# 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.

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

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.

# 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

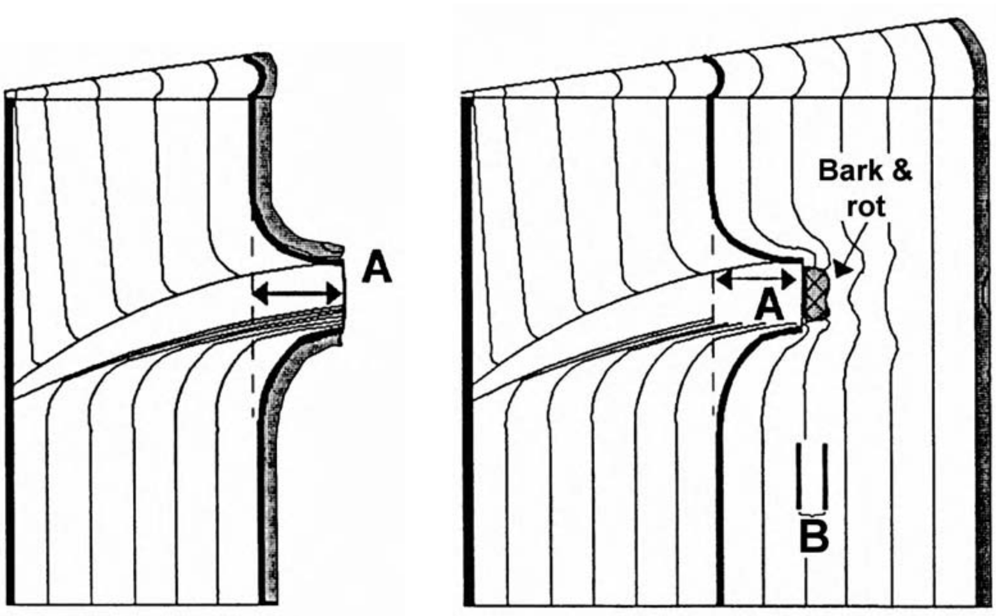

Figure 2—Diagrammatic stem sections showing branch stub immediately after pruning and 6 years later. Healing (occlusion) region is separated into stub length (Zone A) and region beyond the stub where defects may occur (Zone B). Adapted from Petruncio et al. (1997).

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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# On the Effects of Tree Crop Rotation: Red Alder Following Alder or Douglas-fir; Douglas-fir Following Fir or Alder

Mariano M. Amoroso[1] and Eric C. Turnblom[2]

## Abstract

Red alder (*Alnus rubra* Bong.) has been proposed for use in crop rotation due its ability to symbiotically fix atmospheric nitrogen. The ability of this species for increasing nutrient status and ameliorating site deficiencies have been recognized, however whether this will have an effect on a subsequent "crop" or if it can be used in a crop rotation scheme remains unknown. A Douglas-fir – red alder conversion study established in 1984 may shed light on some of these issues. Results 20 years after establishment showed that the previous presence of red alder resulted in an overall increased productivity of the site compared to the adjacent Douglas-fir site.

Keywords: crop rotation, Douglas-fir, red alder, Washington State

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# Introduction

Crop rotation is the alternation of different crops in the same field in some regular sequence. It differs from the haphazard change of crops from time to time, in that a deliberately chosen set of crops is grown in succession in cycles over a period of years; the crop sequence is not randomly chosen either, but is intentionally selected with a specific objective. This technique appeared primarily as a solution to the decline in crop yields resulting from having the same crop continuously grown in the same place. The practice of crop rotation has been widely accepted and successfully applied in the field of the agriculture. There are both direct and indirect benefits from rotational practices. Among them are pest control, maintenance of organic matter and soil nitrogen, protection and complete use of soil, balanced used of plant nutrients, economy of labor, and risk reduction. However, the effectiveness of rotating crops will ultimately depend on the type of crops and crop rotation timing.

When it comes to forestry, "rotation" is recognized as a guide for the economic age to which each stand can be grown before it is succeeded by the next one. It is also a more complex but flexible concept since rotation could also be understood in ecological terms. In practice the rotation time is set by two principles, the physical and the financial rotation, since one can almost never be considered without the other (Smith et al. 1997). In either case the goal is to maximize or optimize the long-term sustained yields and capital return respectively. Nevertheless, forestry faces some of the same issues as agriculture and sometimes silvicultural practices are needed for pest control, maintenance of adequate levels of organic matter and nitrogen in the soils, as well as soil protection. Additionally, and even though it has not been practically demonstrated, the repeated cultivation of same forest stands in some sites could possible result in yield declines.

The concept of crop rotation has not been applied to forestry for practical reasons such as rotation lengths, lack of a variety in crops as well as the fact that forestry is a younger discipline compared to agriculture. The unmodified application of this agriculture concept in forestry will not be that simple for managerial, biological and economical reasons; however, there might be situations, such as in the case of short rotations of fast growing species, where it could be feasible. Other cases could also include situations where some kind of immediate site amelioration is needed, or where the presence of a particular species in the previous crop will result in an improvement of the site quality and thus an increase in the yield of the future species.

Red alder (*Alnus rubra* Bong.) has been proposed for use in both crop rotation and in mixtures with other species (Tarrant and Trappe 1971, Atkinson et al. 1979, DeBell 1979). Due to its ability to symbiotically fix atmospheric nitrogen, this species can increase levels of nitrogen and organic matter to a site (Tarrant and Miller 1963, Trappe et al. 1968, Harrington 1990), and has been experimentally planted to serve as a nitrogen source for other species (Briggs et al. 1978), as an alternative to N fertilization in N-stressed forests, and on other eroded or low fertility areas (Tarrant and Trappe 1971, Heilman 1979). Additionally, it could be used in a crop rotation system or as an alternative in areas containing coniferous root pathogens, such as *Phellinus weiri* (Hansen 1979, Harrington 1990) or Swiss needle cast. The ability of this species for increasing nutrient status and ameliorating site deficiencies have been recognized (Harrington 1990) and some attempts were made simulating different rotation schemes (Atkinson et al. 1979); however, whether this will have an effect on a subsequent "crop" or whether it can be use in a crop rotation scheme remains unknown.

A unique semi-natural experiment was established in 1984 at the so-called "Thompson Site" on the Cedar River Watershed, WA in which two adjacent stands were clear-cut harvested in the same year, one predominantly Douglas-fir (*Pseudotsuga menziesii*, Mirb. Franco), the other predominantly red alder. Each of the stands were divided in two and then replanted to red alder and Douglas-fir respectively; representing alder plantations following both an alder and a fir stand, and v*ice versa*. The goal of this study was to determine the effect of red alder soil nutrient status (leaching vs. mineralization and nitrification rates) on soil fertility, as well as on the growth of subsequent forest rotations (Van Miegroet et al. 1990, 1992). The authors concluded that even though the presence of red alder generally improves the N fertility of the site, the experiment was not able to demonstrate, after 4 years, an improvement in growth (based on height measurements only) of the seedlings planted on sites previously occupied by alder over those planted after Douglas-fir cover (Van Miegroet et al. 1990). Another finding of the study was a decrease in soil and solution pH in the upper soil horizon. The authors hypothesized a phosphorus deficiency and later, two different levels of phosphorus fertilization were applied as well as one level of nitrogen fertilization. No further aboveground analyses of this study were conducted since then. Based on the potential of this alternative on some areas, we decided to investigate the outcomes twenty years after study establishment with the following objectives:

- Whether the presence of red alder improves site fertility and thus growth and productivity of subsequent rotations, or whether it may have a negative impact.
- Whether there are any differences in succeeding species in relationship to this potential growth change.
- Whether the supplementation with N and P may have an effect on productivity.

# Methodology

## Site characteristics

The study was conducted at the Thompson Research Center (aka "Thompson Site") at the Cedar River Watershed, King County, WA. The site has a mean annual temperature of 49.6°F and a mean annual precipitation of 51.2 inches. Two adjacent stands originating after fire in the 1930s were clear-cut harvested in 1984, one predominantly Douglas-fir (*Pseudotsuga menziesii*, Mirb. Franco), the other predominantly red alder (*Alnus rubra* Bong.). At the time of harvesting the stands presented the following characteristics: the Douglas-fir stand had approximately 445 stems per acre (SPA) and 218 $ft^2$ per acre of basal area with a Douglas-fir site index of 106 ft at 50 years breast height age (site class III); the red alder stand was about 324 stems per acre and 156 $ft^2$ per acre of basal area with a Douglas-fir site index of 111 feet at 50 yr breast height age (site class III). Both stands were around 50 years old.

## Experimental design

The study consists of a Split-split Plot Design. In each of the original stands an area of 2.5 acres was cut, divided in two, and replanted in 1985 with 500 SPA to red alder and Douglas-fir respectively; this representing red alder plantations following both an alder and a fir stand, and v*ice versa*. Eight tenth-acre experimental plots were set in each replanted area adding up to a total of 32 plots. Later on, in an effort to assess the effects of additional site amelioration, between two and four of the eight plots in each new plantation were fertilized as follows: i) 180 pounds/acre N as urea at 8 years where Douglas-fir was planted; and ii) 180 and 360 pounds/acre of P at 7 years where red alder was planted. After the fertilization treatments were applied, treatment descriptions resulted as follows:

1. FF C: Cut DF stand, plant 1-1 DF, control (no fertilization)
2. FF N: Cut DF stand, plant 1-1 DF, fertilize 180 pounds/acre N
3. FA C: Cut DF stand, plant RA wildings
4. FA P360: Cut DF stand, plant RA wildings, fertilize 360 pounds/acre P
5. FA P180: Cut DF stand, plant RA wildings, fertilize 180 pounds/acre P
6. AA C: Cut RA stand, plant RA wildings
7. AA P360: Cut RA stand, plant RA wildings, fertilize 360 pounds/acre P
8. AA P180: Cut RA stand, plant RA wildings, fertilize 180 pounds/acre P
9. AF C: Cut RA stand, plant 1-1 DF
10. AF N: Cut RA stand, plant 1-1 DF, fertilize 180 pounds/acre N

We decided to include only the higher level of phosphorus fertilization in this analysis (RA plots with 180 pounds/acre P were not considered).

## Analysis

Data were analyzed as a linear repeated measures experiment with two factors, treatment and time. The treatment factor consisted in the combinations of rotation pattern and fertilization (8 levels), and the time factor in three times post establishment (5, 10 and 20 years). For purposes of the analysis, each of the eight plots representing a rotation pattern were considered as replicates. The authors recognize that in fact, the plots are not strictly independent. So, results obtained from hypothesis testing are likely to have larger p-values in reality than would first appear.

The model describing both fertilization and time is presented as follow:

$$y_{ijk} = \mu + t_i + h_{k(i)} + q_j + tq_{ij} + e_{ijk} \qquad (1)$$

where:

$y_{ijk}$ = (QMD, Volume, Height) for rotation / fertilization combination i, time j, replicate k

$\mu$ = overall average response

$t_i$ = the fixed effect of the i-th rotation/fertilization level

$h_{k(i)}$ = the error accounting for variation between plots

$q_j$ = the effect of time period j

$tq_{ij}$ = time by treatment interaction

$e_{ijk}$ = the leftover error not accounted for by time or treatment

Attempts were made to add covariates to the model to account for uncontrolled factors, especially density, but the results showed the variables not to be significant. A strong interaction was apparently occurring for "FA C" and "FA P" treatments with time. This was resolved with covariance adjustments in the 3rd. measurement when historical records revealed storm damage in those plots. Statistical differences among treatments were tested by using orthogonal contrasts (0.1 level); tables for comparisons between treatments are presented in what follows.

It is important to note before presenting the results that the domain of the study may limit the scope or range of conditions to which results apply (one soil type, location, etc.) It is important to note that some of the plots have suffered physical damage by weather and other abiotic agents, so the results must be interpreted in light of this knowledge.

**Table 1—Contrast results for Quadratic Mean Diameter at ages 5, 10 and 20.**

| Contrast | Age = 5 | Age = 10 | Age = 20 |
|---|---|---|---|
| **ALDER SITE VS. FIR SITE** | **SIGNIF.** | **SIGNIF.** | **SIGNIF.** |
| FFC vs. AFC | NS | SIGNIF. | SIGNIF. |
| FFC vs. FFN | NS | NS | SIGNIF. |
| AFC vs. AFN | NS | NS | NS |
| FAC vs. AAC | NS | NS | SIGNIF. |
| AAC vs. AAP | NS | NS | NS |
| FAC vs. FAP | NS | NS | NS |
| FAP vs. AAP | NS | NS | SIGNIF. |

# Results

## Diameter growth

Both DF and RA exhibited significantly greater QMD in the control plots growing after RA compared to DF (fig. 1). For DF these differences in growth resulted to be significant at age 10 (table 1). From the same figure it can be seen what happened with red alder through time. At age 5 RA growing after DF had a greater QMD compared to the FA rotation. However, 15 years later it seems that initial difference no longer remains and has turned slightly in favor of the AA rotation. Interesting also is the effect RA has on both species growth patterns. When growing after DF, RA resulted in a greater QMD than DF after 20 years. However, growing after RA and despite the initial differences, DF resulted in a larger diameter. Interesting was also the fact that at initial ages alder trees growing after alder presented a smaller QMD compared to those growing after DF. Even though a toxicity effect was initially hypothesized, Van Miegroet et al. (1990) concluded that such response could have been a consequence of competition with a more intense understory vegetation development in the N-richer site.

The fertilization treatments also showed some interesting results (figs. 2 A, B). Nitrogen fertilization resulted in a growth increment only when DF grew after DF. The addition of phosphorus on the RA plots seems to have a small effect in the AA plots resulting in greater QMD although differences were not significant (table 1).

## Height growth

Height growth of DF and RA appears to be enhanced if RA is the previous crop (fig. 3). In addition to this, fig. 3 shows the higher initial growth of RA compared to DF as it has been reported in the literature but also that the stand dynamics is reaching the time where attained heights of RA and DF are just about to reverse as a consequence of RA height growth slowing down.

