The Value of Red Alder as an Integrated Pest Management Tool For Controlling Weevil Damage to Sitka Spruce

Lyle Almond [2]

Abstract

Among the numerous benefits they provide, mixed-species forests are often extolled for their greater resilience than monocultures to disease and insect outbreaks. Evidence of this resistance mechanism was investigated by observing variation in the intensity of leader damage inflicted by spruce weevils (*Pissodes strobi* [Peck] [Coleoptera: Curculionidae]) on Sitka spruce (*Picea sitchensis* [Bong.] Carr.) terminals under a broad gradient of canopy closure densities in stratified mixtures of red alder (*Alnus rubra* Bong.) and Sitka spruce. Analysis using all tree species failed to reveal a substantial correlation between weevil damage and canopy closure, but a very high level of association emerged when all tree species except red alder were removed from the regression model. Further analysis of the whiplash damage that upper stratum red alder imposes on Sitka spruce terminals attempting to emerge into the upper canopy resulted in predictably greater incidence of terminal damage at higher densities of red alder crown closure. As an attempt to address these two inextricably linked concerns, the hypothesis of this research analysis is that, at some ideal spacing of overstory red alder, a balance can be achieved whereby minimally acceptable levels of weevil damage occur without drastically suppressing leader growth. Superimposed linear trends of increasing whiplash damage and decreasing weevil infestation intersected at a red alder canopy closure value of 88% closure. This observational study of pest-host interactions under a broad range of canopy densities establishes an optimal range of threshold values for managing canopy closure that could be useful in managing mixed stands of red alder and Sitka spruce for better commodity production and ecosystem diversity.

Keywords: integrated pest management, Sitka spruce, *Alnus rubra,* red alder, spruce weevil, mixed-species silviculture.

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Introduction

Sitka spruce (*Picea sitchensis* [Bong.] Carr.) is a vital component of the Pacific Northwest's temperate rain forest, set in a unique coastal maritime zone with growing conditions which maintain such high rates of productivity by Sitka spruce that it reaches the largest size of any spruce on Earth, making it the fourth tallest tree in the world (Van Pelt 2001).

Sitka spruce and its primary pest, the spruce-tip weevil (*Pissodes strobi* [Peck] [Coleoptera: Curculionidae]), have successfully coexisted over millennia. Since the advent of single-species plantation management in the 20th century, the spruce-tip weevil population has exploded to epidemic proportions, reaching such levels of infestation that regeneration commitments have begun shifting away from Sitka spruce production altogether. However, avoidance cannot be considered an integrated pest management approach, especially when the tree species in question is as densely distributed and as ecologically and economically valuable as Sitka spruce.

An integrated pest management (IPM) approach is necessary to allow the continued use of Sitka spruce for reforestation and to protect those stands already established, but prone to continued damage from weevil attack. With the possible exception of avoidance, the range of available control options has met with limited success and lacks sufficient coordination. At present, few, if any, practical options are available to minimize weevil damage in susceptible stands. Avoidance of planting spruce obviously works, but at the expense of encouraging lesser valued trees on prime spruce sites. While a successful IPM system should be predicated on studying the biology, population dynamics, genetics, and impacts of the weevil and its host, the overall objective of all lines of research should be to develop forest management practices that will produce and maintain productive forest stands on the riparian floodplain and terrace sites that have proven to be most ecologically suited for Sitka spruce.

The resurgence of heightened research interest in the ecology and silviculture of mixed-species forest communities has recognized, among numerous benefits they provide, that forest mixtures often exhibit greater resistance than monocultures to disease and insect outbreaks (Kelty 1992, Perry 1994, Smith et al. 1997). Evidence of this resistance mechanism is exemplified by natural stands of even-aged red alder (*Alnus rubra* Bong.) and Sitka spruce, a stratified mixture commonly found growing in the riparian floodplains of coastal river systems in the Pacific Northwest. Under the expansive canopies of mature red alder growing along river bottoms and streambanks, shade-tolerant Sitka spruce trees are generally observed to be virtually free of weevil damage. The use of deciduous overstory trees, principally red alder, in mixture with Sitka spruce in the understory could have great value in an integrated pest management program to deter spruce-tip weevil invasion. Initial research trials in British Columbia in a shade versus no-shade study design have shown encouraging evidence that the shade provided by red alders overtopping spruce trees in a nurse-tree shelterwood system can significantly reduce weevil damage. (McLean 1989). This research analysis elaborates upon those findings by investigating the response in spruce-tip weevil damage intensity to a wide range of red alder overstory shade levels.

Dense overstory canopies of red alder may substantially reduce levels of weevil infestation, yet those same canopies may also impose barriers impeding the growth rate of terminal development as spruce trees attempt to emerge through the red alder canopy. Whiplash damage to Sitka spruce terminals abraded by red alder branches breaks down epinastic control, causing primary meristem development of the terminal bud to produce several small shoots that each attempt to assume apical dominance. This results in arrested height growth, unduly extending the rotation period or allowing other tree species to outcompete spruce trees. Whiplashed spruce trees that do emerge above the red alder canopy expose this cluster of terminal shoots to the risk of multiple weevil attacks.

This research investigation was partially intended to construct a predictive tool as a means to assist forest managers in selectively cultivating a red alder canopy as an integrated pest management approach in protecting Sitka spruce from weevil attacks.

The primary research goal in this research study was to determine what optimal level of red alder canopy closure will produce the greatest reduction in weevil attack without overly suppressing growth of Sitka spruce due to whiplash damage. By using a regression model approach, this research investigation also provided a look at the sensitivity with which changes in the level of spruce weevil activity might correspond with differences in the level of overstory canopy closure.

