live branches were pruned from the lower one-third of the crown of 10 trees without damaging branch collars on each of seven dates. Dead branches present in the same region of the stem were also removed at the same time. Most branches were removed by handsaw, but small trees or very small branches with inadequate wood to support a saw were cut with hand clippers. At time of pruning, the trees averaged 7.0 m tall and 6.7 cm in diameter at breast height (table 1), and were pruned to an average height of 3.2 m. Ten trees each from five of the pruning dates, representing a range of phenological stages, were selected for dissection and evaluation: January 1 – mid-dormant season, March 1 – immediately prior to budbreak, May 1 – early growing season (leafed out), June 15 – mid-growing season (leafed out), and September 15—toward the end of the growing season (beginning of some leaf abscission). In addition, 10 trees that had not been pruned were selected for comparative measurements.

The second pruning trial (branch collar wounding) was installed in a 6-year-old plantation (7 years from seed), spaced (after thinning) at 2.8 m by 2.8 m or 1250 trees per hectare. All branches (dead and alive) were pruned on the lower bole by handsaw on May 1. At pruning, the trees averaged 9.4 m tall and 11.0 cm in diameter at breast height (table 1). Two pruning methods were tested on dead branches only: (1) without damaging branch collars (sometimes referred to as a "Shigo cut" [Shigo 1986]), and (2) with deliberate wounding of branch collars. Ten trees were randomly selected for each treatment. All trees treated were selected for dissection and evaluation in our study; an additional 10 trees (of identical age) that had not been pruned were also sampled in an adjacent planting of nearly the same spacing.

Sample Collection, Preparation, and Measurement

Six years after pruning treatments were implemented, the trees for both studies were felled and several measurements taken on stem and branch characteristics. These included total height and diameter at breast height (table 1), height and diameter of every dead branch remaining on the bole, and the same measurements on live branches occurring at a height below the highest dead branch. Height and diameter of epicormic branches were also recorded.

Five pruning scars (or branches or branch scars if sampling an unpruned tree) distributed between the stump and 4.8 m on the bole (nearly all were below 3.3 m) on each study tree were selected for sampling and their height recorded; a 15-cm thick section centered on the scar (or branch) was cut by chain saw. Each section was labeled by tree number and sample location on the bole (1=lowest and 5=highest) and placed in a heavy plastic bag for transport to the laboratory.

Two of the five sections (2 and 4) from the date of pruning study were used to assess presence of decay organisms in the branch stub. After excision from the stub, small samples of woody tissue were surface sterilized by flame; they were then pressed into malt extract agar in petri plate cultures, and examined over time for growth of decay fungi. The remaining three sections (1, 3, and 5) from each tree in the date of pruning study and all five sections from the branch collar wounding study were then kiln-dried at 63°C for 48 hours to reduce decay.

After drying, each section was examined visually to determine the location and orientation of the branch scar (pruned or unpruned) of interest. A band saw was used to dissect each section in the longitudinal-radial plane through the center of the branch and stem pith. Occasionally two