**Table 2—Contrast results for Mean Total Height at ages 5, 10 and 20.**

| Contrast | Age = 5 | Age = 10 | Age = 20 |
|---|---|---|---|
| **ALDER SITE VS. FIR SITE** | **NS.** | **NS** | **SIGNIF.** |
| FFC vs. AFC | NS | SIGNIF. | SIGNIF. |
| FFC vs. FFN | NS | NS | NS |
| AFC vs. AFN | NS | NS | NS |
| FAC vs. AAC | NS | NS | SIGNIF. |
| AAC vs. AAP | NS | NS | NS |
| FAC vs. FAP | NS | NS | SIGNIF |
| FAP vs. AAP | NS | NS | SIGNIF. |

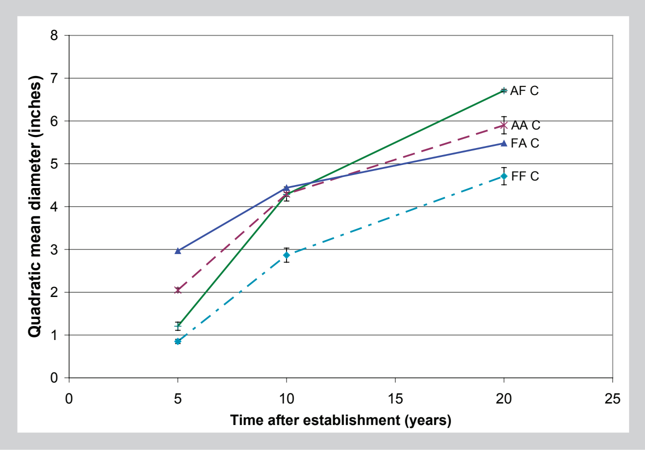

Figure 1—Quadratic mean diameter at 5, 10 and 20 years after establishment. Vertical bars represent standard errors.

The addition of fertilizers had also some influences on the height growth of both species. While nitrogen fertilization resulted in no added increment for DF, phosphorus increased the total height of RA growing after both RA and DF (figs. 4 A, B). It can be seen again that DF growing after RA resulted in taller trees but no differences where found between the control and the fertilization treatment (table 2). In the RA plots the addition of P may result in slightly taller trees. It is interesting that RA height growth slowed down sooner where RA was planted after DF.

## Volume

The presence of RA in a rotation scheme increased the total volume per acre in the DF control plots compared to the FF rotation (fig. 5). After 20 years DF growing after RA doubled the volume per acre of DF after DF. This result parallels those found for diameter and height. No significant differences were found for RA following RA or DF.

Even though some trends can be seen and differences are expected to become significant with time (figs. 6 A, B), the fertilization treatments resulted in no significant effects (table 3).

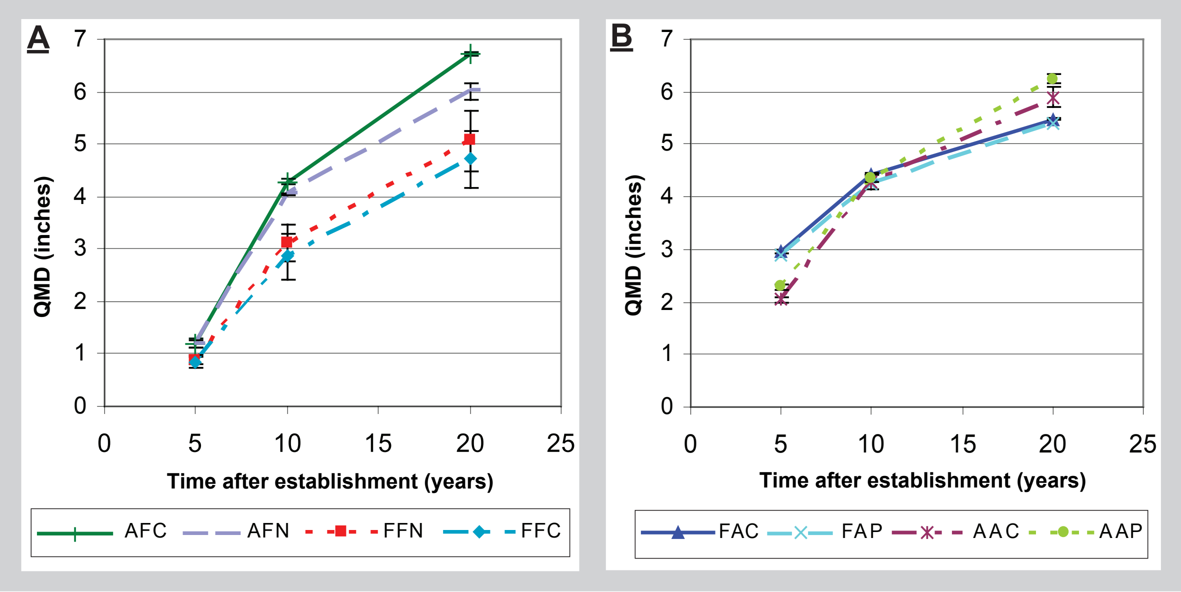

Figure 2—Quadratic mean giameter for Douglas-fir (A) and red alder (B) after 5, 10 and 20 years of establishment. Vertical bars represent standard errors.

**Table 3—Contrast results for Volume per Acre at ages 5, 10 and 20.**

| Contrast | Age = 5 | Age = 10 | Age = 20 |
|---|---|---|---|
| **ALDER SITE VS. FIR SITE** | **NS** | **NS** | **SIGNIF.** |
| FFC vs. AFC | NS | NS | SIGNIF. |
| FFC vs. FFN | NS | NS | NS |
| AFC vs. AFN | NS | NS | NS |
| FAC vs. AAC | NS | NS | NS |
| AAC vs. AAP | NS | NS | NS |
| FAC vs. FAP | NS | NS | NS |
| FAP vs. AAP | NS | NS | NS |

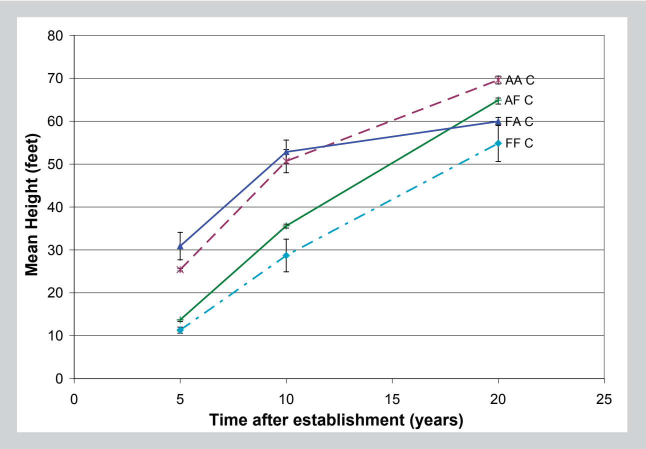

Figure 3—Mean total height at 5, 10 and 20 years after establishment. Vertical bars represent standard errors.

# Conclusions

Results 20 years after establishment show that the presence of red alder resulted in an overall increased productivity of the site compared to the adjacent Douglas-fir site (table 3). The Douglas-fir plantation established after a red alder stand not only exhibited the greatest productivity measured as volume per acre but also doubled that of Douglas-fir growing after a Douglas-fir stand.

In a red alder – red alder rotation scheme growth is enhanced after an initial decline. However, without site amelioration red alder plantations following Douglas-fir yield almost as much as alder following alder.

Results for the fertilization treatment showed that N fertilization in a red alder – Douglas-fir rotation scheme may not result in growth benefit, furthermore it might be detrimental. P fertilization, on the other hand, may be beneficial if the level of nitrogen is not limiting. These results follow what is known as “the law of the limiting factor” that states that the addition of a nutrient will only result in increments when all the rest of growth limiting factors (other nutrients in this case) are not limiting. Fertilization on sites that may have been already enriched by the presence of red alder will not result in any extra growth since nitrogen is no longer the limiting growth factor. The addition of phosphorus on the other hand, could have positive consequences in these situations.

The results presented here only reflect the biological aspect of a crop rotation scheme and the different response to the fertilization treatments. Since no economical analyses are presented and the practice of forest fertilization usually involves a significant capital investment, implementation of fertilization programs should also be evaluated by cost-benefit or other appropriate analyses.

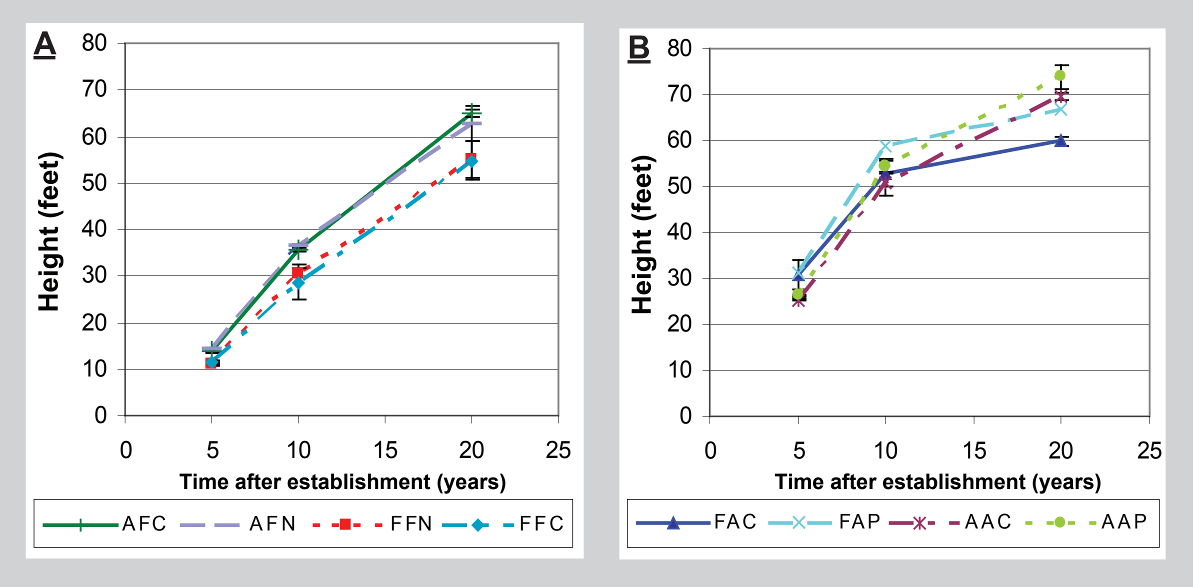

Figure 4—Mean total height for Douglas-fir (A) and red alder (B) after 5, 10 and 20 years of establishment. Vertical bars represent standard errors.

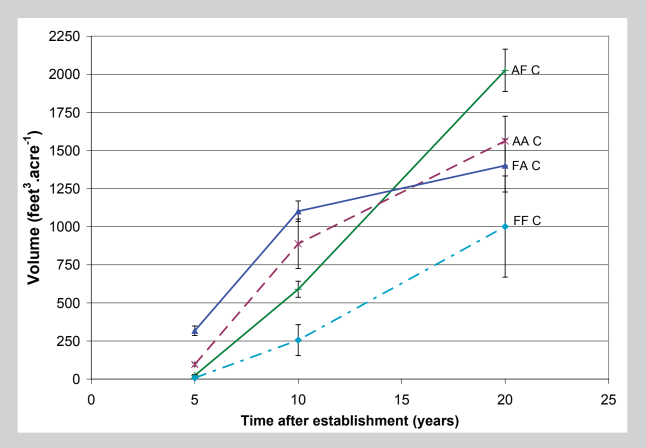

Figure 5—Mean volume per acre at 5, 10 and 20 years after establishment. Vertical bars represent standard errors.

Some comments need to be made again with respect to the results of this study. The domain of this study may limit the scope or range of conditions to which results apply. For this reason results should be understood carefully since the outcomes can be strongly influenced by site quality. Further, N-fixation rates for red alder have been reported to vary significantly from site to site and this will undoubtedly affect the outcomes in other situations.

## Acknowledgments

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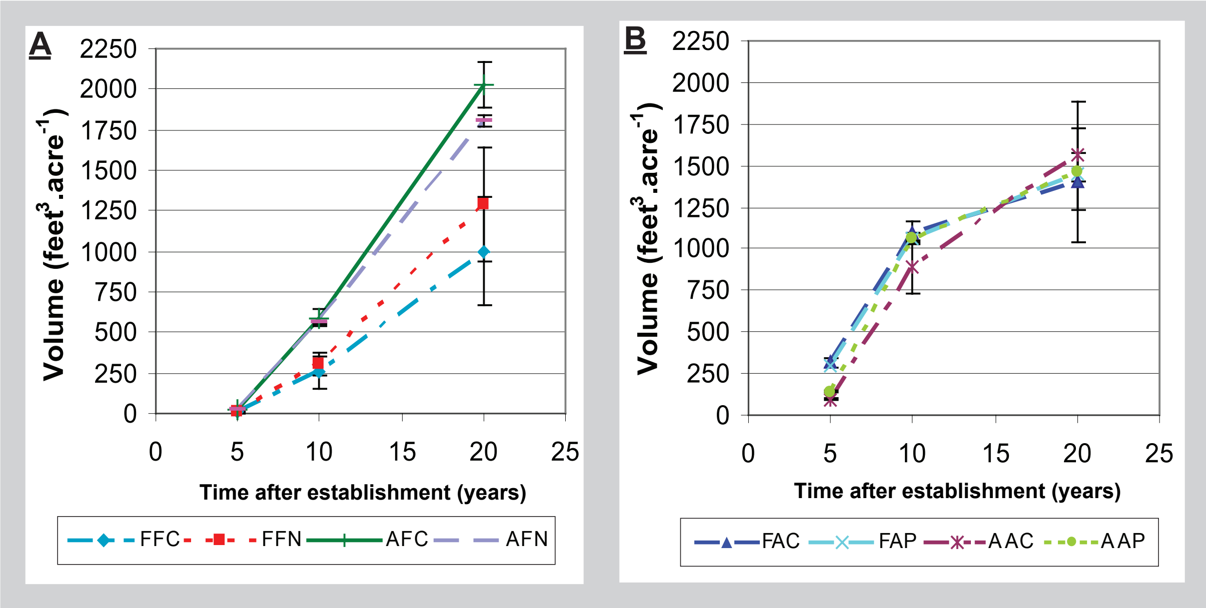

Figure 6—Mean volume per acre for Douglas-fir (A) and red alder (B) respectively after 5, 10 and 20 years of establishment. Vertical bars represent standard errors.

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# Economics

## (Supply / Markets / Returns)

### — Red Alder: A State of Knowledge —

# Overview of Supply, Availability, and Regulatory Factors Affecting Red Alder in the Pacific Northwest

Glenn R. Ahrens[1]

## Abstract

The inventory of red alder timber in the Pacific Northwest is about 265 million cubic meters (30.5 billion board feet), however much of this is not available due to economic, policy, or regulatory factors. Of the total annual harvest of 4.64 million cubic meters (~598 million board feet), 87% comes from private lands in Washington (64%) and Oregon (23%). The remainder comes from other lands in Washington and Oregon (5%), British Columbia (6%), and California (2%).