Weevils respond directly to changes in the level of ambient air temperature, not to canopy closure *per se*, preferring to oviposit at high temperatures. Although weevils will oviposit after emerging from hibernation and before consistently warm weather, they do not do so readily until temperatures above 60°F become common in British Columbia (Silver 1968). In southwestern Washington, egg-laying activity commenced at approximately 75°F and peaked at 90° F (Gara et al. 1971). The air temperature for maximum oviposition in the field was 84.9°F (Overhulser 1973). Maximum rates of oviposition have also been recorded to occur between 50.5° to 79.3°F (Holsten 1977). McMullen (1976) demonstrated that the accumulated heat required for brood development on Vancouver Island, from egg to emergence, is at least 888-degree days above 45°F (Holsten 1977). Oviposition most commonly occurs only at bark temperatures between 77°F and 84°F associated with

20% to 35% relative humidity (Beleyea and Sullivan 1956, Gara et al. 1980).

In conditions where heat accumulation is insufficient for completion of larval development, a Sitka spruce stand cannot sustain viable weevil populations (Holsten 1977). Regulation of understory microclimate temperature is clearly a determining factor in the success of any silvicultural approach to arrest spruce weevil damage.

Methodology and Research Models

Do increasing levels of red alder canopy closure influence the level of spruce weevil damage to Sitka spruce growing in the understory? If so, is red alder the only tree capable of producing this nurse-tree function? Is there some ideal level of canopy closure that can optimize reductions in the hazard of weevil damage as well as the whiplash damage that these canopies may also inflict on developing spruce terminals? To answer these questions, a set of hypotheses was formulated:

Research hypothesis 1: Sitka spruce weevil damage diminishes under canopies of red alder and continues to decrease along a gradient sensitive to the increasing density of canopy closure.

Research hypothesis 2: reductions in spruce weevil damage are uniquely associated with the presence of a red alder canopy in the overstory; the overstory presence of other coniferous canopies has no significant effect on the intensity of spruce weevil damage.

Research hypothesis 3: at some ideal spacing of overstory red alder, a balance can be achieved whereby minimally acceptable levels of weevil damage occur without drastically suppressing leader growth.

Field data collection

Twenty circular quarter-acre plots were established in a 59-acre stand at Merrill and Ring's Pysht Tree Farm located on the north coast of the Olympic Peninsula in western Washington. The stand was planted in 1986 with Sitka spruce. During the intervening years, red alder seeded naturally and became a vigorous component in the stand.

Canopy closure was calculated by measuring and, in many cases, estimating with Schumacher equations, the diameters, heights, and crown lengths of all trees in each plot. This data was then entered into least crown width (LCW) equations developed for each tree species (Hann 1997). The radius of this width was then squared and multiplied by *pi* to calculate each tree's horizontal crown area. Summation of tree crown areas was compiled individually for each species (reduced model) and for all species (full model) in each plot. Percent canopy closure

was calculated as the ratio of square-foot canopy closure within the total square footage of the quarter-acre plot (10,890 ft^2).

With the assistance of binoculars, each Sitka spruce tree was evaluated for leader deformities caused by weevil damage. A four-point damage rating system was developed to identify the morphological characteristics of the damaged terminal. This rating system simulates a chronological sequence of weevil damage over time, whereby a shepherd's crook indicates most recent damage (one year), a broken top indicates two to three years since weeviling, one or more upturned laterals suggest three to four years since weeviling, and a forked top represents the longest time since weeviling, approximately four or more years.

Data analysis

To compare the relative benefits of red alder to other tree species canopies in weevil protection, a full regression model and a partial model were both constructed. Included in the full model were the combined canopy closure values of red alder, western hemlock, Douglas-fir, and Sitka spruce itself (weeviled and unweeviled) that were measured in each plot. All species except red alder were eliminated to formulate the partial model.

The response variable of spruce weevil damage was determined by comparing the ratio of weeviled spruce trees to all spruce trees, resulting in a percentage of spruce weevil damage for each plot.

Polynomial equations, based on a method of curve fitting (Sit and Poulin-Costello 1994), were calculated using SPSS$_©$ for constructing a set of linear regression models to best explain the change in weevil damage under various levels of canopy closure, one for total canopy closure (full model), the other for red alder alone (reduced model).

Results

Weevil damage

Polynomial regression analysis comparing percent canopy closure with percent of Sitka spruce damaged by spruce-tip weevils resulted in the graphs and equations displayed in figures 1 and 2.

Preliminary analysis of total canopy closure by all tree species within each quarter-acre research plots, including mixtures of red alder, western hemlock, Douglas-fir, and Sitka spruce itself (weeviled and unweeviled), revealed a very poor relationship (r^2=0.0626) to the percentage of weevil damage.

When all other tree species were removed from the model except red alder, a conspicuous well-defined relationship emerged between levels of red alder canopy closure and the intensity of weevil damage, indicating that
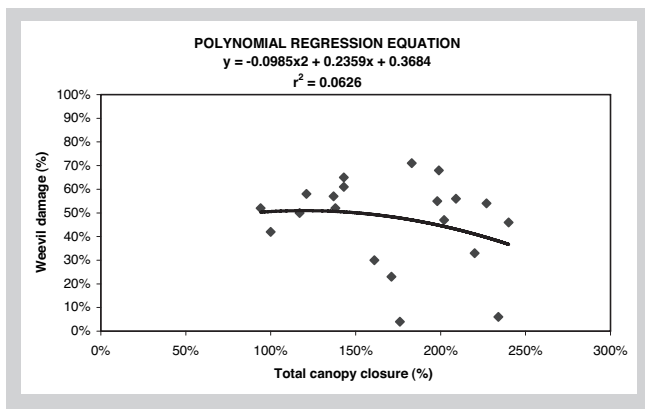
Figure 1—Comparison of weevil damage to the amount of total canopy closure.

Figure 2—Comparison of weevil damage to changing levels of red alder canopy closure.

73% of the change in weevil infestation could be explained solely by the amount of red alder canopy shade present in the overstory (r^2=0.7301). ANOVA testing confirmed a very high level of significance to red alder canopy closure as a predictor of weevil damage (p<0.001).

Whiplash damage

The percent of spruce trees whiplashed in each plot was compared to the density of red alder canopy. The slope of this linear trend conforms to the expectation that the incidence of whiplash damage rises with an increasing density of red alder canopy closure (fig. 3).