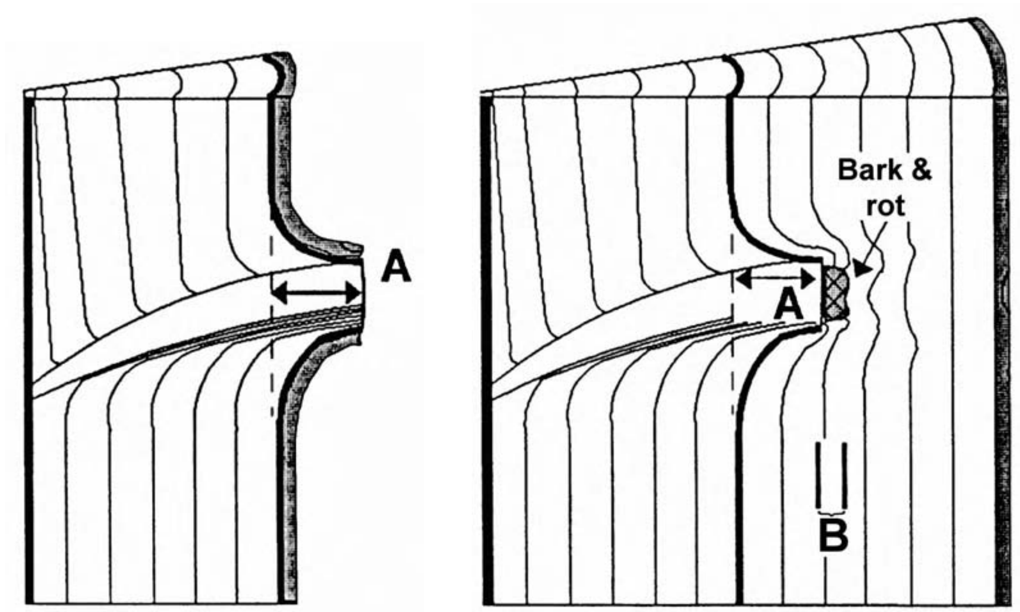

Figure 2—Diagrammatic stem sections showing branch stub immediately after pruning and 6 years later. Healing (occlusion) region is separated into stub length (Zone A) and region beyond the stub where defects may occur (Zone B). Adapted from Petruncio et al. (1997).

or more cuts were needed to achieve good radial exposure through the branch. The radial surface was then sanded with a belt sander to aid identification of rings and various growth and healing (occlusion) boundaries (fig. 2).

Qualitative branch characteristics (dead or alive, pruned or unpruned) were recorded as were various ring counts. Linear measurements such as branch diameter, ring widths, and distances from the pith to point of branch death (branch collar wounding study only), end of stub, occlusion, and beginning of clear wood were determined to the nearest 0.1 mm. Ring counts and distances as defined in Petruncio et al. (1997) plus some additional variables were calculated from the above measurements (table 2). For pruning treatments applied during the growing season, some measurements of ring count (CAM) and radial distance (AW, RIB) were adjusted as appropriate based on the phenology of stem cambial growth (i.e., seasonal pattern of cumulative radial increment) as determined in the plantations and reported in DeBell and Giordano (1994).

Summary and Analysis of Data

Analysis of variance procedures were used to assess effects of treatments (date of pruning in study 1, and branch collar wounding in study 2) on time and distance to clear wood, and treatment means were separated by least significant difference procedures (SAS 1994). Correlation matrices containing all variables were examined to evaluate relationships to time and distances to produce clear wood on pruned trees. All samples (stem sections) were assumed to represent independent observations. Differences among treatment means and correlation coefficients were considered significant if $p<0.05$. Data on live, dead, and epicormic branches originating on the bole below 3.3 m were summarized by 1.0 m height intervals above the stump (0.3 m).

Results

The young trees in the plantation responded well to pruning. No trees died, and except for the pruning wounds, none were obviously injured in the pruning operation. There was no excessive sap flow or bleeding from wounds. At time of sampling, external evidence of pruning scar locations was still observable but occlusion was complete on all trees and there were no visual differences among treatments.

General Nature of Tree Characteristics and Pruning-Healing Variables

Values for pruning-healing variables measured on the stem sections for Study 1 and Study 2 are listed in table 3. Age and size of the stem sections and branches differed substantially between the two studies at time of pruning: cambial age of the stem section (3.6 vs. 5.0 years); its mean radius (25.5 vs. 48.5 mm); mean stub diameter (13.4 vs. 17.0 mm); and stub length (13.2 vs. 18.7 mm) had much lower values in Study 1. Average time (ABR) and distance (ABW) to clear wood also differed markedly, even though radial growth rate after pruning (RWAP) was rather similar in the two studies (5.7 and 6.0 mm/yr).

Table 2—Definition of variables.

Ring counts	
CAM	Number of rings from the pith to the year pruned. i.e., age of cambium when pruned
AR	Number of rings (years) to grow over zone A. i.e., since the year of pruning to the stub end
BR	Number of rings (years) to grow over zone B, i.e., from the end of stub to clear wood
ABR	Total number of rings (years) of zones A and B combined
DPRG	Number of rings between branch death and pruning (study 2 only)
Distances (mm)	
AW	Zone A width = stub length: the distance from the stem cambium at the time of pruning to the stub end (See Fig. 2)
BRDIA	Stub end diameter
BW	Zone B width: the radial distance from the end of stub to clear wood (Fig. 2)
ABW	Width of zones A and B combined (ABW = AW + BW)
RIB	Radius from pith to year of pruning (RIB= ROS – AW)
ROS	Radius-over-stub: distance from pith to end of stub
ROO	Radius-over occlusion (ROO = ROS + BW)
DPDIS	Distance from point (ring) of branch death to prune (study 2 only)
Other measures	
BRANG	Branch angle (measured from vertical)
RWAP	Average ring width (rate of growth) for the 6 years after pruning