The current supply of alder is a legacy of past practices, which increased the alder component during most of the 1900s. Modern forest practices generally reduce the alder component. Regulations protecting riparian zones, unstable slopes, and wildlife habitat reduce the availability of alder timber. Declines in abundance of alder are becoming apparent and the rates of removal of alder in the 1990s do not appear sustainable. Knowledge of and management for alder are increasing however, and there is much potential for foresters to maintain or increase alder. The supply of alder in the future depends on the uncertain balance of these positive and negative factors.

Keywords: red alder, timber supply, availability, management, regulatory factors.

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# Introduction

As the value and utilization of red alder have increased in the Pacific Northwest, so too have concerns about sustaining supplies of red alder timber. A previous assessment of hardwood supply in the Pacific Northwest (Raettig et al. 1995) concluded that short-term supply was favorable, but there was cause for concern about long-term supply due to lack of management for hardwoods. Since 1995, harvest volumes of red alder have declined and shortage of alder logs has been cited as a major factor limiting lumber production and sales (Washington Hardwoods Commission). Increasing prices for red alder sawlogs are also consistent with declining alder timber supply (fig. 1.) The last assessment of hardwood supply in the region was based on USFS forest inventory data for Oregon (federal lands 1976, non-federal lands 1986, 1987) and Washington (1991), with no information from other states or British Columbia (BC). Updated information on timber inventory across the range of alder is now available and it is important to revisit the question of alder supply for the International Symposium, Red Alder: A State of Knowledge (March 23-25, 2005, University of Washington, Seattle).

This paper provides an overview of red alder timber supply and the major factors affecting the alder resource across the geographic range of the species. The purpose is to revisit the key trends identified in the 1995 analysis (Raettig et al.) and provide an updated assessment of the red alder resource, including:

- Timber inventory, growth, and removal;
- Forest management practices and regulations, and
- Sustainable supplies in the future.

# Timber Inventory

The total inventory of about 265 million cubic meters (30.5 billion board feet Scribner) of red alder is well-distributed across Washington (36%), BC (35%), and Oregon (27%), with small amounts in California (3%) and Alaska (1%) (fig. 2). These inventory volumes indicate the relative abundance of red alder across its range and should not be confused with actual timber supply.

Note that the relatively large inventory estimate for red alder in BC (91.9 million m$^3$) is for all stand types in the coast region (Canadian National Forest Inventory System 2001). Previously published estimates of the alder inventory in BC of about 33 million m$^3$ (Massie 1996) were based only on the amount of alder in stands where alder was the most abundant species (leading species). For comparison, an updated estimate for the amount of alder in stands where alder is the leading species in coastal BC is 29.7 million m$^3$ (Canadian National Forest Inventory System 2001).

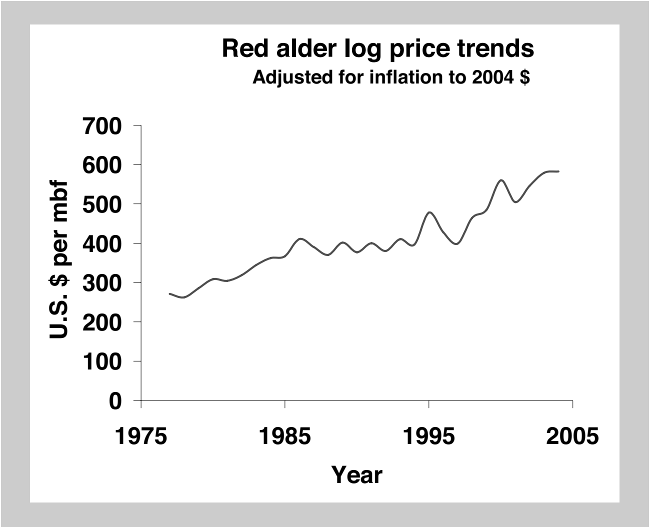

Figure 1—Price trends for red alder sawlogs (8-inch and larger at small end) for northwest Oregon and southwest Washington. Prices represent delivered log prices per 1000 board feet Scribner log scale. Source: Oregon Department of Forestry quarterly log price reports.

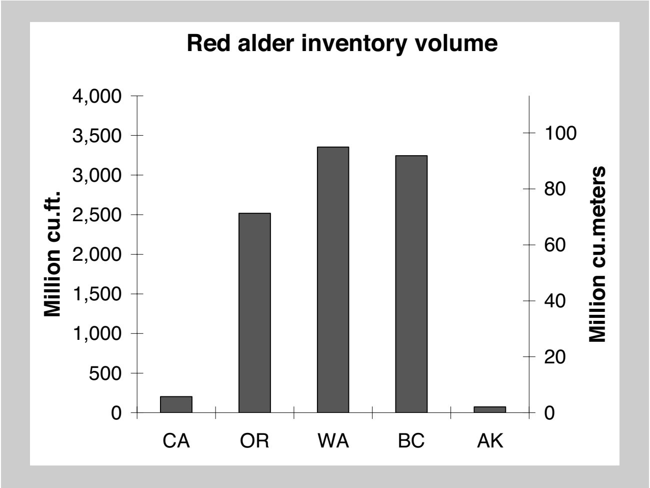

Figure 2—Timber inventory volume to a 10-cm top (4-inch) of red alder across its range in California (CA 1995 inventory - Waddell et al. 1996), Oregon (OR 1997 inventory – Azuma et al. 2002), Washington (WA 2001 inventory – Gray et al. 2005), BC (BC 2000 inventory – Canadian National Forest Inventory System 2001), and Alaska (AK 2000 inventory – van Hees 2003). Inventory for federal lands in Washington and Oregon: HIserote and Waddell 2004.

# Timber harvest and removal

The actual supply of alder for industrial utilization depends on the portion of the timber inventory that is made available for harvest. This is influenced by many factors including landowner goals, policies, regulations, local resource quantity and quality, access, logging costs, transportation costs, etc. Recent volumes of alder removal are used below to provide an indication of available alder wood volumes from forests across the range of alder (fig. 3). Removals include some wood volume that may not be utilized. Consistent estimates of removal volumes are

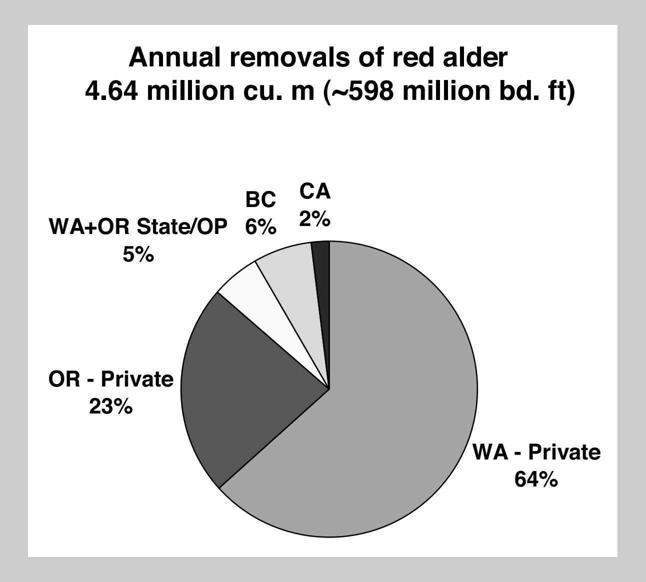

Figure 3—Annual removals for red alder showing the relative proportion of the total removals provided by selected states and ownerships. Data sources for the U.S. as in Figure 1. Figures for BC are harvest volumes reported by the BC Harvest Billing System for 1998-2000, with board-foot volume computed using the average ratio of board-foot : cubic foot volume removals reported for alder in the U.S. (3.65 bf/cf).

provided by inventory reports for all U.S. states. For BC, actual harvest volumes were used.

Annual removals of red alder totaled about 4.64 million $m^3$ (598 million board feet Scribner scale) across the range of the species (fig. 3). About 87% of the alder removals were provided by private lands in Washington (64%) and Oregon (23%). Non-federal public forests in Washington and Oregon (primarily State-owned) provide about 5 percent of total removals, which is relatively small in proportion to the share of the alder resource in State ownership (14%). Removals of alder from federal forests in Washington and Oregon amount to less than 1% of the total and are not shown.

Annual harvest volumes of alder in coastal BC amount to about 6% of total alder removals, which is small in proportion to the amount of alder in BC (35% of the total inventory). Removals of alder in northern California amount to about 2% of the total, similar to the state's share of the inventory (2.5%). Alder is being harvested and utilized in Northern California, particularly from Industrial Private lands. No estimates of harvest or removals of alder in Alaska were found. With less than 1% of the total alder resource, potential harvest and utilization of alder from Alaska could be locally important but it would amount to less than 1 % of the total alder harvest.

Washington and Oregon are the major sources of alder supply, accounting for over 90% of the harvest. Total inventory of alder in California and Alaska are too low to have a major impact on the overall supply of alder. While there may be potential to increase supplies of alder from BC forests, current plans for timber supply areas and tree farm licenses in BC do not indicate substantial increases in harvest of alder in the future (BC Ministry of Forests 1999-2004. H. Reveley, pers. Comm, BC Ministry of Forests, Defined Forest Area Management, Coastal Region.).

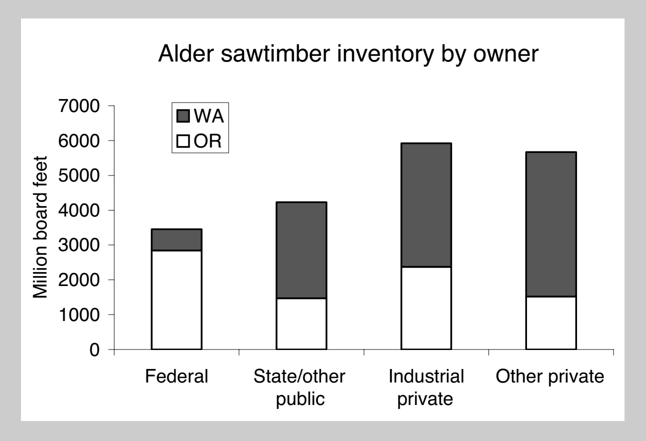

Figure 4—Inventory of red alder sawtimber (million board feet Scribner scale) across major land ownerships in Washington (2001 - Gray et al. 2005) and Oregon (1997 - Azuma et al. 2002).

Therefore, discussion of resource trends affecting alder supply will focus on Washington and Oregon. Within these two states, a further breakdown of the alder inventory shows that private owners have 60% of the resource, about evenly divided between industrial and non-industrial (small woodlands or family forestlands) ownership (fig. 4). Between the two states, Washington has about 2 times as much alder as Oregon.

## Forest resource trends

The current supply of alder is a legacy of past management practices, which increased the component of alder and other hardwoods in the Pacific Northwest (fig. 5). During most of the 1900's, growth and inventory of hardwoods increased, while rates of removal and utilization were low (Raettig et al. 1995, Figure 17, p. 42). Since the 1970's, however, removals of alder have increased while forest management to favor conifers has become increasingly effective. This is expected to reduce both the abundance of hardwood-dominated forest and the proportion of hardwoods in conifer-hardwood mixtures. The increase in abundance of hardwoods seems to have stopped in the 1990s (fig. 5).

Declines in abundance of alder are particularly apparent as illustrated by decreases in estimates of growing stock inventory since the previous inventories in both Oregon (28% decrease) and Washington (24% decrease) (Raettig et al. 1995, Azuma et al. 2002, Gray et al. 2005). Likewise, estimates of the area of hardwood-dominated

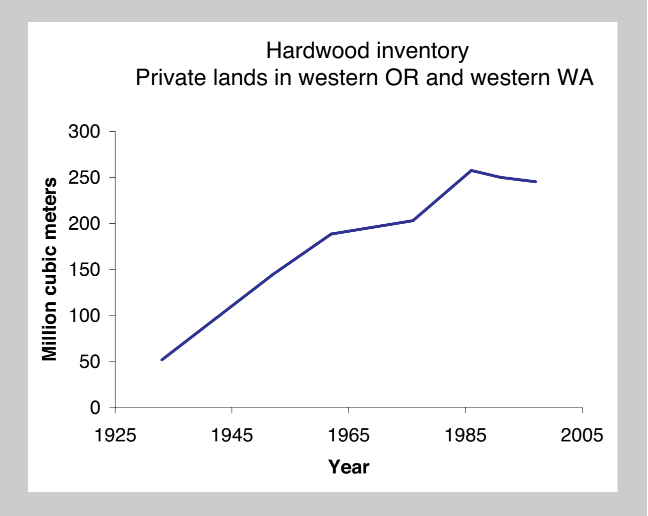

Figure 5—Hardwood inventory volume estimates on private lands in Washington and Oregon from 1931 to 2001 (from Haynes, tech. coord. 2003).

forest decreased by about one third over the last 3 periodic inventories in both Washington (1980, 1991, 2001) and Oregon (1976, 1987, 1997). The trend is apparent on both industrial and non-industrial private lands (fig. 6). Similar trends are described by Alig et al. (2000), who projected a 35% decrease in alder timberland on forest industry lands and an 18% decrease on non-industrial private timberland in the westside Pacific Northwest for the period 1980-2010.

During the 1990s, removals, mortality, and forest conversion (to non-forest) contributed to a 28% net loss of hardwood inventory on non-federal lands in Washington (fig. 7). In Oregon, both removals and mortality are lower, and forest conversion is negligible, so that there was 14% net growth in total hardwood inventory between 1987 and 1997. Removals and mortality are proportionally higher for alder than other hardwoods in both states. For Washington and Oregon combined, red alder comprises 73% of the hardwood removals and mortality, but only 58% of the hardwood inventory. Annual removals plus mortality of alder in the two states exceed growth on industrial forests by 30%; removals plus mortality are about equal to growth on non-industrial private forests (fig. 8).

Since some of the forest growth occurs in areas that are not available for harvest, the levels of alder removal in Washington and Oregon during the 1990s do not appear to be sustainable. Future declines in available supplies of alder should be expected on private lands—the primary source of alder timber supply.

## Policy and regulatory factors reducing alder supply

Availability of alder timber for harvesting is reduced by landowner policies and forest practices regulations.