Balancing levels of weevil damage vs. whiplash damage

Is there a balance that can be achieved between minimally acceptable levels of weevil damage and spruce leader whiplash damage in a nurse-tree shelterwood system? As an attempt to address these two inextricably linked concerns, the linear trend of the impacts made by various levels of red alder canopy closure on weevil damage reduction was superimposed with the linear trend of height growth suppression measured as a function of whiplash damage. The intersection of these two lines in the resulting model indicated that a threshold target of 88% red alder canopy closure would best optimize control of both weevil attack and whiplash damage (fig. 4).

Relative density of unweeviled Sitka spruce

Another finding was revealed by graphical comparison of the relative stem density by various species in each plot. Under a broad range of different species mixtures, including Douglas-fir, red alder, western hemlock, and weeviled spruce, the stocking level of unweeviled spruce trees consistently remained at around 25% of the plot stem density.
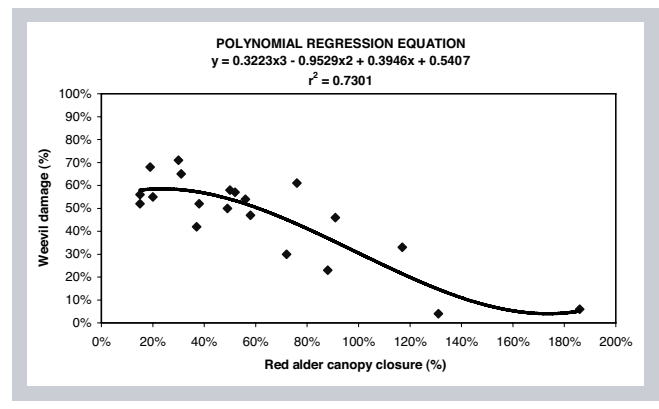
Figure 5 shows three representative distributions of plot species composition; in all three, unweeviled Sitka spruce comprised about 25% of the plot's stem density. In Plot MR13 (fig. 5A), red alder comprised half of the stem density; the remaining plot area was shared equally between weeviled and unweeviled spruce. Plot MR07 (fig. 5B) was comprised of red alder, weeviled and unweeviled spruce, as well as western hemlock and Douglas-fir. Even with the introduction of a more diverse tree species mixture, unweeviled spruce maintained a relative density of 25%. Under ideal conditions for managing an unweeviled Sitka spruce stand, red alder comprised 75% of Plot MR19 (fig. 5C), leaving only 25% of the growing space for unweeviled spruce.

Conclusion

The high coefficient of determination produced by the linear regression model constructed for this research analysis illustrates the sensitivity with which spruce weevil activity changes with corresponding shifts in the level of red alder canopy closure. By analyzing this phenomenon under a broad continuum of canopy closure levels, compelling evidence revealed the enormous—and unique—impact that red alder canopy shade exerts on the reduction in spruce weevil damage. As a natural resistance mechanism to facilitate healthy spruce leader development, red alder creates a thermal barrier that significantly reduces spruce-tip weevil infestation levels on young Sitka spruce by lowering the high ambient temperatures required by the spruce weevil to complete larval development and carry out much of its subsequent life history.

To optimize reductions in spruce terminal damage by maintaining a threshold range of 88% canopy closure, a carefully executed red alder management plan must be pursued, both in initial stem density and in intermediate density management, particularly during that period in stand development when Sitka spruce is most susceptible to weeviling, approximately between seven and twenty-
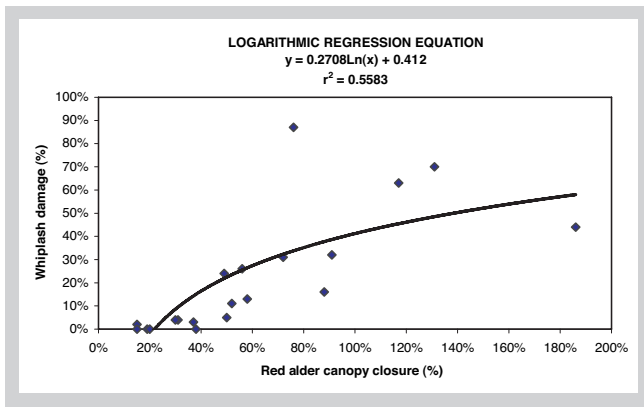
Figure 3—Comparison of whiplash damage to the amount of red alder canopy closure.
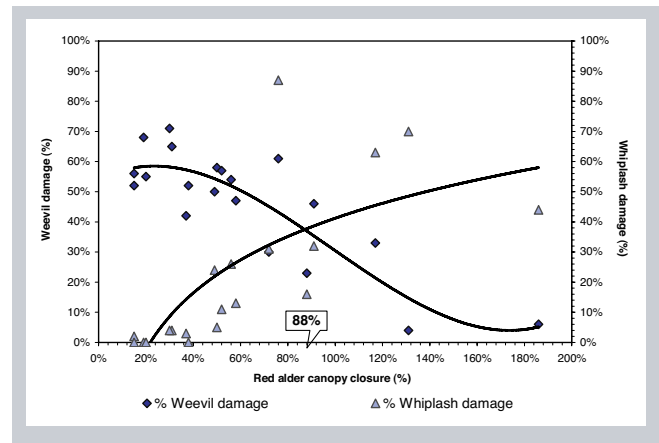

Figure 4—Superimposed trends of weevil and whiplash damage indicating best practices in managing red alder canopies to protect spruce leader development.

five years of age. The 88% threshold recommended by this research analysis should be thought of as a range, not a fixed point, to provide direction for continued investigation of interspecies interactions between Sitka spruce, the spruce weevil, and red alder within the complex dynamics of mixed-species forest stand development.

Results from this retrospective, primarily descriptive, case study of spruce-tip weevil damage occurring in a single Sitka spruce stand leave many questions to be answered. A controlled and more sophisticated research effort must be undertaken to measure the effects of managing various red alder canopy closure levels to achieve crown characteristics that are most effective in facilitating healthy Sitka spruce leader development.