Study 1 — Date of Pruning

Although there were no significant differences among pruning dates for number of rings (AR) from time of pruning to end of the pruned stub, significant differences were present among some treatment means for other "healing" or occlusion variables (table 4a). On average, fewer than 2 years (1.4 to 1.9) and no more than 15.2 mm (AW) of radial growth were needed to reach the end of the branch stub. Such values are, of course, strongly influenced by growth rate after pruning and closeness of the prune to the stem (stub length). Statistically significant differences among pruning dates in time and distance from the end of the stub to formation of clear wood (BR and BW) reflect defects of various kinds (primarily bark or rot). Pruning in the dormant season (January 1) and just prior to the beginning of the growing season (March 1) resulted in longer times beyond the stub to clear wood (BR) than for pruning in mid-June (0.86 and 0.82 vs. 0.41 years); distances from the end of stubs to clear wood (BW) were, on average, twice as long for January pruning as those for any other date (5.1 vs. 2.5 mm). Because total time (ABR) and distance to clear wood (ABW) is the summation of both A and B variables (radius or time at pruning to end of stub plus end of stub to clear wood), they both show significant differences among treatment dates. In general, pruning during the growing season (May 1 and June 15) and, to a lesser degree, late in the growing season when some leaf abscission has started (September 15) results in shorter times and distances from pruning to formation of clear wood (average–2.1 years and 14.5 mm radial distance) than does pruning in the dormant season (January 1) or just prior to the beginning of the growing season (March 1) (average–2.6 years and 18.6 mm radial distance).

The relatively short time to produce clear wood after pruning live branches contrasts sharply with the time required for branches in unpruned trees to die, break off, and heal over. Many of the unpruned trees still had live and dead branches on the lower stem: one third still had live branches in the 1.3 to 2.3 m section and two thirds had live branches in the 2.3 to 3.3 m section. Dead branches were even more common; one third of the unpruned trees had dead branches in the lowest (0.3 to 1.3 m) section and all trees had some dead branches on the bole below 3.3 m. All trees evaluated in this study were components of intensively measured research plantations; as such, lower dead branches were no doubt broken off sooner and closer to the bole by activities of field personnel than would be typical in production plantations. Thus, not only is the presence of dead branches on the unpruned study trees likely to be lower than what would usually be expected, but also our assessment of times and distances required to produce clear wood beyond those branches that did break off may be biased toward the low end. Even so, average times and distances to clear wood after branch death were markedly greater in unpruned trees (4.2 years and 23.9 mm) than after pruning in pruned trees (2.4 years and 16.2 mm).

Table 3—Values of healing-pruning variables measured on pruned branch stubs of studies 1 (date of pruning) and 2 (branch collar wounding).

		Study 1				Study 2			
Variable (unit)	Code	Mean	Std dev	Min	Max	Mean	Std dev	Min	Max
Age branch was pruned (years)	CAM	3.6	0.9	1.0	5.0	5.0	0.2	4.0	5.0
Rings in zone A (years)	AR	1.7	1.2	0.0	6.0	2.9	1.2	1.0	7.0
Width of zone A= stub length (mm)	AW	13.2	7.1	0.0	32.0	18.7	5.5	6.0	30.0
Rings in zone B (years)	BR	0.6	0.8	0.0	3.0	0.3	0.5	0.0	1.0
Width of zone B (mm)	BW	3.0	3.6	0.0	17.0	4.9	4.4	1.0	21.0
Rings in zones A and B (years)	ABR	2.4	1.3	0.0	6.0	3.2	1.3	1.0	7.0
Width of zones A and B (mm)	ABW	16.2	7.8	0.0	37.0	23.5	6.8	7.0	38.0
Radius-inside-bark (mm)	RIB	25.5	8.4	8.0	51.0	48.5	7.2	29.0	69.0
Radius-over-stub (mm)	ROS	38.4	8.9	16.0	60.0	67.2	8.5	46.0	90.0
Radius-over-occlusion (mm)	ROO	41.4	9.8	20.0	75.0	72.0	10.2	47.0	107.0
Ring width after pruning (mm/year)	RWAP	5.7	1.8	2.3	11.0	6.0	1.6	2.7	11.0
Stub diameter (mm)	BRDIA	13.4	6.8	4.6	38.6	17.0	5.2	6.6	33.8
Rings between branch death and prune (years)	DPRG	N/A	N/A	N/A	N/A	1.1	0.5	0.0	3.0
Distance between branch death and prune (mm)	DPDIS	N/A	N/A	N/A	N/A	9.2	5.7	0.0	27.0
Branch angle (degrees)	BRANG	35.3	11.4	4.0	68.0	36.7	11.4	3.0	77.0