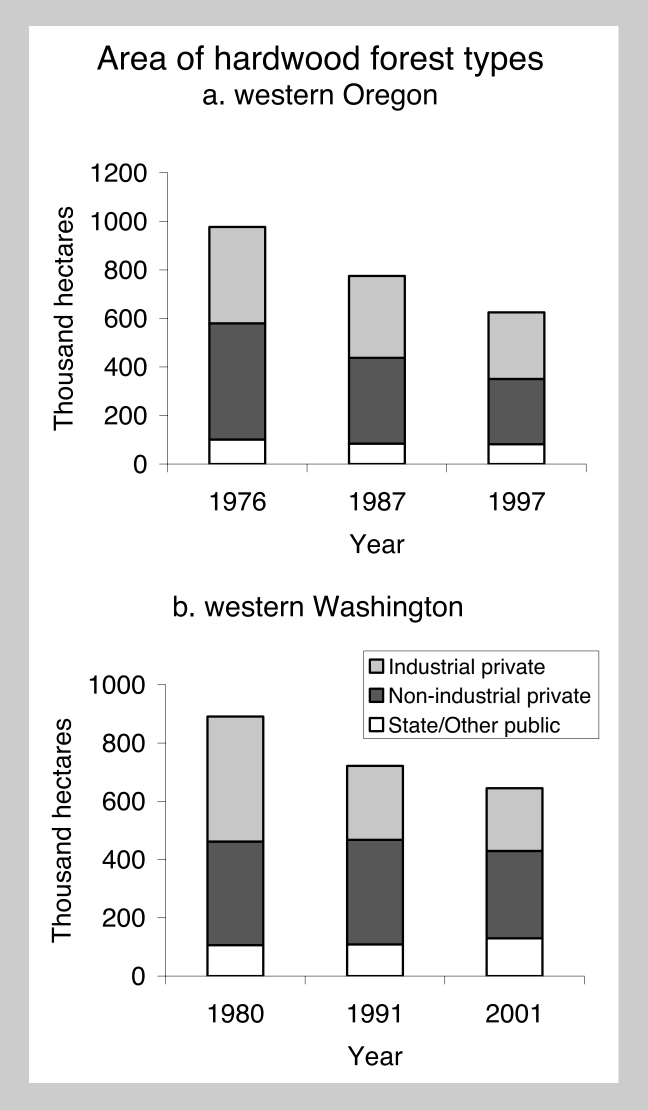

Figure 6—Periodic estimates of the area of hardwood forest types in western Oregon (a. Raettig et al. 1995, Azuma et al. 2002) and western Washington (b. Raettig et al. 1995, Gray et al. 2005).

Forest policy clearly limits timber supply on federal lands in the U.S. since these lands contain about 17% of the alder inventory but provide less than 1% of the total alder timber harvest. On actively managed state forests, alder is harvested along with softwoods, although state forest policies do limit the amount of harvest more than on private lands. Protection of riparian areas, unstable slopes, and retention of trees for wildlife habitat reduces the harvestable portion of the alder resource on all ownerships.

Protection of riparian areas and unstable slopes are expected to have a disproportionate impact on availability of alder compared to conifers due to the relatively high abundance of alder in these areas. Accurate estimates of the amount of alder affected are difficult to obtain due to the variety of protection requirements and options across the range of alder, along with diverse landowner behavior in implementation.

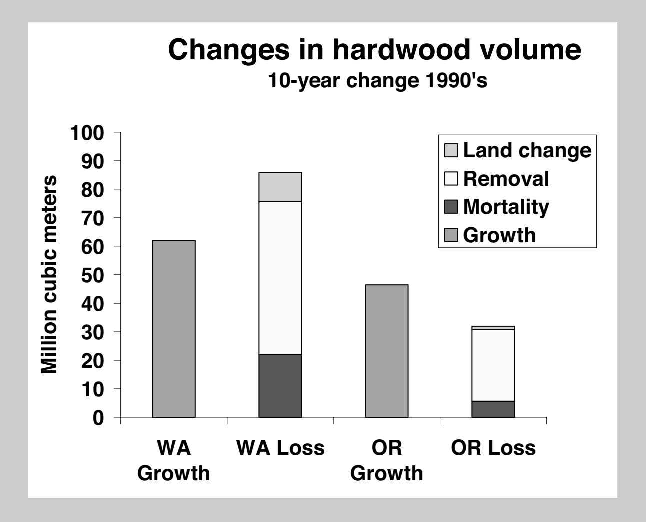

Figure 7—Changes in hardwood timber volume between inventories in western Washington (WA 1991-2000, Gray et al 2005) and western Oregon (OR 1987-1997, Azuma et al. 2002).

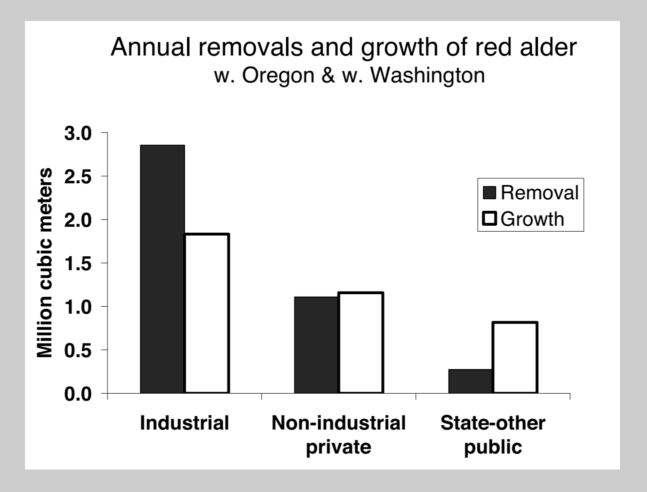

Figure 8—Annual removals and growth of red alder in western Oregon (1997 – Azuma et al. 2002) and western Washington (2001 – Gray et al. 2005).

Estimates of the amount of alder that is unavailable due to policy and regulation have been made for Washington, based on analysis using Geographic Information Systems (GIS) to overlay land ownership and protection (buffer) areas on maps of alder occurrence. A study for western Washington estimated about 7.6 billion board feet of red alder available for harvest after deducting about 46% of the resource as unavailable due to landowner policies and riparian regulations (Washington Hardwoods Commission 2002). This same assessment estimated that while riparian buffers comprise about 8% of the timberland area, they contain 18% of the red alder sawtimber volume.

Comprehensive assessments of alder availability using spatial analysis (GIS) have not been published for Oregon or BC. General estimates of about 5-10% of the alder resource affected by riparian regulations have been made (Raettig et al. 1995, G. Lettman, Oregon Dept. of Forestry, pers. Comm.). Under a scenario of increasing riparian harvesting restrictions, Adams et al. (2002) projected a 24.4% reduction in harvest volume (all species) on private timberlands in western Oregon assuming a 100-foot no cut buffer. Given the overall warmer, drier conditions in western Oregon compared to Washington, the moisture-loving red alder should be even more concentrated in riparian areas compared to upland areas in Oregon.

Much of the alder in BC does not appear to be available for harvesting. The alder harvest in BC is quite low for the level of inventory. Review of allowable harvest determinations and discussions with BC Ministry foresters suggest a variety of factors limiting availability of alder (Pederson 2000, 2001, 2002, 2004. H. Reveley, pers. comm., BC Ministry of Forests, Coastal Region.). Much of the alder in BC may not be economically available due to difficult access and high costs of logging and transportation. While delivered log prices for alder in BC are comparable to associated conifer values (2004 prices per cubic meter were $70, $55, and $110 for red alder, western hemlock, and Douglas-fir respectively; Log Market Reports from BC Ministry of Forests, Revenue Branch), relatively low economic returns per hectare are still expected for alder, which discourages both harvesting and management focused on alder in BC. Concentration of alder in riparian protection zones was also indicated as a reason for relatively low harvest volumes.

Riparian protection rules as implemented in Washington are generally more restrictive than those in Oregon and BC, based on the widths of no-harvest buffers along predominant stream types (table 1). The current emphasis on retention and development of a conifer component in riparian areas provides some potential for removal of alder in riparian zones, particularly under site-specific plan options in both Oregon and Washington. Due to the complexity of the riparian protection rules, private forest owners may not choose to harvest in riparian zones even when they have the option to do so. Compliance monitoring in Oregon showed that 60% of riparian management areas surveyed were treated with no-harvest prescriptions and only 2% were treated with a hardwood conversion/conifer restoration prescription (Robben and Dent 2002). In Washington, only 23 riparian hardwood conversion plans were filed, out of thousands of forest practices applications, by non-industrial private owners during 2002-2004 (Washington Department of Natural Resources, Small Forest Landowner Office). Harvesting behavior by industrial forest owners in Washington has not been summarized.

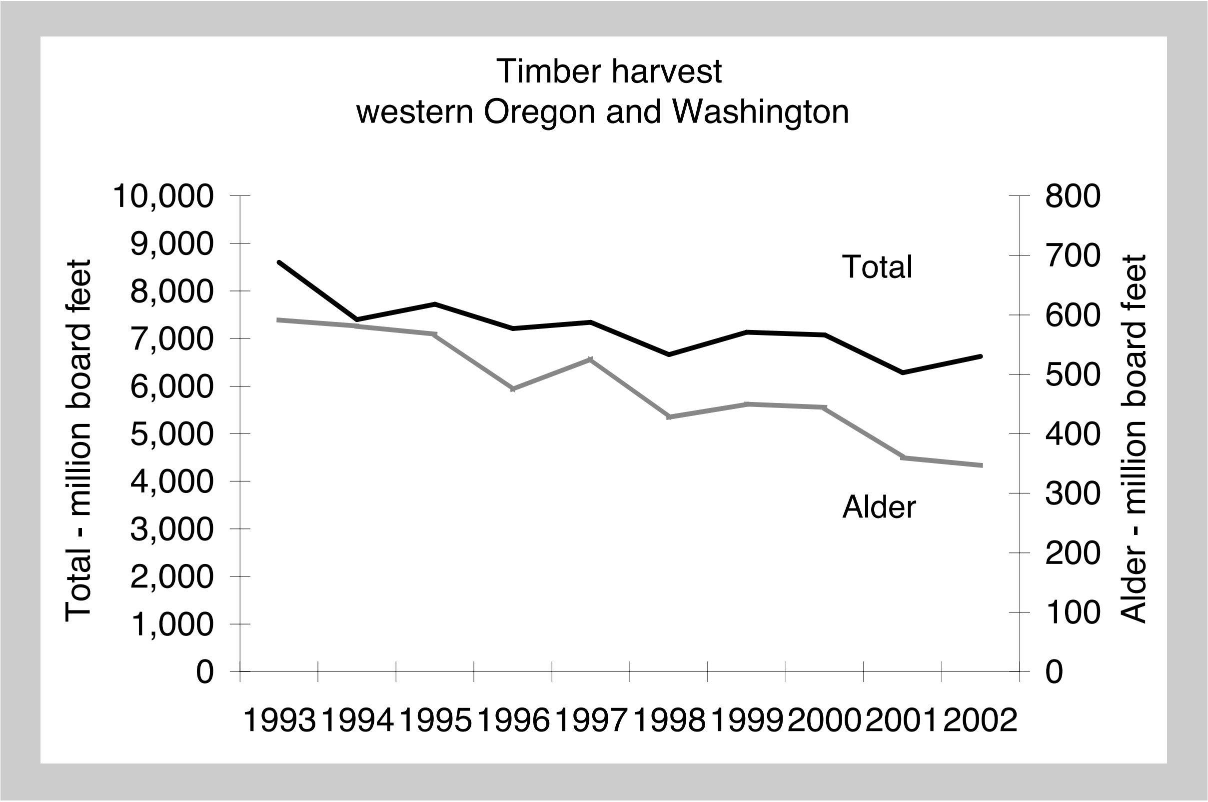

Figure 9—Annual timber harvest rates for red alder and for all species (total) in western Oregon (Oregon Department of Forestry Timber Harvest reports) and western Washington (Washington Department of Natural resources timber harvest reports for all species, Washington Hardwoods Commission hardwood processor reports for red alder).

## Declining timber harvest volumes

The declining area and volume of alder available for harvest does indicate decreases in supply of alder timber in the future. The question remains as to how soon and how much lower? Timber supply projections for Oregon and Washington in the 1990s predicted reductions in hardwood timber supply using various assumptions about forest management and harvesting behavior on private lands (Sessions et al. 1990, Adams et al. 1992). More recent timber harvest projections for western Oregon and Washington have not projected specific hardwood harvest levels (Adams et al. 2002, Zhou et al. 2005).

While there is still no comprehensive timber supply assessment focused on red alder in the Pacific Northwest, trends in timber harvest levels between 1994 and 2003 do show a gradual decline in the volume of alder harvested annually in Washington and Oregon (fig. 9). The harvest of alder generally goes up or down with total harvest and the total timber harvest level also declined between 1994 and 2003. The volume of alder harvested, however, declined about 33% while the total harvest declined only 20% (based on 3-year running averages). A reduced proportion of alder in the total timber harvest is the expected result of the declining hardwood component in Oregon and Washington. Total timber harvest projections for western Oregon and Washington indicate slight decreases in the overall timber harvest level during the next 2 decades (Zhou et al. 2005).

## Management of alder

There has been a great deal of research focused on management of red alder since the 1980’s, as illustrated by numerous presentations (OSU Hardwood Silviculture Cooperative, Weyerhaeuser Co., USFS PNW Research Station) at the 2005 Symposium, *Red Alder: A State of Knowledge* (March 23-25, 2005 University of Washington, Seattle). Nearly 20 years of private and public research focused on alder management indicate the potential for relatively high yields (8-12 $m^3$/ha/year) in short rotations (25-35 years) in managed stands.

In a detailed assessment of management plans and practices affecting alder across major forest ownerships, Raettig et al. (1995) identified several key issues preventing management for alder, including: uncertainty about economic returns, lack of information on growth and yield in managed stands, and lack of experience with alder management. These issues persist across the range of alder, even after 10 more years of alder research and continued increases in alder prices (fig. 1).

Non-industrial private forest owners in general do not manage intensively to favor conifers and they are expected to produce an increasing share of the alder given the reductions in alder on industrial ownerships. While this generality continues to hold, alder supply from non-industrial forests has also declined slightly and conversion of these ownerships to non-forest uses reduces sustainable alder supply in the future.

Recent revisions of management plans for state forests in northwest Oregon (2001) address the potential for maintaining alder for both timber and habitat purposes. In Washington, increasing the production and harvest of red alder has been recommended as increased alder timber values are incorporated in the Washington Department of Natural Resources' timber marketing program (Jon Tweedale, WA DNR pers. Comm.).

Along with the growing knowledge-base for management of alder, on-the-ground management for alder appears to be increasing. Forest managers often leave alder during weeding and pre-commercial thinning of young forests when it appears to be the best crop tree. Nursery production and planting of alder seedlings also appear to be increasing. These observations are based on informal surveys of forest managers across private and state ownerships conducted in the course of producing and teaching alder management workshops in Oregon and Washington between 1997 and 2004 (45 events, ~1500 participants). Attitudes about alder have clearly changed since the 1980's, however, formal surveys have not been conducted to quantify increases in management for alder.