Mixtures of red alder planted at, and thinned to, various densities in a range of proportions with Sitka spruce would provide the ideal opportunity to analyze variations in stand development patterns that maximize overall production by Sitka spruce and red alder. Empirical analysis or theoretical modeling could be carried out to establish what initial spacing of red alder seedlings will produce a canopy at 88% closure at a given age of fifteen years. A review of the red alder data gathered for this research indicates that dominant 17-year old red alders have a largest crown width of approximately 25 feet, based on LCW equations devised by Hann (1997). Red alder seedlings could be interplanted with Sitka spruce at a relative density of 1:1 on a 12' x 12' spacing. As alders mature and overtop the spruce seedlings, their crowns may close at age 15.

However, graphical comparison of the relative stem density by various species in each plot suggests that healthy, unweeviled Sitka spruce will consistently comprise no more than 25% of the stocking density in any mixture. The significance of this finding indicates that initial and intermediate density management of a spruce-alder forest stand should maintain a 1:3 balance of spruce-to-alder. Greater red alder density will accelerate height growth competition, promote better self-pruning, and force alder
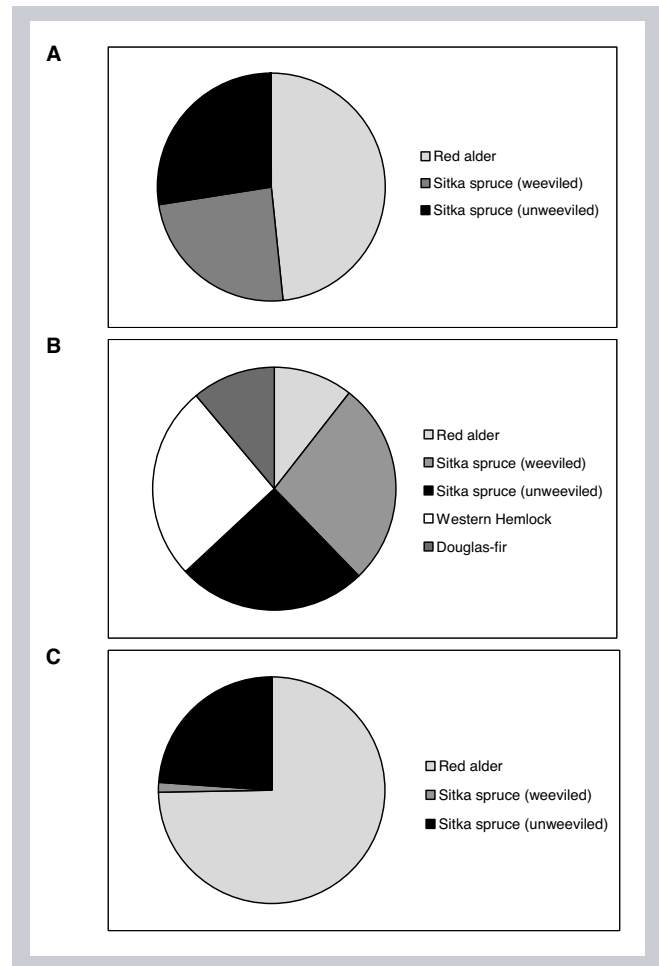

Figure 5—Relative density of component species in a weeviled spruce stand.

branching to assume a more acute upright angle, all of which are important canopy design features for reducing the hazard of whiplash damage to understory spruce.

Successful innovation in mixed-species stand management is a critical requirement to meet increasing multiple resource demands for improved wood utilization and greater biodiversity on a shrinking land base. Developing silvicultural methods that are congruent with the ecological compatibility of red alder and Sitka spruce, such as the nurse-tree two-cropping system of management recommended by this study, will lead to increased commodity production in an environmentally acceptable manner.

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Experimental Studies of Red Alder Growth and Nutrition on Vancouver Island

Kevin R. Brown[1] and Paul J. Courtin[2]

Abstract

Correlative field studies suggest that productivity in red alder stands on Vancouver Island increases with P availability. We have examined this in glasshouse and field experiments.

In the glasshouse, triple superphosphate (TSP) and dolomite were added to seedlings potted in soil from alluvial alder stands. Growth increased with P additions, less so in soils with high Bray-P levels and in higher-pH soils. Dolomite additions did not affect growth. We then added P and a blend of other elements to 10 young plantations on eastern Vancouver Island. P, as TSP, was added with or without other elements. The initial experiments applied 0, 20, or 40 g P per tree to plantations ranging from 2-4 years old. The second set applied 0, 10, 20 or 30 g P per tree within one year of planting. Additions of P increased growth in two of five older and in all five younger plantations through three years. Adding other elements did not increase growth.

We are now assessing the effects of P additions on stand development and carbon and nitrogen accretion at a slightly dry site. Seedlings were planted in fall 1999, with additional seedlings fill-planted in spring 2001. P (0, 15, 30 g per tree as TSP) was added in 2001; additional P has been added subsequently (cumulative additions of 0, 41, 88 g per tree through 2004) in order to maintain differences in foliar P concentrations. Through fall 2004, individual stem volumes have increased by 52 % (1999 cohort) or 164 % (2001 cohort). Mortality increased in 2003, but is not yet related to P treatment.

Growth of very young red alder on eastern Vancouver Island appears often limited by P deficiencies. How long effects of P additions persist and how responses vary with stand development remain unknown.

Keywords: Growth, nutrition, phosphorus, *Alnus rubra,* red alder, Vancouver Island.

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Introduction

Red alder (*Alnus rubra* Bong.) is the most widespread deciduous broadleaved tree species in low-elevation forests of coastal British Columbia. In B.C., as in Oregon and Washington, red alder was long considered an undesirable competitor with its coniferous associates. More recently, management *for* alder growth has been encouraged, in view of its rapid juvenile growth rates (Harrington 1990), ability to fix atmospheric nitrogen (N_2) (Binkley et al. 1994), immunity to laminated root rot, *Phellinus weirii* (Thies and Sturrock 1995), suitability for a variety of valuable products (Tarrant et al. 1994) and contribution to habitat diversity in a conifer-dominated forest landscape. In B.C., low-elevation sites on eastern Vancouver Island and the Sunshine Coast have the greatest potential for intensive management of red alder (Massie et al. 1994).