The preliminary assessment of decay organisms indicated that decay fungi were present in the branch stubs of unpruned trees to a somewhat greater extent than in the wound centers or branch stubs of pruned trees (29% vs. 19%, respectively, for the average of all dates). There was a trend by pruning date in the percentage of stubs from pruned trees that contained decay fungi, however: January - 4%, March - 8%, May - 22%, June - 21%, and September - 39%.

Study 2 — Pruning and Branch Collar Wounding

Times and distances between pruning and the end of the stub (AR and AW) and to the production of clear wood (ABR and ABW) differed significantly between sections with damaged and undamaged branch collars (table 4b). The amount of defect beyond the stub (reflected in BR and BW), however, was essentially the same in the two treatments, 0.3 years and about 5 mm of radial growth. The times and distances to production of clear wood after pruning averaged slightly more than 3 years and about 23 mm of radial growth. Times and distances associated with intentional wounding of the branch collar were shorter, and were associated with shorter stub lengths (AW) for limbs pruned at the stem (damaged branch collars) rather than those pruned just beyond at the branch collar.

As discussed above, estimates of remaining branches on unpruned trees are probably conservative. Because the plantation in the branch collar wounding study was older, no trees had live branches (except for epicormic branches) below 3.3 m. All unpruned trees, however, still had dead branches in the 1.3 to 2.3 m bole section and higher, and a few had a branch in the lowest 0.3 to 1.3 m section. Times and distances required for formation of clear wood for those branches in unpruned trees that did die and break off were at least one year longer and 5 mm greater in distance than those required by pruned trees.

Other Factors that Influence "Healing" Variables

Correlations among all variables listed in table 2 were examined to determine which factors (other than date of pruning and branch collar wounding) might influence time and distance to formation of clear wood. Correlation coefficients for most variables that were significantly correlated with one or more healing variables are listed in tables 5a and 5b.

Only live branches were evaluated in the date of pruning study (table 5a), and the factors associated with *increased* time and distance to formation of clear wood (ABR and ABW) were branch diameter (increased lengths

Table 4a—Treatment means for "healing" variables Study 1—date of pruning. Means in a column followed by the same letter are not significantly different at p = 0.05.

Date	AR	AW	BR	BW	ABR	ABW
	yrs	mm	yrs	mm	yrs	mm
January 1	1.7a	14.5bc	0.9b	5.1b	2.6ab	19.6b
March 1	1.9a	15.2c	0.8b	2.4a	2.6b	17.6ab
May 1	1.4a	10.9a	0.5ab	2.6a	1.8a	13.5a
June 15	1.7a	11.0a	0.4a	2.9a	2.2ab	13.9a
September 15	1.8a	13.8abc	0.6ab	2.2a	2.4ab	16.0ab

Table 4b—Treatment means for "healing" variables (study 2). Means followed by the same letter are not significantly different at p = 0.05.

Treatment	AR	AW	BR	BW	ABR	ABW
	yrs	mm	yrs	mm	yrs	mm
Damaged	2.54a	17.0a	0.32a	4.9a	2.85a	21.9a
Undamaged	3.17b	20.2b	0.30a	4.8a	3.47b	24.8b

Table 5a—Correlation (r) of healing variables to other characteristics of stem cross sections (study 1-date of pruning). Based on 106 samples (all dates, live branches only): minimum r for statistical significance at p = 0.05 is 0.20.