When harvests of red alder were at their highest levels during the 1990s, alder comprised about 6% of the total timber harvest in western Oregon and western Washington, and about 1% of the harvest in coastal BC. While a gradual decline in alder is now evident after decades of conifer forestry, management for alder on a relatively small portion of the landscape (~5%), along with continuing production of incidental alder could maintain current levels of supply. Raettig et al. (1995) estimated at most 1% of the managed forest landscape was intentionally regenerated to red alder. Although there are indications that this will increase, the question remains: will the major forest landowners manage more alder in the future?

## Conclusions

A gradual decline in available supplies of red alder timber is now evident in Washington and Oregon, which currently provide over 90% of alder supply. Major factors that reduce supply of red alder include management favoring conifers, increased protection of riparian areas, shifts in public timber policy, and conversion of forest to non-forest land use. Knowledge of and management for alder are increasing and there is much potential for forest managers to maintain or increase alder across its range. Changes in policy and practice could also greatly increase availability of current alder inventory in BC (or federal lands in the US). The supply of alder in the future depends on the uncertain balance between these positive and negative factors.

Increased management of alder timber is the key to sustaining alder supply. While increased log prices for alder have stimulated great interest, major forest landowners are still reluctant to invest in managing alder until management techniques become well-demonstrated and there is better information on growth and yield in managed stands.

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# Red Alder Market Implications for Management; Reasons for Optimism

C. Larry Mason[1]

## Abstract

In 2000, red alder *(Alnus rubra)* log prices, after more than two decades of steady price gains, surpassed Douglas-fir *(Pseudotsuga menziesii)* log prices for the first time in history and have retained a price lead ever since. Alder, once considered a negative value weed, is now recognized as a valuable commercial timber species. As a result, there is increasing interest among forest managers in the potential for investments in alder plantations. A common concern, however, is an uncertainty about the future reliability of strong alder log markets. This paper will consider available information on alder log and lumber market influences and offer speculation that alder products appear well positioned for continued market success.

Keywords: red alder, hardwoods, wood market economics

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## Introduction

While red alder has long been recognized by tree farmers as a suitable species to plant in areas that are wet, nutrient poor, infected by Swiss needle cast or root rot, or in other ways unsuitable for Douglas-fir, until recently alder has not been widely considered as a plantation alternative to Douglas-fir on high quality sites. A strong performance by alder log prices in recent years when compared to Douglas-fir prices may lead some foresters to reconsider the potential for planting alder on their best sites. The following graph displays historic prices, adjusted for inflation to 2004 dollars, for Douglas-fir and red alder saw logs (average price of #2 and #3 saw logs for each species) from 1970 to 2004 in the Puget Sound region of western Washington. Alder log prices surpassed those for Douglas-fir for the first time in history in 2000 and have retained a price lead ever since. Historically, alder log prices have been less volatile than Douglas-fir prices and display a stronger upward trend (fig. 1).

Financial performance simulations can help in making species comparisons for return on planting investment. For demonstration purposes, assumptions will be that plantations are hardy and on a good site, costs and prices are treated in constant dollars, 5% is the expected real rate of return, results are reported based upon current log prices and management cost estimates before taxes, and yield estimates in thousand board feet (MBF) and ton wood are consistent with expectations listed below (Mason 2003).

- DF-45. A 45-year Douglas-fir rotation; no commercial thin. (30 MBF & 70 tons)
- RA-35. A 35-year Red Alder rotation. (20 MBF& 30 tons)

A soil expectation value (SEV) calculation suggests that, due to price advantage and shorter rotation length, alder plantations may provide better return on investment than Douglas-fir plantations (fig. 2).

A common concern, however, is an uncertainty about the future reliability of strong alder log markets. Alder logs are manufactured into a number of primary lumber products for domestic and export markets. An examination of available information about alder product markets will provide a better understanding of the future potential performance of alder log prices.

## Alder Lumber

In March of 2004, the Hardwood Review Weekly reported its North American Hardwood Outlook for 2004. Alder lumber sales were characterized as some of the hottest in the hardwood markets with strong domestic and overseas demand. The expectation was that demand would continue to exceed production for the foreseeable future. A little more than a year later, in spite of little to no gain for other species in hardwood lumber export markets, this forecast held true (Hardwood Review 2005). Alder export sales increased world wide by more than 30% in the first five months of 2005 as compared to the first five months of 2004 (table 1) with big gains in important international markets like China and the European Union (figs. 3 and 4).

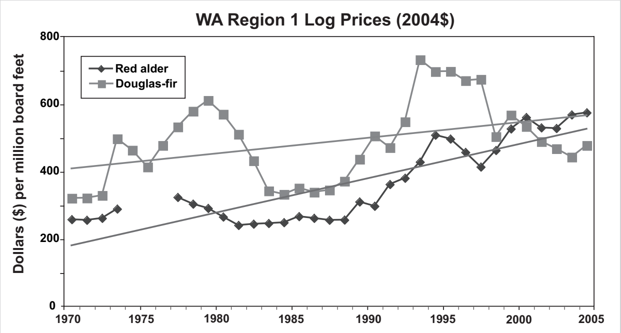

Figure 1— Historic prices, adjusted for inflation to 2004 dollars, for Douglas-fir and red alder saw logs (average price of #2 and #3 saw logs for each species) from 1970 to 2004 in Region 1 (Puget Sound) of western Washington. Source: Log Lines, Fox, U. S. Dept of Labor.

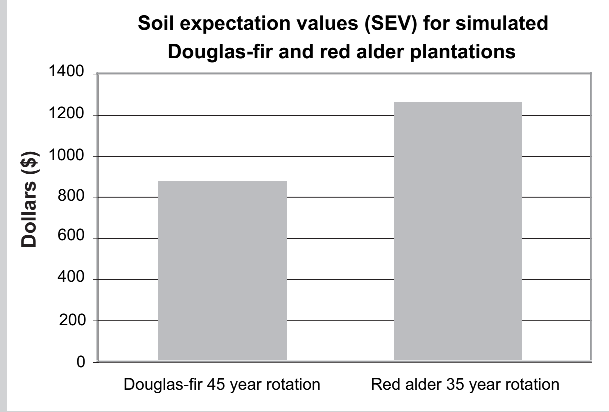

Figure 2—Simulated soil expectation value (SEV) comparison at a 5% target rate of return for Douglas-fir and red alder plantations. Source: Rural Technology Initiative.

Most wood species experience fluctuating demand for individual lumber grades with favorable markets for some items coincident with poor markets for others. Alder lumber, however, is in increasing demand for the full spectrum of lumber grades with product sales limited only by supply. The higher grades of select, #1, and #2 have long been desirable for furniture and cabinet manufacture due to the excellent workability characteristics of this species (fig. 5). Workability is important to manufacturers not only to ensure production of high quality products but also to reduce operation costs. Good workability minimizes unit production time, increases product recovery, and extends the life of production equipment and materials. Unique to alder, because of its uniform color and grain characteristics, is its ability to readily accept both light and dark stains which

**Table 1—Alder lumber export statistics for Jan-May of 2004 and 2005. Source: Hardwood Review (2005) and USDA Foreign Agricultural Service (2005).**

| Alder LBR Exports by Country | Jan-May 2004 Vol. (m3) | Jan-May 2005 Vol. (m3) | Change 05 vs. 04 | Jan-May 2004 Value (1000 $) | Jan-May 2005 Value (1000 $) | Change 05 vs. 04 |
|---|---:|---:|---:|---:|---:|---:|
| China | 47,397 | 65,349 | +37.9% | $12,897 | $19,620 | +52.1% |
| Canada | 13,467 | 18,515 | +37.5% | $3,751 | $4,283 | +14.2% |
| Mexico | 11,740 | 12,380 | +5.5% | $4,065 | $4,552 | +12.0% |
| Italy | 7,990 | 8,774 | +9.9% | $5,125 | $6,517 | +27.2% |
| Germany | 3,031 | 6,657 | +119.6% | $2,506 | $5,433 | +116.8% |
| Spain | 5,483 | 4,961 | -9.5% | $3,479 | $3,601 | +3.5% |
| Taiwan | 5,504 | 4,049 | -26.4% | $1,548 | $1,209 | -21.9% |
| Philippines | 1,388 | 2,617 | +88.5% | $617 | $1,365 | +121.2% |
| Vietnam | 855 | 1,907 | +123.0% | $313 | $746 | +138.2% |
| Portugal | 1,762 | 1,501 | -14.8% | $952 | $829 | -12.9% |
| World Total | 107,159 | 135,315 | +26.3% | $40,304 | $52,589 | +30.5% |

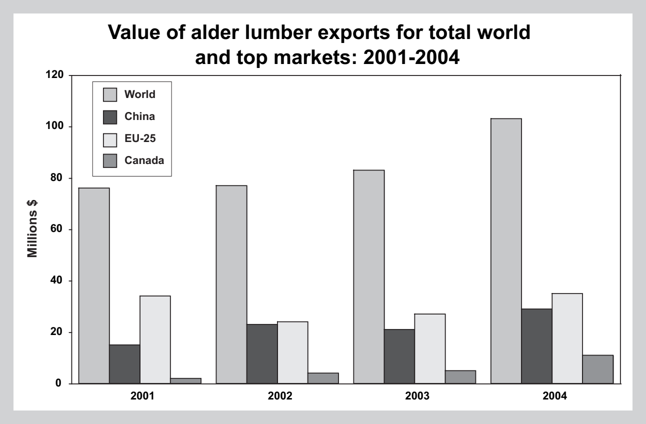

Figure 3—Value of alder lumber exports for total world and top markets: 2001-2004. Source: USDA Foreign Agriculture Service.

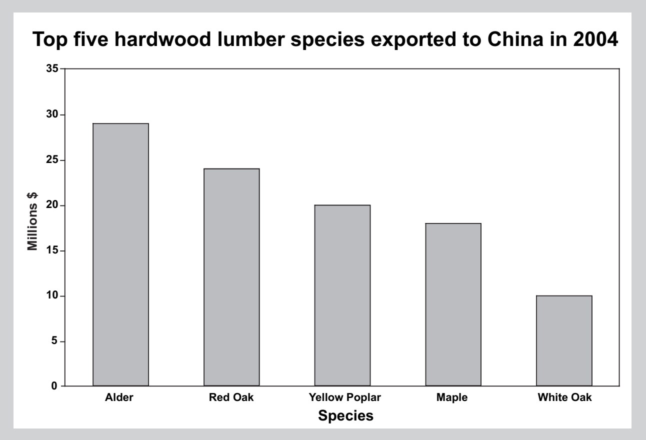

Figure 4—Top five hardwood lumber species imported to China in 2004. Source: USDA Foreign Agriculture Service.

change its appearance to resemble that of more expensive hardwoods such as black cherry *(Prunus serotina)*. After many years of serving as a low cost substitute, alder has gained an industry nickname of "poor man's cherry." Current wholesale kiln-dry prices for the highest quality alder lumber are respectably comparable to those of Douglas-fir with ranges from $1000/MBF to over $2000/MBF depending upon grade (Redmond 2005).

Recent market popularity of "southwest rustic" furniture and cabinets has increased industry demand for knotty lower grades of alder lumber such as frame, standard, and #3 shop. Strong markets for these grades have resulted in prices that currently range from $550 to $825/MBF (Redmond 2005). Emergence of strong demand for lower quality lumber for furniture and cabinet products has created tight supplies for pallet markets with subsequent price improvements for this low grade product. Pallet and crating manufacture is the largest hardwood end-use application in the United States with an estimated consumption of 3.5 billion board feet of lumber for 2005 (Hardwood Review

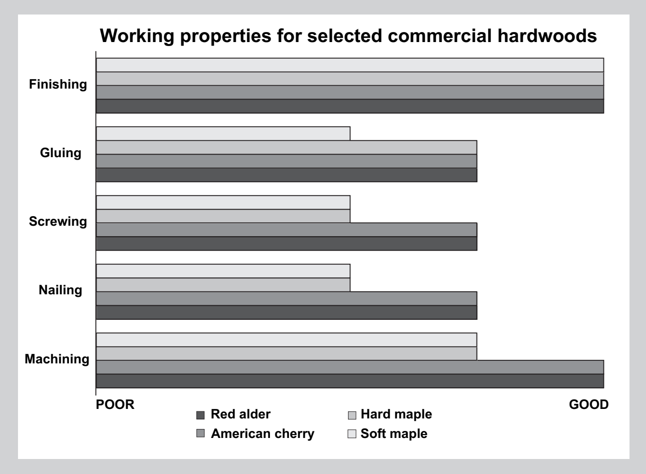

Figure 5—Working properties for selected commercial hardwoods. Source: American Hardwood Export Council.

2005). Alder pallet lumber has long been preferred by markets within the grocery industry because it imparts no resins or other toxins to foodstuffs. Alder pallet lumber, an equivalent to utility grades of other species, has seen prices in excess of $300/MBF during 2005 (Redmond 2005).

With favorable markets for pallet stock, chip production is limited to trim and side-cut. While chip prices have been lackluster for all species, hardwood chips are in stable demand as hardwood fiber is needed to produce high quality paper. Given that the west produces less than 3% of the total U. S. supply of hardwood chips (Warren 2004), alder chip markets are not likely to experience price reduction due to oversupply or substitution.

## Discussion

Red alder log and lumber prices have demonstrated stable upward growth for the last several decades. Hardwood markets tend to be less cyclical than commodity-driven softwood markets. The use of alder in the manufacture of value-added wood products means that the demand is secured by niche-product positions with little risk of substitution (Eastin et al. 1999). Favorable price positions have been established for the full spectrum of alder lumber grades. Alder logs have generally been priced between the more expensive cherry and the lower priced varieties of maple species *(Acer)*. The uniform grain pattern and light color of alder allow it to be stained to match changing consumer preferences and market trends. Alder is widely used as a substitute for more expensive traditional species like cherry. Past price relationships indicate that cherry and maple provide the upper and lower bounds for alder price fluctuations. No evidence was found in a review of the literature and trade publications to suggest that this relationship might not continue. Important to markets such as the European Union, alder is not an old growth or tropical hardwood species. Alder has well-established export positions and is the preferred species in the fast-growing China market.

Trend analysis of Pacific Northwest hardwood timber harvest and growing stock (dominated by alder) indicates that standing inventories will far exceed harvest volumes (Haynes 2003) through 2050. Regulatory constraints on harvest, however, appear to limit market supply of logs relative to growing domestic and international demand resulting in continued upward price pressure.

International trade data available from the USDA Foreign Agriculture Service show that alder export lumber markets are expanding faster than other international markets for U.S. hardwood species. The short rotation length and strong market position of red alder should result in increased interest in alder plantation establishments on well-drained, high sites in western Oregon and Washington that have previously been preferred for Douglas-fir.