Increased harvest of mature alder has led to concerns that the current inventory of red alder will not meet projected demands (Rural Technology Initiative, Tarrant et al. 1994, Weyerhaeuser BC Coastal Group 2005). In B.C., the reliability of inventory data for red alder is questionable, but there is insufficient alder in the 1-20 year age class to supply projected demands without plantation establishment and intensified management. In anticipation of these needs, studies have been conducted in B.C. to assess the effects of site characteristics (Courtin 1992; Harrington and Courtin 1994), proportions of conifers (Comeau et al. 1997, Courtin and Brown 2001), and spacing, thinning and pruning on tree growth and log quality (Courtin et al. 2002).

The extent to which elemental deficiencies limit the growth of red alder is relatively unknown and unstudied (previously reviewed by Radwan and DeBell 1994), perhaps because alder fixes atmospheric N_2 and deficiencies of N most often limit the growth of Pacific Northwest coastal forests (e.g., Weetman et al. 1992). Indeed, a significant amount of research has examined how much N is added to soil at the scale of stands (reviewed by Binkley et al. 1994) and watersheds (Compton et al. 2003). Growth responses to supply of phosphorus (P) have been of interest because P is required in relatively high quantities in all plants and requirements may be greater in N_2-fixing species in association with nodulation and N_2-fixation (Marschner 1995). In earlier research, conducted in western Washington, additions of P to potted seedlings increased growth (Radwan and DeBell 1994) and either increased (Radwan and DeBell 1994) or did not affect growth (Harrington and DeBell 1995, Hurd and DeBell 2001) of young plantations. Alder planted on a site previously containing alder grew less and had lower tissue concentrations of P, calcium (Ca), and magnesium (Mg) than did alder planted on a site previously containing Douglas-fir (Cole et al. 1990, Compton et al. 1997), possibly as a consequence of N_2-fixation.

The purpose of this paper is to review recent and ongoing experiments examining the effects of nutrient supply on growth of red alder on Vancouver Island. Our reasons for initiating these studies in the mid-1990s were: (1) site index of red alder on Vancouver Island and the adjacent mainland increased with foliar and available soil P concentrations on low-pH soils, even on sites classified as rich or very rich (Courtin 1992; Harrington and Courtin 1994); (2) experimental confirmation of nutrient deficiencies on such sites was lacking, except for a single study with potted seedlings (Binkley 1986) which inferred deficiencies of P and S in a single soil; (3) red alder was increasingly being replanted on sites from which mature alder stands had been harvested, raising the question of whether nutrient supply might limit the growth of a second consecutive rotation of red alder (e.g., Compton et al. 1997); (4) there was increasing experimental evidence of P deficiencies in other tree species (Brown 2004; Brown and van den Driessche 2005, Zabek and Prescott 2001) on sites considered suitable for red alder.

The long-term objectives of our studies have been to determine: (1) what mineral nutrients are deficient for red alder; (2) on what sites deficiencies are most likely and, presumably, correctable, and (3) long-term effects of additions of limiting nutrients on stand growth and site characteristics, particularly carbon and nitrogen accumulation. Such information should assist in site selection and refine the use of fertilization for red alder management.

Throughout the paper, we refer to soil moisture regimes (SMR) and soil nutrient regimes (SNR) in discussing variation of response to nutrient additions on different sites. SMR and SNR are integral parts of the B.C. biogeoclimatic ecosystem classification system and are identified through presence and abundance of indicator plant species, topographic (e.g., slope position) and soil (e.g., humus form, soil depth, soil texture and coarse fragment content, type of A horizon, and soil color) characteristics (Green and Klinka 1994). SNR is linked to measures of nutrient availability, particularly for N (Kabzems and Klinka 1987); SMR has been related to soil water balance (Giles et al. 1985). Combined, SMR and SNR indicate the site series (site classification), which is linked to site index for different species (Anonymous 1997), including alder (Courtin, 1992) and is used to guide silvicultural decision-making (Green and Klinka 1994).

The initial nutrition experiments were conducted with potted seedlings in glasshouses, followed by short-term field experiments employing single-tree plots, and currently, long-term field experiments with multi-tree plots. The experimental approach varied with the question asked and the availability of appropriate sites and plantations. Studies employing potted seedlings were used first because appropriate plantations were unavailable and because they allowed assessment of which essential nutrients were limiting when other factors (e.g., light, moisture, competition, herbivory) were not. Subsequently,

single-tree plot experiments were conducted because available young plantations were small and of variable size and tree spacing; this approach allowed for experimental confirmation of elemental deficiencies. As larger plantations became available, we initiated multi-tree plot experiments. The primary objective in the latter studies is to assess growth responses of young red alder to a restricted (and manageable) number of nutritional treatments over time at a stand level.

Nutrient analyses were conducted on all foliage (potted seedlings) or on recently-matured leaves from the upper crown (field studies). Collected leaves were oven-dried at 70°C for 48 hours, and ground using a coffee grinder. Total N and C were determined by micro-Dumas combustion using an automated NCS analyzer. For other elements, samples were digested in a microwave digestor with a mixture of 30% H_2O_2 and concentrated HCl and HNO_3 (Kalra and Maynard 1991), then analyzed by inductively coupled argon plasma emission spectrometry (ICAP). Soil extractable P was determined colorimetrically by autoanalyzer following extraction with Bray P1 extractant (Kalra and Maynard 1991).

Experiments

Glasshouse: Effects of phosphorus fertilization and liming on red alder seedlings grown in soils from mature alluvial alder stands

The impetus for this experiment (Brown and Courtin 2003a) came from field data relating alder site index to foliar and soil available P concentrations in low pH soils (Courtin 1992), data indicating that growth of alder, soil pH and availability of P and other elements all decreased when alder was grown in consecutive rotations (Compton et al. 1997), and recognition that alder might be preferred for reforesting recently-harvested and potentially brushy alluvial sites. The objectives were to determine if: (1) seedling growth was limited by elemental deficiencies in soil from alluvial alder stands; (2) seedling growth response to growth of alder seedlings to P additions differed in higher and lower pH alluvial soils; and (3) liming could alleviate deficiencies of P (or other elements) by increasing soil pH.