Healing variable	Other characteristics				
	RIB	CAM	BRDIA	BRANG	RWAP
AW	-0.37	-0.44	0.36	0.28	0.10
AR	-0.43	-0.45	0.14	0.17	-0.05
BW	0.20	-0.02	0.22	0.11	0.25
BR	0.14	-0.02	0.42	0.18	-0.08
ABW	-0.25	-0.41	0.43	0.31	0.20
ABR	-0.29	-0.40	0.38	0.27	-0.08

Table 5b—Correlation (r) of healing variables to other selected characteristics of stem cross sections (study 2—branch collar wounding). Based on 88 samples (both treatments, dead branches only): minimum r for statistical significance p = 0.05 is 0.21.

Healing variable	Other characteristics		
	RIB	BRDIA	RWAP
AW	-0.13	0.15	0.25
AR	-0.03	0.32	-0.23
BW	0.24	0.33	-0.09
BR	-0.20	0.07	-0.25
ABW	0.05	0.33	0.15
ABR	-0.07	0.32	-0.31

of both stub [AW] and defect [BW] and time to grow over defect [BR]), branch angle (mainly increased stub length), and radial width after pruning (RWAP) (increased defect [BW]). Increased radius (RIB) and age (CAM) of the stem section at pruning were associated with *decreased* time and distance to formation of clear wood, primarily because stub lengths (AW) for stem sections having larger radii and greater numbers of rings were significantly shorter and fewer years were required to grow over them.

In contrast to table 5a which examines correlations between distances and times to clear wood production and other stem and branch traits after pruning *live* branches of trees in the 3-year-old plantation used for the date-of-pruning study, table 5b shows correlations among some of the same plus additional variables after *dead* branches were pruned from trees in the 6-year-old plantation used for the branch collar wounding study. Healing variables for dead branches were not correlated with cambial age (CAM) or branch angle (BRANG) as they were for live branches in the date-of-pruning study (table 5a). Neither were distance or time from branch death to pruning (DPDIS and DPRG) related to any of the healing variables. Stem radius at pruning (RIB) and defect (BW), however, were positively correlated. Larger diameter branches (BRDIA) had slightly (though not significant statistically) longer stubs (AW), greater defect (BW), took more years to grow over stub (AR), and resulted in longer times and distances to clear wood (ABR and ABW). Increased radial growth

Table 6—Epicormic branching in pruning studies compared with comparable unpruned trees of the same age.

	Study 1 (date of pruning)				Study 2 (branch collar wounding)			
	Stem section (ht (m) above ground)				Stem section (ht (m) above ground)			
	0.3 to 1.3	1.3 to 2.3	2.3 to 3.3	All heights	0.3 to 1.3	1.3 to 2.3	2.3 to 3.3	All heights to 3.3 m
Trees with 1 or more epicormic branches (%)								
Pruned	16.0	6.0	12.0	20.0	55.0	20.0	25.0	65.0
Unpruned	9.1	17.3	36.4	54.5	60.0	40.0	30.0	90.0
Mean number of epicormic branches per tree (number) all trees								
Pruned	0.20	0.10	0.24	0.60	1.45	0.20	0.40	2.05
Unpruned	0.18	0.36	0.82	1.36	1.20	0.90	0.40	2.50
Mean diameter of epicormic branches (mm)								
Pruned				2.5				2.3
Unpruned				3.3				2.1

after pruning (RWAP) was associated with decreased time to grow over stubs (AR), any defect (BR), and produce clear wood (ABR). Although RWAP was also significantly correlated with increased stub length (AW), no reasons for this relationship are apparent.

Epicormic Branching (Both Studies)

Epicormic branching was minimal in the two pruning studies. Averaged over all pruned trees, there was less than one epicormic branch per tree in the date of pruning study and only two branches per tree in the branch collar wounding study (table 6). The branches averaged only 2-3 mm in diameter at 6-7 years after pruning. Moreover, such epicormic branching as did occur could not be attributed to pruning because an examination of 10 comparable unpruned trees near each study revealed that incidence of epicormic branching was equal to or greater than in their pruned counterparts. The percentage of trees with epicormic branches and the number of branches per tree tended to be greater for the lowest (0.3-1.3 m) stem section than for the two higher stem sections (table 6); and only in this lower section was epicormic branching sometimes greater for pruned than for unpruned trees.