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# Red Alder—Regeneration and Stand Initiation: Techniques and Field Craft as Related to Final Returns on Early Investments

Pete Holmberg[1]

## Abstract

Red alder (*Alnus rubra* Bong.) exhibits juvenile height growth rates that far exceed other commercially important conifer species in the U.S. Pacific Northwest. This rapid growth rate together with desirable wood characteristics and promising market prospects are attractive to forest managers. However, red alder's silvical characteristics and site sensitivity imply high early investment costs as well as risk factors that might well be higher than for conventional conifer management. Relatively certain high return on investments require careful site selection and judicious management, particularly during the first decade, in ensuring uniform tree spacing. This detailed attention to spacing require substantial early investments in site preparation, planting and planting stock, pre-commercial thinning, and pruning. This paper illustrates how Hardwood Silviculture Cooperative studies have influenced a Washington State Department of Natural Resources manager's assumptions about red alder cultivation in relation to silvics and expected returns on investments.

Keywords: Red alder, return on investment, silviculture, plantation, stumpage, techniques and field craft.

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## Summary

Red alder (*Alnus rubra* Bong.) exhibits juvenile height growth rates that far exceed commercially important conifer species in the U.S. Pacific Northwest. In addition, the species is highly phototropic and has low apical dominance. Therefore, in order to secure maximum return on investment, spacing in red alder plantations must be carefully managed from the earliest stages. This requires substantial early investments. Although accurate growth simulators for managed stands of red alder are yet to be developed, data from natural stands as well as plantation growth data from Hardwood Silviculture Cooperative (HSC) research through year 12 are sufficient to enable initial projections of merchantable volume and financial plus-ups attributable to intensive management. HSC data sets are from 26 plantations initiated at varying densities and subjected to differing silvicultural treatments. This information lends itself to initial projected estimates and also indicates that growth (and thus yield) of intensely managed red alder plantations dramatically exceeds that of natural stands. Assessments of relative magnitudes of return on investments may thus be performed. If current red alder stumpage trends hold, return on investments from intensively managed red alder plantations could be on the order of twice or more high site mixed Douglas-fir and western hemlock plantations that are grown to culmination of periodic annual increment. A drawback of red alder stands is the high risk associated with frost and ice-storm damage (casual observation indicates this risk may considerably reduced in red alder plantations); which has frequently caused irredeemable damage to the commercial value of natural red alder stands.

## Introduction

A forester considering cultivation of red alder (*Alnus rubra* Bong.) in Oregon, Washington, or British Columbia would be well served to take into account the Hardwood Silviculture Cooperative's (HSC) red alder plantation data. This cutting edge research describes growth responses of red alder to intensive management on 26 plantations throughout western Oregon, Washington and British Columbia. Each site has four initial planting densities subdivided into varying treatments that cover a range of pruning and thinning options through year 12. From an operational perspective, feasible approaches gleaned form this research should be adapted to practical techniques and field craft that should be analyzed from cash flow and investment perspectives for a whole rotation. Facts, or in their absence, logical assumptions, regarding site selection, site preparation, stocking control, planting stock, thinning techniques, and pruning together with market assumptions and financial investment analysis must be brought together into a plausible and practical whole. To that end, this paper will present such a synthesis in the form of an optimal silvicultural prescription for a red alder rotation on a suitable, and presumably typical, site. The prescription will, in particular, endeavor to devise a regime for treatments and investments likely to best attain the desired high-value outcome.

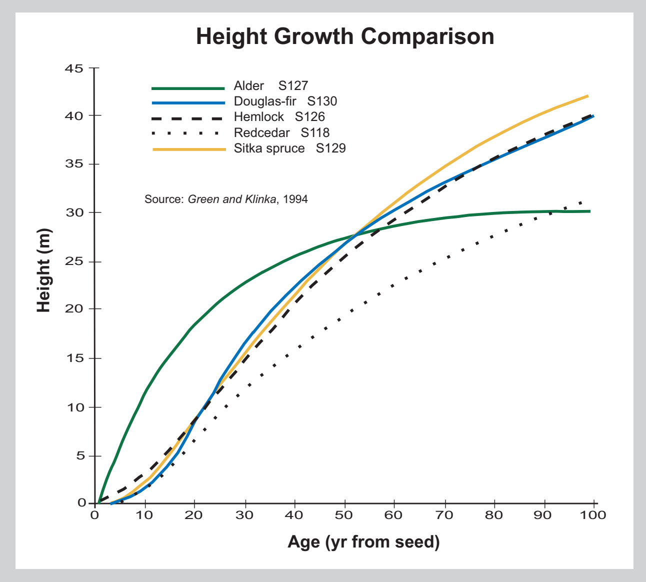


Figure 1—Height growth of red alder compared to commonly associated commercial conifers. Source: Peterson, E.B., Ahrens, G.R., and Peterson, N.M. (eds). 1996. Red Alder Managers' Handbook for British Columbia. FRDA Report 240.).

## The Case for Red Alder

### Pros

So, why red alder? Biologically, red alder has juvenile height growth rates that exceed Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and western redcedar (*Thuja plicata* Donn ex. D.Don) by as much as a factor of four during the first five decades. Figure 1 illustrates this situation. Not until around age 50 do most of these conifers overtake red alder in total height. Red alder's quick accumulation of merchantable biomass implies short rotations and therefore relatively assured markets and favorable investment recovery.

Red alder occupies a special niche in domestic and world markets due to grain uniformity, stain acceptance, and workability. These markets—the Chinese furniture industry in particular—are likely to foster an increasing demand for superior quality red alder for an extended future. Probably adding to this trend is the fact that countries and regions outside the native range of red alder have not taken on their own cultivation programs for red alder as many have done with Douglas-fir.

Thus, an image of the future begins to form in which red alder emerges as a market niche of potentially sustained high value.

**Natural Stand—Ample stocking as well as stem sweep**

**Planted 100TPA—Branches and forks**

**Planted 525 TPA—Straight and clear**

Figure 2—The photos above show phototropic-induced stem sweep in a natural stand (upper left), excessive branching and multiple stems due to low apical dominance (right), and straight and clear stems with around six feet of crown lift in a stand planted at 525 trees per acre at age nine (lower left). Source: Hardwood Silviculture Cooperative.

## Cons

Is there a downside? As we shall see, red alder cultivation requires disciplined adherence to specific site selection criteria as well as to silvicultural regimes that have considerable front-end investments. Financial rewards will be tightly linked to specific sites that capitalize on red alder's high juvenile growth rates and to regimes that judiciously manage red alder's high degree of phototropism and low apical dominance (fig. 2). Associated risks for irrecoverable error might dissuade foresters to whom lower but more conventional returns on investment from conifer plantations represent their risk management comfort zone. More about this later.

Red alder (rightly, at present) is touted as immune to most pests that affect conifer forests. However, little is known about pests that might yet emerge as epidemics should sizable acreages in pure red alder plantations begin to proliferate. At present, outside of susceptibility of older trees to white heart rot (*Phellinus igniarius*) and sapsucker (*Sphyrapicus* spp) bark and cambium damage, there are few pests known to have caused serious damage to red alder in forest stands. Regarding mechanical damage (and associated compartmentalized rot), it is well known that red alder is more sensitive than conifers to logging damage, and natural stands of red alder are also more prone to top breakage from ice or snow storms (with subsequent generation of multiple tops due to low apical dominance). One should note, however, that casual observation of plantation red alder indicates that straight and well-spaced red alders are less susceptible to top breakage than natural stands with their clumpy spacing and near-universal stem sweep.

Thus, the robust picture of red alder management becomes nuanced with some negative factors that must be minimized through judicious management and site selection. Next, I will discuss two of these factors, site selection and mechanical damage, in more detail.

## Site Selection

Red alder, because of its ability through bacterial root nodules, to fix and use atmospheric nitrogen and thereby fertilize itself, grows competitively on a wide variety of sites. However, within this wide spectrum, there is a limited range of sites suitable for cultivating superior commercial-grade red alder. Characteristics of this limited range are: (1) moist but well drained soils; (2) northerly through easterly aspects, especially on steeper and drought-prone slopes; (3) a frost-free growing season (paying particular attention to avoiding localized frost pockets); and (4) a relative absence of elk (which may cause rubbing and trampling damage). One should also avoid areas prone to even rare (such as bi- or tri-decadal) ice storms and heavy snow loads. Thus, sites suitable for intensive management for red alder are also excellent sites for Douglas-fir (or other low elevation westside conifers), site class I to high III. Site selection will most likely become less time consuming (but not less critical) with development of GIS site selection models such as the newly fielded Washington Department of Natural Resources pilot model.

## Mechanical Damage

As regards mechanical damage from snow and ice, a brief digression on risk assessment is warranted. In conifer forestry, site characteristics are relatively easy to determine, and errors in judgment are often benign. Not so with red alder. Imagine, for example, a red alder plantation selected per the above site criteria but with only a casual look to rare historic weather. Imagine also that a more judicious look at rare historical weather would have revealed ice storms having occurred only every 10 to 20 years, and that we are now at a point at which our fictional red alder plantation has, though significant investments and treatments, progressed as intended to mid-rotation. Consider the effects on this stand of a single ice storm lasting but a few hours and causing a ¼-inch ice build-up on this red alder plantation versus a similarly aged conifer stand. Personal observations indicate that in both red alder and conifer stands the weight of the ice might cause top breakage at stem diameters down to around 6 inches. In observed conifer stands, apical dominance generally re-established single new leaders, and the resultant future grade defect could be bucked out at harvest with a relatively modest loss of value. In observed natural red alder stands, on the other hand, high phototropism combined with low apical dominance caused broken-topped trees to often sprout multiple new leaders (and epicormic branches on stems around larger openings) to quickly dominate canopy openings. The result was significant loss of commercial value; only the stem portion below the breakage could develop future commercial value. Thus, careful site selection and risk assessment are imperative. A single brief ice event one or two decades after planting may render a red alder plantation nearly financially worthless. One must therefore carefully analyze site-related risks before committing to intensive and expensive red alder management. Next, we will consider some techniques and field craft that should prove useful in preparing, reforesting, thinning, and pruning a correctly sited red alder plantation.

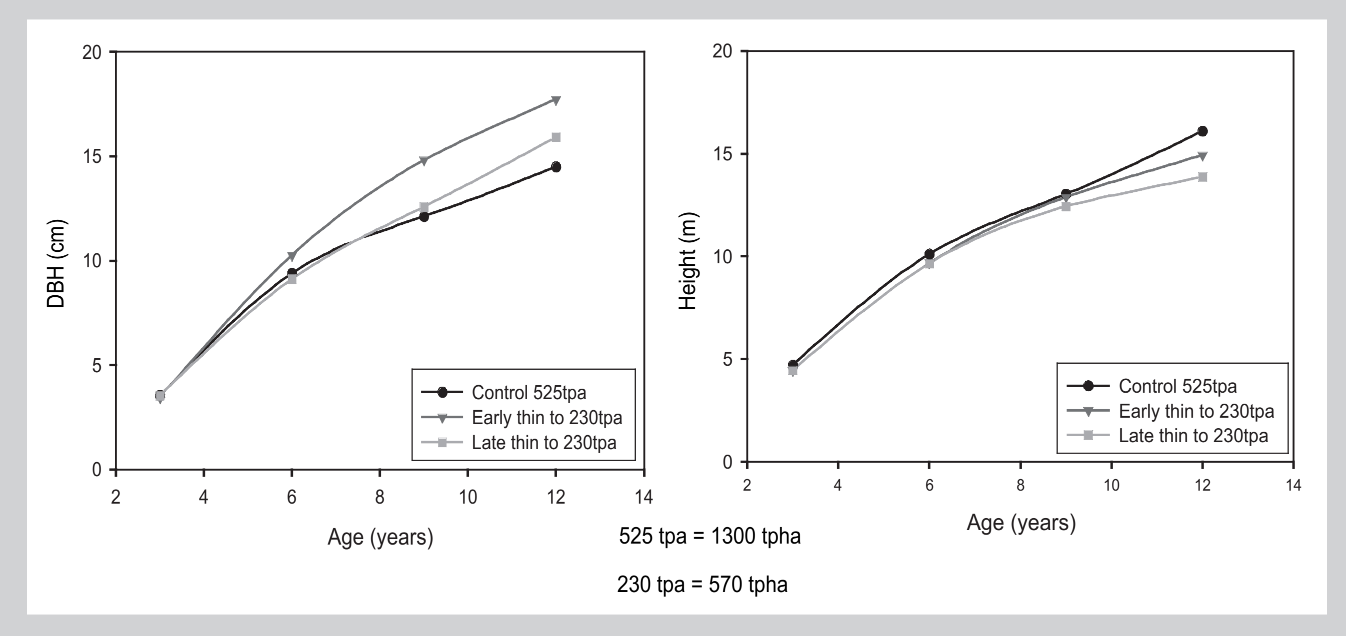
## Site Preparation

When it comes to site preparation, one should realize that herbicide control of competing vegetation after planting is infeasible, because current herbicides fail to distinguish between red alder and undesirable vegetation. Hence, the site preparation stage prior to planting is the only feasible opportunity to control vegetation, and gambling with the outcome ought not be an option. Other important considerations regarding red alder and site preparation are: (1) salmonberry *cannot* be controlled through manual means, only herbicides or broadcast burning are effective; and (2) certain woody species, notably vine maple, may be "plucked out" in the course of logging the previous stand. The up-shot is that if vegetative suppression is likely to cause seedling mortality, site preparation is imperative. If red alder captures the site early due to proper site preparation and planting, rapid growth rate, and full stocking, it will outgrow all other vegetation, and further vegetation control will be unnecessary. In most cases, however, site preparation with herbicides capable of controlling targeted vegetation is necessary in order to assure full stocking and even spacing of planted seedlings. I will re-visit the importance of even spacing and full stocking i.e., no planting mortality, later when I discuss how silvical characteristics of red alder are used to produce high-value log characteristics.

## Planting Techniques and Field Craft

First, a primary activity objective for planting is a practically 100 (and no less than 95) percent first-year survival with good vigor on, or close to, a nine-foot-square grid pattern. Red alder seedlings are different from their conifer counterparts in that seed germination in a bare root seed bed is poor and unpredictable. (A trial is currently underway at Webster Nursery to study if this obstacle can be overcome—moisture regimes and frost control may prove crucial factors.) To overcome the uncertain germination rate, DNR's Webster Nursery grows a so-called "plug-½" that, coupled with proper temperature and irrigation regimens and newly developed techniques for top-mowing, produces a relatively inexpensive high quality red alder seedling in eight to 10 months. The seeds are germinated in very small containers in an atmospherically controlled and "fertigated" greenhouse in April, thus achieving higher germination rates than with bare root sowing. These mini-plugs are lifted and transplanted into a bare-root bed in early summer, inoculated with *Frankia* bacteria to speed formation of nitrogen-fixing root nodules, lifted from the bare-root bed and put in freezer storage in January or February, and thawed and stored in a cooler approximately two weeks prior to out-planting. Seedling characteristics when packed and stored are: (1) crown height of 12 to 31 inches (30 to 80 cm), (2) caliper of 5 mm, (3) healthy buds and branches along the entire length of the stem, (4) prolific root nodules, and (5) healthy terminal. Seedling care at out-planting must be extensive to prevent damage to succulent terminals and buds, desiccation, and root damage. Tree planters must, for example, avoid stuffing too many seedlings into their planting bags and exposing unplanted seedlings to heat and drying.