Soils were collected from 0-15 cm depth (mainly Ah horizon) in six mature alluvial red alder stands on Vancouver Island, screened and potted into 3 L capacity pots in the glasshouse. Soils from four stands were classified as low pH (mean = 4.4) and two were classified as high pH (mean = 5.3); soil nutrient regimes (SNR) were classified as "very rich" at all sites. Three levels (0, 0.4, or 0.8 g P pot[-1], equivalent to 0, 225, or 450 kg P ha^{-1}) of triple super phosphate (0-45-0) and two levels of dolomitic lime (0 or 8.8 g pot[-1], equivalent to 5 t ha^{-1}) were applied in factorial
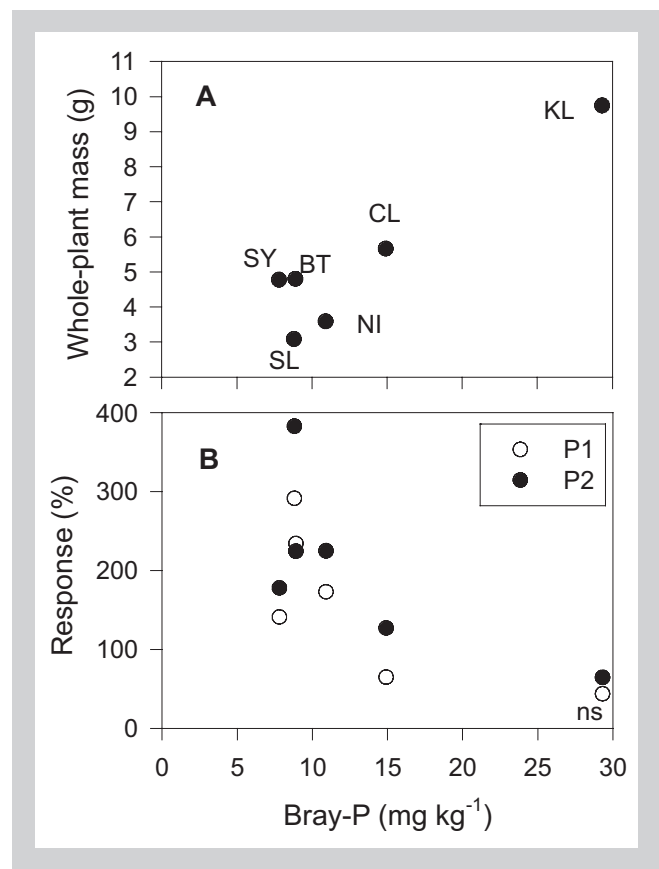

Figure 1—Effects of soil Bray-1 P concentrations on (A) whole-plant dry mass of unfertilized red alder seedlings (B) response (%) of whole-plant mass to P additions, potted seedling experiment (adapted from Brown and Courtin 2003).

combination. Seedlings were grown for 54 days, dried and weighed, and analyzed for tissue nutrient concentrations.

Growth in unfertilized soils increased with P availability (fig. 1). Additions of P increased growth, but the response decreased with increased P availability (fig. 1) and was greater in low-pH soils. Liming did not increase growth, but increased pH and whole-plant and foliar concentrations of Mg. The increases in growth with P additions were accompanied by increases in whole-plant and foliar concentrations of P, but also of N, Ca, and S. Growth increases were probably due mainly to increased uptake of P, because: (1) concentrations of P were lower than those previously suggested as deficient (Brown 2002) and (2) the correlations of growth and P concentrations were consistent across soils. Conversely, Ca concentrations were high compared with concentrations previously reported (Radwan and DeBell 1994) and increases in N, Ca, and S concentrations with P additions or liming were not always associated with increased growth. P additions increased masses of all plant parts, but increased root mass the least and branch mass the most. Consequently, P additions resulted in decreased root weight ratios and increased branch weight ratios, without affecting allocation to stems or leaves.

Table 1—Selected site and plantation characteristics, alder single-tree plot fertilization experiments.

Site	Age	Bray-P (mg kg^{-1})	CEC (cmol kg^{-1})	Previous Stand
Malaspina (M)	4	37.8	5.6	*P. menziesii*
Bowser (B)	4	11.4	4.3	*P. menziesii*
French Creek (FC)	4	48.5	3.5	*P. menziesii*
Quinsam River (QR)	3	91.6	2.8	*P. menziesii*
Hillcrest (Hill)	2	118.5	4.1	*P. menziesii*
Fanny Bay Dry (FBD)	1	3.0	7.5	*A. rubra*
Fanny Bay-Wet (FBW)	1	6.8	10.8	*A. rubra*
Campbell River Lower (CRL)	1	3.5	5.7	*A. rubra / P. trichocarpa*
Campbell River Upper (CRU)	1	124.9	2.3	*P. menziesii*
Harry Road (HR)	0	6.8	9.1	*A. rubra*

Note: age represents years since planting. Previous stand refers to dominant tree species on site prior to plantation establishment.

The data suggested that P deficiencies might limit the growth of alder in "very rich" soil from mature alluvial alder stands. Interpretation of such bioassay results is problematic. Glasshouse conditions should maximize uptake of added nutrients and expression of potential growth responses to nutrient additions (i.e., elemental deficiencies should be more obvious). Conversely, soil processing might increase nutrient availability and lessen growth response to nutrient additions. In short, field experiments are required to confirm whether deficiencies exist and to assess magnitude of response to nutrient additions.