Discussion and Conclusions

That vigorous red alder saplings can heal over and produce clear wood after only 2 to 3 years and about 25 to 40 mm (or about 1 to 1.5 inches) of *diameter* growth following pruning (fig. 3) is good news for forest owners and managers who may wish to accelerate the production of clear wood on relatively short rotations. Berntsen's (1961) earlier work on alder trees that were pruned at age 21 also indicated that *some* pruning stubs were grown over in two years but there was no indication as to the proportion of wounds that healed over in that time. In our study, clear wood was being laid down over about 60% of the pruning wounds within two years, and nearly 80% of the wounds within 3 years.

Our date-of-pruning trial identified differences among pruning dates that were significant statistically, but managers will want to consider whether a difference of 0. 8 years or 6 mm in time and radial distance is sufficient to warrant scheduling of operations to coincide with the *best* times for pruning. Certainly it would not if one had to postpone pruning operations until the next year to do it at the optimal time. Nevertheless, the finding that early to mid-growing season is, in fact, the most effective time for rapid healing is fortunate from the standpoint of operational planning because many other silvicultural activities such as planting and fertilizing usually must be scheduled before or after the growing season. Although no other research on date of pruning has been done for red alder, our results are generally consistent with findings for eastern hardwoods. Neely (1970), for example, found that spring (May) wounds healed much more rapidly than wounds created in summer (July), fall (October), or winter (March) for ash, honey locust, and pin oak. Although McQuilkin (1950) recommended pruning eastern hardwoods (except red maple) in late winter and early spring to achieve fastest wound occlusion, he favored pruning red maple in late spring or early summer to reduce excessive bleeding. Leban (1985) concluded that spring wounding of red maple led to less dieback around the wound and less decay than fall wounding. Colder than normal temperatures at time of the January pruning in our study may have been responsible for greater tissue damage and defect (BW or rot plus bark) in January than occurred for other pruning dates (decay associated with this pruning date, however, was low).

Figure 3—Stem section from tree pruned as part of the branch collar wounding study. Clear wood was produced after only 2 years following pruning.

Our study of branch collar wounding indicated that it is unnecessary to avoid wounds of the branch collar (i.e., as in a "Shigo cut") when pruning dead branches of red alder. Healing times and distances to clear wood were, in fact, slightly shorter when branch collars were intentionally wounded. Most pruning studies with other hardwood species have involved removal of live branches, and it has been recommended that branch collars should not be damaged when live branches are pruned (cf., Shigo 1986). Shigo et al. (1979), working with black walnut, recommend against injuring the branch collar even when pruning dead branches because it may increase the amount of decay spreading inward (and upward and downward) from the dead branch. Ring shakes and dark vertical streaks also were associated with injured branch collars (flush cuts) in the black walnut trees. We saw little evidence of such development of decay (or shake and discolorization) in red alder, however. And years ago, Berntsen (1961) also reported that "decay rarely extended beyond the extremities of knots." Recent work has determined that living red alder is very efficient in its ability to compartmentalize decay, and most decay events do not extend beyond the injured tissue (Allen 1993, Harrington et al. 1994).

Our examination of the healing over of broken branches in unpruned trees indicated that times and distances to clear wood were substantially greater than those associated with pruning of either live or dead branches. Such data obviously applies only to the period after the branch has died and has broken off; if one adds the period prior to such events to that recorded in our comparison, one is probably looking at differences of 5 or more years to produce clear wood in the lower 3 m of stem of unpruned trees. Thus, the decision *to prune or not prune* is of much greater practical importance than that of when to prune live branches or how to prune dead ones.

Examination of correlation coefficients served mainly to underscore some logical relationships between stem and branch traits and healing. Times and distances to clear wood were longer as branch diameter and branch angle increased. Healing times and distances for trees in the 3-year-old plantation were shorter, however, for stem sections of greater cambial age and larger diameter (radius). Apparently it was easier to make close prunes (shorter AW) on larger rather than smaller stems. We suspect this finding was associated with use of clippers to prune branches on some of the smaller trees that lacked sufficient rigidity for use of the saw; the relationship did not occur in the larger trees in the 6-year-old plantation pruned in the branch collar study, all of which were pruned by saw. Correlation coefficients for the date of pruning study suggested that increased growth rate after pruning was associated with greater defect (BW). Such a trend seems counter-intuitive and may be associated with some peculiarity or confounding relationship in our sample, and it was not apparent in the branch collar wounding study. The correlation in the latter study of increased radial growth rates with decreased time to grow over the stub, defect, and produce clear wood, however, is what one would expect.