The planting window is short: mid-March through mid-April, and after predicted last frost for the site at hand.



525 tpa = 1300 tpha

230 tpa = 570 tpha

Figure 3—Results of diameter and height response of red alder stands planted at 525 trees per acre to early and late pre-commercial thinning through age 12. Source: Hardwood Silviculture Cooperative.

## Planting Density

In determining stand establishment criteria, rotational stand objectives must first be clearly defined. By combining a defined desired end-state objective with silvical characteristics of red alder seedlings and saplings, one is positioned to chart the optimal pathway from the initial stand condition to the desired end state. Accordingly, I assert that a desired end state objective for a commercial red alder plantation is maximum return on investment manifested by full stocking at rotation's end with each tree's lowest 22 feet (6.7 meters) being a log of superior grade. A superior grade log is straight, clear, and with a dbh of at least 15 inches (38 centimeters). This implies (1) even spacing to preclude stem sweep (fig. 2) and (2) stocking that is periodically adjusted to (a) induce natural pruning at branch diameters of one-half inch or less (no "black knots") and (b) sustain diameter and height growth at maximal levels when considering natural pruning criteria without inducing opportunities for phototropic stem sweep. The HSC—using 12-year plantation data from test plots in Oregon, Washington, and British Columbia—found promise in planting red alder at nine-foot square spacing (525 trees per acre or 1,300 trees per hectare).

The HSC further tested the concept of planting 525 trees per acre by comparing the response to pre-commercial thinning (PCT) at various ages. The graphs in figure 3 compare dbh and height growth in response to PCT to 230 trees per acre at four ("early") versus eight ("late") years since planting.

The results clearly indicate that diameter growth benefits from thinning as early as age four while height growth response is not as succinct. There are also indications that stands receiving the late PCT have a tendency to catch up with earlier thinned stands (fig. 3). Moreover, casual observation of several red alder plantations aged four through 15 indicate that thinning at age four delays natural pruning processes and results in excessive branch diameters in the lower crown. Accordingly, one might deduce (while awaiting further research) that the window of consideration for PCT opens at age four, but the optimal time (factoring in both the value of clear wood and growth rate) is most likely in the eight to 10-year range. From this author's viewpoint, these emerging parameters (planting at nine-foot spacing and PCTing near age 10 and taking out one-half of the trees per acre) are on, or very near, the optimal silvicultural pathway towards the highest possible return on investment. As we shall soon see, financial analysis of the entire rotation lends credibility to this assumption.

## Some Thoughts on Thinning Techniques and Field Craft as Related to Red Alder Silvics and the Objective of Maximum Return on Investment

From red alder's extreme shade intolerance comes a corresponding phototropism i.e., a strong proclivity to bend towards direct sunlight. In natural stands of red alder, stocking depends entirely on the stochastic nature of seed and seed bed availability, germination conditions, etc. Stocking therefore tends to be universally clumpy, and phototropic stem sweep becomes nearly universal. Crown ratios in densely stocked clumps quickly diminish to the point of being too low to respond to thinning, while diameters are uneven (although tree height is not), and

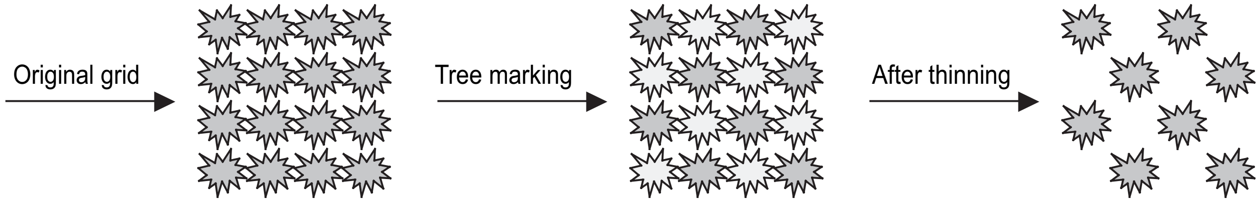


Figure 4—The even-spaced thinning solution: Start with 9-foot square spacing (far left). In thinning, remove every other diagonal row (gray crowns, center). The post-thinning spacing is even and square, although the squares are turned 45 degrees, at 9 feet x √2 ≈ 13 feet. Even spacing supports uniformly vertical phototropic response in red alder.

suppression mortality occurs. More stem sweep follows around openings created from suppression mortality (fig 2). From an economic standpoint, the stand has lesser valued, slow growing logs and makes inefficient use of available growing space. In intensively managed red alder plantations, we intend to preclude these negative factors. We accomplish that through *very* even initial spacing coupled with stocking controls intended to balance viable crown ratios (maintaining approximately 60 percent) with natural pruning at branch diameters of less than one inch. The need for even spacing may be considered proportional to red alder's phototropism. Therefore, red alder's need for uniform spacing in order to produce high-value logs is far greater than Douglas-fir or other conifers.

Thus, a question arises of how to "plant on a grid" and then sustain the grid through one or more thinnings. The first step, of course, is to select sites with even availability of planting spots—good soil throughout, requisite site preparation, and sufficient planting contract provisions to ensure a seedling every nine feet in a square pattern. Such strict spacing arrangements may be sustained when PCTing by taking out every other diagonal row (thus removing one-half of the basal area and trees per acre). PCT would shift the square pattern 45 degrees while widening the spacing by the square root of two (approximately 1.4). In other words, if planting is at nine foot spacing, PCT would be to 9 x 1.4 ≈ 13 foot spacing, and a subsequent commercial thinning would be to a spacing 13 x 1.4 ≈ 18 feet. Seen from above, the original grid, trees to be removed in thinning and the grid after thinning would appear as in figure 4.

### Where Does This Take Us?

In review, we initially established a desired end-state and then devised the best way to get there from a silvically optimal initial stand condition. Note that we first established two desirable parameters for maximizing return on investment: full stocking and superior-grade first logs in practically every tree. Next we looked at planting as well as thinning techniques and field craft to maximize value potential value at final harvest. We noted that planting between 500 and 600 trees per acre on a uniform and square grid enabled us to PCT by removing one-half of the trees per acre and thus sustained a high and uniform rate of desirable stand development. The phototropic nature of alder compelled us to develop techniques and field craft to sustain uniform and square spacing before and after thinning. Thus, by removing every other diagonal row, we PCTed to 13-foot square spacing (from the initial spacing of nine feet). A subsequent commercial thinning—if we do one—would be to13 x √2 ≈ 18 feet, assuming that future research will indicate similar desirable development for slightly older stands. The final stocking would be around 130 evenly spaced trees per acre, with each tree being straight and clear (through natural pruning and possibly dead branch knock-down) up to at least 22 feet while sustaining maximal diameter accrual to attain the desired 15 inches dbh. Although, currently available data for natural stands indicate 14 inches at dbh for 120 trees per acre, I anticipate additional growth from judicious plantation management. We can now flesh out these concepts with a rudimentary regime simulation combined with robust financial analysis to scope whether or not the financial outcome warrants early investments.

## Stand Development Simulation and Financial Analysis

Although the HSC has thus far developed 12 years of information on intensive red alder management, a notable gap exists in the lack of a good growth and yield simulator for managed stands. For the interim, I will note that existing knowledge lends itself to mathematical calculations sufficient to project rough stand averages at important decision nodes. Growth projections are derived by coupling HSC plantation growth data through year 12 with natural stand site index curves. However, growth and yield simulations based on site trees have inherent over-estimation bias that is perpetuated when used to extrapolate 12-year HSC plantation data to final rotation. A subjective downward adjustment of projections is therefore prudent. In order to remain financially conservative, it is also prudent to assume investments, such as thinning and dead branch knock-down, occur at the earliest possible juncture. Thus, growth and yield calculations with a prudent downward adjustment and coupled with what seems as reasonable future stumpage assumptions may be used for projecting returns on investments. The tabulation below contains what is, after comparison to feasible alternative regimes, thought to be both an optimal and practical rotation-length silvicultural prescription.

**Stand chronology and cash flow tabulation:**

| Activity | Year | Cost/Revenue |
|---|---|---|
| Site prep (aerial herbicide) | 0 | ($110) |
| Plant (seedlings + contract) | 0 | ($300) |
| PCT | 4 | ($100) |
| Dead branch knock-down | 8 | ($100) |
| CT (3 MBF/ac @ $200/MBF) | 18 | $600 |
| Final Harvest (20 MBF/ac @ $600/MBF) | 30 | $12,000 |

The investment value of this rotation, using a discount rate of four percent, results in a bare land value (BLV) of just under $5,000 per acre. BLV is defined as net present value of an infinite succession of identical rotations.[1] Rotation length is therefore immaterial when comparing present value of silvicultural regimes of various rotation lengths to each other. This is because the calculated investment period in all cases is the same i.e., infinity. This would not be true if using the pure form of net present value (NPV), in which case comparison of different rotation length scenarios is invalid. Thus, comparing the BLV from the above stand tabulation to a likewise optimal mixed Douglas-fir – western hemlock regime final-harvested at culmination of periodic annual increment, one finds that the red alder regime is more than twice as profitable in terms of BLV.[2] Although the red alder projection is admittedly crude, its financial advantage over mixed conifer is sufficiently large to confidently state that red alder cultivation merits serious consideration on suitable sites.

## Conclusions

- Red alder cultivation for commercial purposes requires management intensity not matched by conifer forestry and therefore requires a level of investment higher than for conifer plantations.

- Site selection is of critical importance in intensively managed red alder; effects of error in this regard are not benign as in conifer plantations.

- Windows for management intervention are relatively short, and if not acted upon, the commercial value of red alder regimes go from potentially superior to assuredly mediocre.
- Returns on investment show potential to be on the order of more than twice the value of mixed conifer rotations, given what today seems to be reasonable assumptions on growth, yield, and stumpage values, and provided that risk is analyzed and judiciously managed.
- Further research is needed to develop state-of-the-art growth and yield simulators for managed stands of red alder.

## Acknowledgements

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[1] In the formula $BLV = NFV \div [(1 + i)^{n} - 1]$, "NFV" is net future value i.e., the net of all revenues and costs, each compounded until the end of the rotation; "i" is the compounding rate; and "n" is the number of years—compounding periods—in the rotation. BLV, or Bare Land Value, may be thought of as Net Present Value (NPV) for an infinite succession of identical rotations. Since the investment period would thus be equal i.e., infinity, BLV lends itself to equitable financial comparison of various regimes and rotation lengths.

[2] Net future value for the red alder regime when the value of all activities are accumulated at 5 – 1percent to year 30 is $11,117 per acre. Applied to the formula for calculating bare land value, the result is $4,955 per acre. By comparison, a similarly optimal regime for mixed Douglas-fir and associated conifers terminated at approximately the culmination of periodic annual increment (ages 40 to 60), yields a maximum bare land value in the $1,700 to $2,400 per acre range, depending upon species mix and other site specific variables and assumptions.

# Alternate Plans for Riparian Hardwood Conversion: Challenges and Opportunities

Kevin W. Zobrist and C. Larry Mason[1]

## Abstract

Many riparian stands in western Washington are dominated by red alder and other hardwood species. Riparian harvest restrictions designed to protect salmon habitat can be problematic in these stands, as they may preclude establishment of desirable large conifers while also resulting in economic losses for landowners. Washington forest practices rules allow for development of "Alternate Plans" which are intended to provide flexibility for solutions to avoid unintended consequences. A case study has been done of a hardwood conversion alternate plan. Observations from this case study have identified problem areas in the alternate plan approval process. Approaches such as templates may help address these problems.

Keywords: red alder, riparian management, economics

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# Introduction

The state of Washington has recently updated its forest practices regulations, adding new restrictions on timber harvesting in riparian areas. The purpose of the new rules, known as the "Forests and Fish Rules," is to protect endangered salmon and other aquatic resources in compliance with the federal Endangered Species Act and Clean Water Act. In western Washington, the Forests and Fish Rules are specifically intended to put riparian stands on a trajectory towards desired future conditions (DFC). The DFC are conditions of mature, unmanaged riparian stands, characterized by large conifers that provide shade and a long-term source of large woody debris (LWD) thought to be important for fish habitat.

The Forests and Fish Rules for western Washington require a three-zone riparian buffer along fish-bearing or potentially fish-bearing streams. The total buffer width is one site potential tree height, which varies from 90 to 200 feet depending on site class. No harvest is allowed in a 50-foot core zone immediately adjacent to the stream. The next zone is the inner zone, which extends from the core zone to two-thirds or three-fourths of the site potential tree height depending on the size of the stream. Partial harvest may be allowed in the inner zone if the number and basal area of the conifers in the core and inner zones are projected to meet minimum requirements when the stand is 140 years old. The remainder of the buffer is the outer zone, in which harvest is allowed so long as 20 conifers per acre with a diameter at breast height (DBH) of 12 inches or greater are retained.

Many riparian stands in western Washington are dominated by red alder (*Alnus rubra*) and other hardwoods. In these situations, the Forests and Fish Rules can be problematic. Because of inadequate conifer density and basal area, no harvest will be allowed in either the core or inner zones. However, without active management to harvest some of the alder and establish a greater conifer component, it is unlikely that these riparian stands will achieve the DFC within the desired time frame. Instead, as the alder, which is not a long-lived species, becomes senescent, the riparian stand may become dominated by salmonberry (*Rubus spectabilis*) and other brushy vegetation. The lack of opportunity to harvest valuable hardwood timber in the riparian zone also means economic losses for landowners. The economic impacts of the riparian harvest restrictions can be significant, especially when no timber can be harvested from the inner zone (Zobrist 2003; Zobrist and Lippke 2003).

In order to accommodate situations where the rules may hinder the achievement of the DFC and to provide opportunities for landowners to find lower cost approaches for protecting riparian areas, the rules allow landowners to submit a site-specific alternate plan for managing a riparian stand. A case study has been done of one of the first "hardwood conversion" alternate plans to be submitted. This case study offers insights into some of the challenges of and opportunities for using alternate plans as a solution for the sustainable management of riparian hardwood stands.