Field: Responses of young red alder plantations on southeastern Vancouver Island to additions of P and other elements using a single tree plot design

This study was initiated in 1997 (Brown 1999); ultimately, ten experiments were established from 1997–1999 (table 1), mainly in the coastal western hemlock very dry maritime subzone (CWHxm) of eastern Vancouver Island between Duncan and Campbell River. Soil moisture regimes (SMR) ranged from moderately dry to very moist (preferred, Courtin et al. 2002); soil nutrient regimes (SNR) ranged from poor – very rich (fig. 2). Site series ranged from 03 - 07 where 07 is considered optimal for red alder (Courtin et al. 2002) and 03 and 05 are drier than optimal.

Plantation age at time of fertilization ranged from 0 (within one month of planting) – 4 years. Older plantations (> 2 years old) were fertilized in 1997 or 1998; younger plantations (fertilized within one year of planting) were fertilized in 1998 or 1999. The types of plantations available necessitated use of single-tree plot designs, for reasons discussed previously. Only healthy trees were selected for treatment and a minimum distance of 8 m (> one tree height) was maintained between treatment trees. The basic treatments consisted of three levels of P (P0, P1, P2), added as triple super phosphate (TSP, 0-45-0), with or without the "C" fertilizer (C0, C1), a blend of potassium magnesium sulphate (0-0-22K-11Mg-22S) and fritted micronutrients (table 2). Treatments were either randomly assigned across the plantation or within blocks. The number of trees per treatment ranged from 14 to 25.

Experiments differed between older and younger plantations as follows:

(1) Older plantations were located on sites generally classified as less fertile and drier than were younger plantations (fig. 2).

(2) Of five older plantations, four were established in infection centers of laminated root rot (*Phellinus weirii*) requiring the removal of infected Douglas-fir; the fifth also previously contained Douglas-fir. In contrast, four of five younger plantations were planted following the harvest of an alder stand. Hence, previous stand history and plantation age at the time of treatments were confounded.

(3) Older plantations were generally smaller in area and numbers of potential treatment trees; consequently, only three treatments (P0C0, i.e., control; P1C1 and P2C1) were applied in two experiments. Conversely, three younger plantations were large enough to allow adding four levels of P, with or without C.

(4) All plantations received the same balance of nutrients in a given treatment; however, the maximum mass of nutrients added per tree was less in younger plantations (table 2) because trees were smaller.

Table 2—Nutrient additions by treatment (Trt) for fertilized plots. P0 and C0 treatments did not receive P or the C blend, respectively.

| Site | Trt | Element Added (g tree^{-1}) | | | | | | | | | | |
		P	K	Ca	Mg	S	Fe	Mn	Zn	B	Cu	Mo
M, B, QR, FC	P1	20		12								
	P2	40		24								
	C1		11		7	13	6.3	2.6	2.4	1.1	1.1	0.03
Hill, FBD,FBW, CRL,CRU,HR	P1	10		6								
	P2	20		12								
	P3	30		18								
	C1		5.5		3.5	6.5	3.2	1.3	1.2	0.6	0.6	0.015

Note: Site abbreviations are as shown in Table 1.

	SNR				
SMR	VP	Poor	Med	Rich	VR
Very Dry	*02*				
Mod-Dry	*03*	**Hill**	**M FC** **CRU**	*04*	
Slightly-Dry	*01*		**B**	*05*	
Fresh				**Q**	
Moist	*06*			*07* **FBD**, **HR**,	
Very Moist				**FBW**, **CRL**	
Wet	*11*			*12*	

Figure 2—Site series (italics), soil moisture regime (SMR) and soil nutrient regime (SNR) of alder plantations in the single-tree plot fertilization study. A site series of 07 (CWHxm subzone) is considered optimal for red alder (Courtin et al. 2002).

(5) In older plantations, vegetation was removed to 1 m from the base of each tree and fertilizers applied in a band 0.6 – 0.8 m from the tree base. In younger (0-2 year old) plantations, vegetation was removed to ca. 0.3 m distance from the seedling. Fertilizer was applied in 2 (P1), 4 (P2), or 6 (P3) dibble holes 0.2 – 0.3 m from (and spaced equidistant around) the seedling. The objective in both was to ensure that added fertilizer was available for uptake by the target tree.

Height and basal diameters were measured in the spring at the time experiments were established, in the fall after one and two growing seasons and, in younger plantations, after three years. Individual tree stem volume was estimated assuming the stem was a cone and using basal diameter (bd) to estimate basal area of the cone. An earlier study (Brown 2002) indicated that this approach reasonably estimated stem volumes of red alder to the sizes seen in younger plantations, in the two years of measurement at two older plantations, and in the first year of treatment at two other older plantations.

Growth responses to P additions were significant (α=0.05) in the five youngest plantations (fig. 3). Averaged across the five plantations, P additions increased foliar
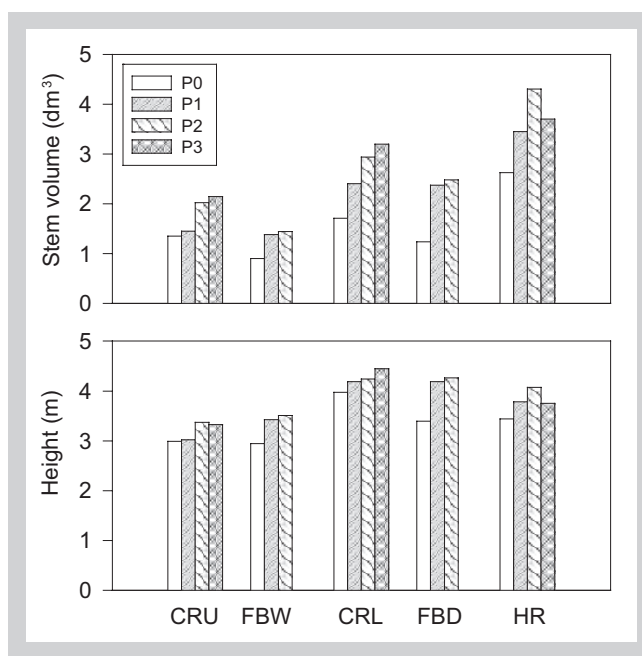

Figure 3—Effect of P addition on stem volumes and heights of young red alder (< 2 year old at time of fertilization) after 3 years, single-tree plot P fertilization experiment.