Epicormic branching does not appear to be a problem when young, vigorous red alder trees are pruned. More than half of the pruned trees had no epicormic branches; those that did averaged fewer than two epicormic branches per tree and these were small, averaging only 2.4 mm in diameter. Moreover, such epicormic branching as did occur was just as prevalent or more so in unpruned trees in the same plantation. Only in the lowest section of the bole (0.3 to 1.3 m) did the incidence of epicormic branching average slightly higher in pruned than unpruned trees. The tendency toward increased sprouting in the lowest section of both pruned and unpruned trees in the branch collar damage study (6-year-old plantation) may result from decreased apical control at greater distances from the terminal, and the much greater distance from the live crown in pruned than in unpruned trees may account for the slightly greater epicormic branching at this level in pruned trees.

Why do our findings and interpretations with respect to epicormic branches differ so greatly from those of Bernsten (1961)? We believe at least two factors may contribute: (1) general vigor, and (2) other changes in the stand environment. Trees in Berntsen's study were undoubtedly less vigorous; they were 21 years old and growing in natural stands when pruned whereas ours were growing in 3- and 6-year-old plantations. Red alder grows very rapidly in height during the first two decades, especially so in the first 10 years (Harrington and Curtis 1986). Beyond that time height growth is markedly reduced, and some studies have shown that response of natural alder stands to an initial thinning at older ages is much reduced and sometimes negligible (Berntsen 1962, Warrack 1964). In addition, tree crowns begin to lose their conical form at about the same time, indicating that apical control is diminishing. Skillings' (1958) research on defects and healing following pruning in northern hardwoods is consistent with our suggestion that tree vigor plays a role; he found epicormic branching to be substantial in lower crown classes, but limited in dominant and codominant trees. In another study (Skilling 1959) on yellow birch (a relative of red alder), only dominant and codominant trees were pruned; epicormic branching was slight and branches short-lived, and "for all practical purposes could be disregarded." Secondly, other information indicates that the pruned trees examined by Berntsen (1961) came from a stand that was not only pruned, but also had been released from overtopping conifers and thinned at the same time (Rapraeger 1949, Berntsen 1962). If so, the epicormic branching may have been a response to sudden opening of the stand by release and thinning as well as pruning, and perhaps was particularly stimulated by the combination of these treatments at a stand age (21 years) when growth (particularly height growth) is normally decreasing. Other studies have indicated that epicormic branching can increase when red alder stands are thinned, and such observations were made primarily in stands thinned beyond age 15 (Warrack 1964, Smith 1978). Some epicormic branching may occur even when younger stands are thinned, however (Hibbs et al. 1989). In another pruning trial established in a 10-year-old plantation, trees at the edge of the stand or near openings had greater numbers of epicormic branches than trees in fully-stocked portions of the stand (Brodie and Harrington 2006). Given these observations, we suggest that epicormic branching is unlikely to be a problem when pruning is done on interior trees early in the life of alder plantations—i.e., when height growth is in its most rapid phase (before age 15)—and at least a year or so after (or before) any significant thinning of the stand. There may be logistical as well as biological reasons to schedule thinning and pruning operations in different years.

Trees in our study were pruned by removal of about one-third of the live crown (retaining crown ratios of 50% or more) and no top breakage occurred. Pruning 50% or more of the total height on young trees, however, may greatly increase the chances that high winds will snap off the top during the first growing season or so after pruning. Such damage has been observed when operational plantations were pruned to that degree. Although not a problem in these trials, there is some anecdotal evidence that pruning can increase the attractiveness of the bole to sapsuckers (possibly because increased sugar content at base of now raised live crown).

Based on this work and that reported in Brodie and Harrington (2006), there seem to be no major biological concerns about pruning live and dead branches in the lower one-third of crowns of young red alder. Pruning can be done at anytime of the year (even during the growing season; if anything, preferably so) and without particular concern about damage to branch collars. On average, clear wood will be produced in fewer than 3 years and less than 40 mm (1.5 inches) of diameter growth after pruning. Decisions on whether or not to prune must be based on price differentials for clear versus knotty wood and the costs of investments in pruning. Currently available data on tree growth, log volume, and lumber recovery can be used to evaluate the economic benefits (or lack thereof) of pruning stands of various ages on sites of different quality, and harvested at a range of ages.

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