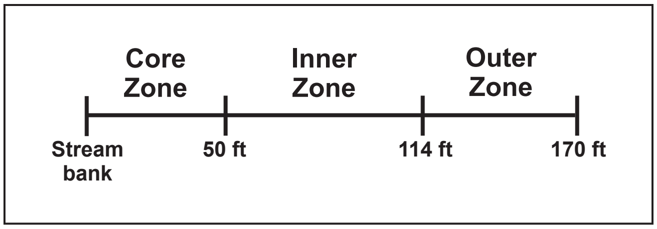

Figure 1—A 170-ft riparian buffer is required for small streams on site class II. The buffer includes a 50-ft core zone, followed by a 64-ft inner zone and a 56-ft outer zone.

# Hardwood Conversion Case Study

The case study is of a hardwood conversion alternate plan that was submitted in 2002 by a small forest landowner in southwest Washington. The landowner planned to harvest a 26-acre stand that bordered 1,570 feet on the east side of a north-south stream. The stream ran dry in the summer, but it was identified as potential winter fish habitat and so was classified as fish-bearing. The stream was considered small, as its bankfull width was less than 10 feet. The stand was site class II, requiring a total riparian buffer width of 170 feet. The first 50 feet from the stream was the no harvest core zone. The inner zone then extended 64 feet from the edge of the core zone out to two-thirds of the buffer width (114 feet), as required for small streams. The remaining 56 feet was the outer zone (fig. 1).

The dominant species in the riparian zone was red alder, which was 30 years old, had a density of 105 trees per acre (TPA), and ranged in size from 6 to 18 inches DBH. There were also 35 TPA of 55-year-old Douglas-fir (*Pseudotsuga menziesii)* ranging in size from 6 to 40 inches DBH, along with a few (less than 6 TPA) other hardwoods, such as black cottonwood (*Populus trichocarpa*) and bigleaf maple (*Acer macrophyllum*) (fig. 2). The core and inner zones, which comprised approximately 4 acres, had an inadequate conifer component to allow harvesting in the inner zone under the default rules. The landowner proposed a hardwood conversion alternate plan to harvest some of the existing alder in both the core and inner zones to establish more conifers and generate some revenue.

The alternate plan addressed the riparian zone as two different management units, with unit 1 bordering the southern 1,070 feet of stream and unit 2 bordering the northern 500 feet of stream (fig. 3). For unit 1, the alternate plan proposed leaving all of the Douglas-fir and 49 red alder along the stream bank in the core zone while harvesting the rest of the hardwoods in that zone. For the inner zone the plan proposed leaving 13 Douglas-fir (12 less than 9 inches

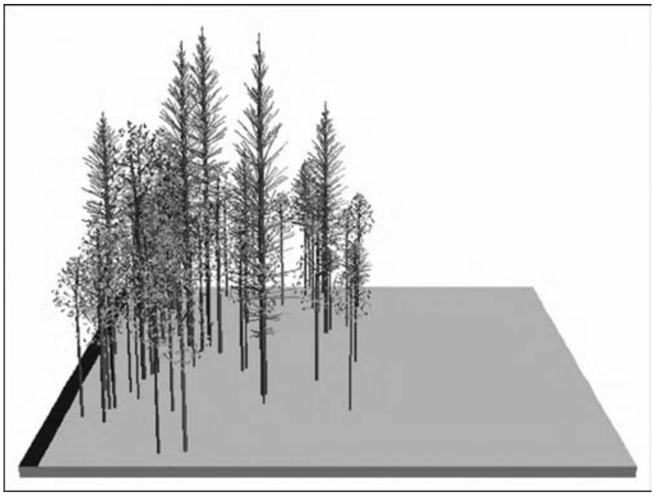

Figure 2—A visualization of the case study riparian stand, which is predominantly 30-year-old red alder with some older conifers and additional hardwood species present.

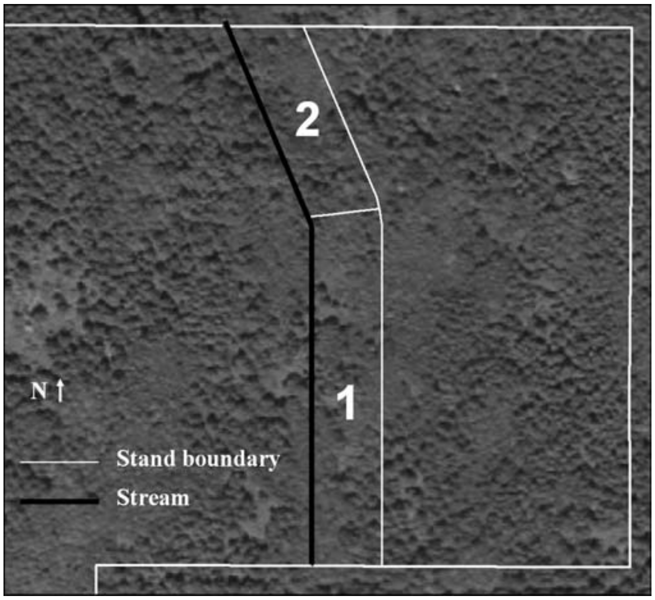

Figure 3—The case study riparian zone comprised two management units along 1,570 feet on one side of a small, north-south stream.

DBH and one with 28 inches DBH) and harvesting the remaining Douglas-fir and all of the hardwoods. All trees would be harvested in the outer zone. For unit 2, no harvest would be done in the core zone. The plan proposed to leave 8 Douglas-fir dispersed in the inner zone, while harvesting the remaining Douglas-fir and all of the hardwoods. All trees would be harvested in the outer zone.

The alternate plan called for the harvested areas to be replanted with 300 TPA of 1-1 seedlings. The seedlings would be 80 percent Douglas-fir and 20 percent western hemlock (*Tsuga heterophylla*). Brush control would be done at 3 years and 7 years after planting to ensure that the planted conifers become free to grow. To evaluate the expected results of the proposed alternate plan over time, the riparian stand was treated according the prescription and then projected over 140 years using the Landscape Management System (LMS). LMS is an analysis tool that integrates growth, treatment, and visualization models (McCarter et al. 1998). The projected stand conditions immediately, 10 years, 40 years, and 140 years after treatment are shown in fig. 4. These projections suggest that in the long term this alternate plan would result in a riparian stand dominated by large conifers and characteristic of the DFC.

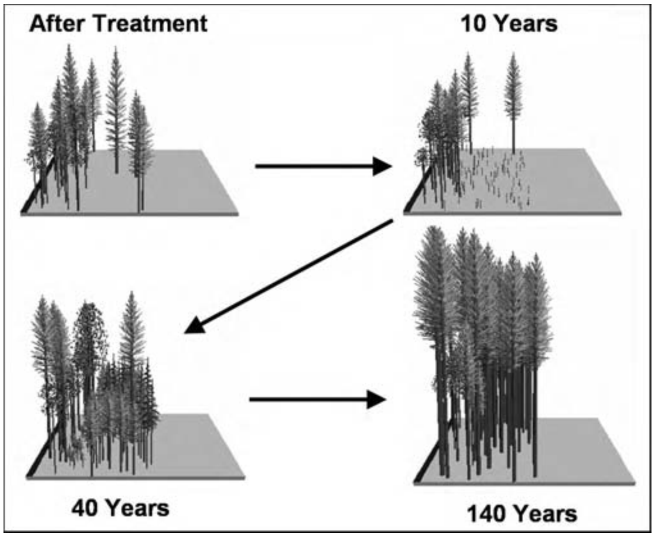

Figure 4—LMS simulation of the riparian stand conditions over time under the proposed alternate plan.

In order for an alternate plan to be approved, it must be reviewed by an interdisciplinary (ID) team that includes representatives from the Washington Departments of Natural Resources, Fish and Wildlife, and Ecology, along with local tribes. The ID team that reviewed this alternate plan proposed several revisions. The ID team proposed a wider no-harvest area in the core zone of unit 1. They proposed that only the smallest Douglas-firs be harvested in the inner zone, and only those leaning away from the stream. They also proposed in-stream LWD placement of 37 to 45 conifer logs originating from outside the riparian area (i.e. the upland portion of the harvest unit).

The economic costs of the revisions proposed by the ID team were unacceptable to the landowner. However, a compromise was reached in which the logs for LWD placement were allowed to include leave trees and downed wood from the core and inner zones. This eliminated the cost of using merchantable upland logs for LWD placement by allowing the placement of logs that would not otherwise have gone to the mill. The final revised plan included an additional 54 red alder and 5 cottonwood leave trees in the core zone of unit 1. In the inner zone of unit 1, 12 Douglas-fir leave trees were to be retained with an average DBH of 18 inches. In the inner zone of unit 2, 10 Douglas-fir leave trees were to be retained with an average DBH of 26 inches.

**Table 1—Itemized cash flows for the original proposed alternate plan, the plan with proposed revisions, and the final approved compromise. Only the additional cash flows associated with the alternate plan are included.**

| Cash Flow | Proposed Plan | Proposed Revisions | Approved Compromise |
|---|---|---|---|
| Net Harvest Revenue | $12,210 | $8,710 | $8,710 |
| Site Preparation | -$625 | -$625 | -$625 |
| Planting | -$810 | -$670 | -$670 |
| LWD Log Value | $0 | -$4,000 | $0 |
| LWD Placement Cost | $0 | -$1,000 | -$1,000 |
| Brush Control Year 3 (discounted at 5%) | -$275 | -$230 | -$230 |
| Brush Control Year 7 (discounted at 5%) | -$225 | -$190 | -$190 |
| Consulting Fees | -$1,500 | -$1,500 | -$1,500 |
| Net To Landowner | $8,775 | $495 | $4,495 |

Using figures provided by the consulting forester who prepared the alternate plan, a breakdown of the costs and revenues for the original alternate plan, the proposed revisions, and the final, approved compromise is given in table 1. These are only the costs and revenues exclusive to the alternate plan that are above what would be expected if management was done according to the default rules. The original proposed plan would have resulted in a net return to the landowner of $8,775. The revisions proposed by the ID team would have reduced this by 94% to $495, at which point the landowner was no longer willing to pursue the alternate plan. The compromise resulted in a net return of $4,495, a 49% reduction from the original proposal.

## Discussion

Alternate plans are potential solutions for situations such as hardwood-dominated riparian areas in which the regulatory prescription is unlikely to achieve the DFC in a timely manner. However, observations from this case study suggest that the development and approval of such plans may be problematic. The approval process can be long and costly for both the landowner and the agencies participating on the ID team. In this case, the plan development and approval process took approximately one year and involved three ID team field visits. The cost to the landowner was $1,500 for consulting fees, which was 17% of the net harvest revenue for the approved plan and represents approximately $1 per foot of stream. Agency costs included the personnel and equipment costs of the three field visits, plus the associated office time. Additional agency costs were expected for supervision of the LWD placement.

Another problem observed was the lack of guidelines for alternate plan development and approval. There were no objective, measurable performance criteria to gauge the effectiveness of the proposed plan or subsequent revisions. At the same time, a lack of economic guidelines almost resulted in a failure to reach an agreement. Without clear guidelines and objective, measurable performance criteria, the overall goals of alternate plans can easily get lost in the negotiation process and opportunities for "win-win" solutions of greater effectiveness and lower compliance costs can be missed.

The problems observed with this case study were not unexpected. This was one of the first alternate plans to be submitted, and as with any new process, time and experience are needed to work out logistical issues. The purpose of this case study was to identify areas of need and potential solutions for improving process efficiency and results. One such solution suggested in the rules is the development of alternate plan templates. These templates would be pre-established guidelines to expedite the development and approval of alternate plans for common situations. Conversion of predominantly hardwood riparian stands for conifer regeneration has been identified as a common situation for which a template approach would be appropriate.

Alternate plan templates for hardwood conversion present an opportunity to provide for short and long term riparian habitat goals while also providing economic relief to landowners. These templates could provide landowner incentives for future stewardship. They could also facilitate an increase in the available short term supply of red alder, as much of the current inventory is located in riparian areas. A streamlined approval process would make alternate plan implementation more feasible for both landowners and regulatory agencies, which is necessary for the large-scale success of alternate plans.

Several key elements will likely be needed for a successful hardwood conversion template. A narrow, no-harvest buffer will be needed immediately adjacent to the stream for interim shade, bank stability, and short term LWD recruitment. Sufficient harvest of the remaining riparian hardwoods will be needed to create adequate growing space for conifers. Regeneration specifications (species mix and density) should be appropriate for the site and for long term growth. The template process should be simple and affordable and provide sufficient economic benefits to landowners.

The observations from the case study suggest several challenges that will need to be addressed in developing a hardwood conversion template. Short term function needs, such as shade and bank stability, will need to be balanced with the long term establishment of the DFC. Specifically, the appropriate width of the no-harvest buffer adjacent to the stream will need to be identified. Appropriate regeneration strategies will need to be developed. These strategies will need to extend beyond planting, such as brush control and pre-commercial thinnings. This will increase landowner costs but may be necessary for establishing conifers while preventing the subsequent development of too densely stocked conditions. Treatment of existing conifers will also need to be addressed. As was the case for the case study, hardwood-dominated stands often include some conifers—too few to achieve the DFC, but enough to potentially impact regeneration. Finally, it will be important to establish sufficient conifers to achieve the DFC while still maintaining a hardwood component. Hardwoods play an important role in riparian forest ecosystems. Ultimately the goal is not the eradication of riparian hardwoods in favor of purely coniferous stands, but rather the sustainable management of both conifers and hardwoods.

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## Metric Equivalents

| When you know: | Multiply by: | To find: |
|---|---:|---|
| Degrees Fahrenheit (°F) | (F-32)/1.8 | Degrees Celsius (°C) |
| Inches (in) | 2.54 | Centimeters |
| Feet (ft) | .3048 | Meters |
| Acres (ac) | .4047 | Hectares |
| Trees per acre (TPA) | 2.471 | Trees per hectare |
| Thousand board feet (MBF) | 2.4 | Cubic meters ($m^3$) |

## English Equivalents

| When you know: | Multiply by: | To find: |
|---|---:|---|
| Degrees Celsius (°C) | (C* 9/5)+32 | Degrees Fahrenheit (°F) |
| Centimeters (cm) | .3937 | Inches (in) |
| Meters (m) | 3.2808 | Feet (ft) |
| Square meters per hectare ($m^2$/ha) | 4.36 | Square feet per acre ($ft^2$/ac) |
| Cubic meters per hectare ($m^3$/ha) | 14.30 | Cubic feet per acre ($ft^3$/ac) |
| Kilograms per hectare (kg/ha) | 0.89 | Pounds per acre (lb/ac) |
| Kilometers (km) | 0.6214 | Miles (mi) |
| Hectares (ha) | 2.470 | Acres |

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