concentrations of P from 1.3 (unfertilized) to 2.0 g kg^{-1}, within the range considered deficient (Brown 2002). P additions also increased foliar N and decreased foliar Zn in four of five young plantations and increased (Ca, Mg, S) or decreased (K, B, Cu, Mn) in one to three plantations, depending on the element. The "C" fertilizer increased foliar concentrations of K, S, and B in all five plantations and N Mg, and Zn in three of five plantations without increasing growth; increases in S and Mg were of the same or greater magnitude as those resulting from P additions (Brown and Courtin, submitted). The data indicate that, on eastern Vancouver Island, low availability of P limits growth of young (within one year of planting) alder plantations on sites classified as rich – very rich and suitable for alder management. This is consistent with results of the potted seedling trial discussed above and with correlative data presented for mature alder stands (Courtin 1992).
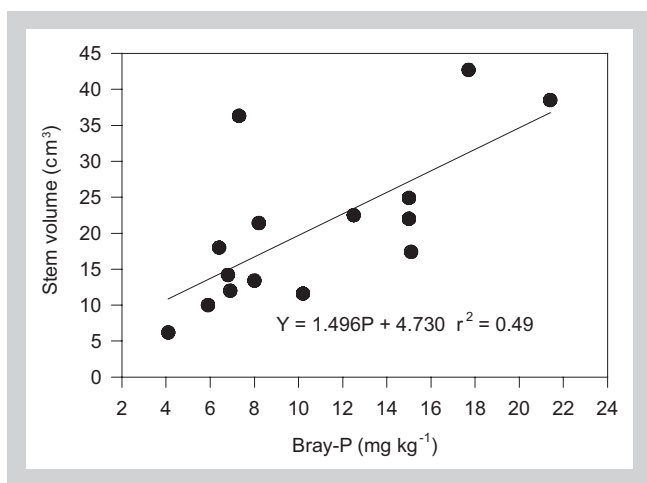
Figure 4—Stem volume prior to fertilization in relation to soil Bray-P concentrations, multi-tree plot fertilization experiment.

Table 3—Foliar concentrations of N, P, and Zn of red alder over time in relation to P treatment (Trt) at the McColl Road experiment. Trees were planted in fall 1999 and initially fertilized in spring 2001.

Element	Trt	Year 2000	2001	2003	2004
P (g kg⁻¹)	P0	1.41	1.53	1.44	1.44
	P1	----	1.95	1.44	1.52
	P2	----	1.99	1.48	1.60
N (g kg⁻¹)	P0	29.3	29.7	28.8	28.0
	P1	----	32.1	30.5	29.2
	P2	----	32.7	30.0	29.6
Zn (mg kg⁻¹)	P0	62.0	37.0	28.0	24.0
	P1	---	32.0	22.0	20.0
	P2	---	31.0	20.0	21.0

In the older plantations, growth increased with addition of combined P and C fertilizers at Bowser and French Creek, the latter only when in combination with understory vegetation removal around the tree base (Brown 1999). Volume responses at both sites were significant through two growing seasons following fertilization (Brown and Courtin, submitted). The Bowser plantation had relatively low soil Bray-P concentrations, compared with other plantations > two years old at the time of fertilization.

Several factors might explain the more frequent growth response of younger plantations to P additions. Foliar P concentrations in unfertilized trees were much less in younger than in older plantations (mean of 1.3 and 2.1 g kg⁻¹, respectively) and much more likely deficient (Brown 2002). With the exception of the CRU site, soil Bray-P concentrations were also less in younger plantations (table 1). The greater soil and foliar P concentrations in

older plantations may have been due to differences in site characteristics (e.g., parent materials, climate) or stand history (e.g., Compton et al. 1997), as most older alder plantations in the study were established after harvest of a Douglas-fir stand, rather than after harvest of an alder stand. If P was deficient in the older plantations, insufficient amounts of P may have been added to the older and larger trees to elicit any detectable increase in P uptake and growth. Tree volumes in plantations four years old at the time of fertilization were 75 times greater, on average, than in plantations fertilized one year after planting. However, trees in older plantations received only two times as much P as did the corresponding trees in younger plantations and foliar P concentrations did not increase with P additions.

Multi-tree plot experiments: Stand-level responses of young plantations to P additions

In 2001, we established a multi-tree plot field experiment in a young alder plantation on eastern Vancouver Island (Brown and Courtin 2003b). The long-term objectives are to assess effects of P additions on stand growth and ecosystem properties (specifically, carbon and nitrogen accumulation). The site is relatively dry; SNR was classified as medium-rich and soils were relatively low in Bray-1 extractable P (mean = 10.7 mg kg⁻¹), suggesting that P might be deficient. The site previously contained a *Phellinus*-infected Douglas-fir stand. Although the greatest growth potential for red alder is on moist and nutrient-rich sites, its immunity to *Phellinus* may make alder appropriate to plant on sites that are less moist and fertile than considered optimal. Such sites are common on eastern Vancouver Island. We felt P additions might be beneficial to red alder under such conditions because growth responses of alder to P additions were greater when moisture supply was suboptimal than when optimal (Radwan and DeBell 1994) and P additions increased instantaneous water use efficiency on a unit leaf area basis (Brown 2002; Brown and Courtin 2003a).

Following harvest of the existing Douglas-fir stand, the site was stumped and a portion of the site planted with alder seedlings in fall 1999. Survival was patchy and the site was fill-planted in March 2001 to a target density of 1300 seedlings ha⁻¹. Fifteen plots, each 45 x 45 m, were established in March 2001. Each plot consisted of a 25 x 25 m inner plot surrounded by a 10 m wide buffer and was separated from adjacent plots by an untreated buffer.

Soil was sampled at the beginning of the experiment from 0-30 cm depth at two points randomly selected along each of four lines extending from the plot center to a corner and analyzed for Bray-P, exchangeable cations, total N and P. Coarse fragment contents were estimated in each plot near the plot center and pits were excavated for description of soil profiles.
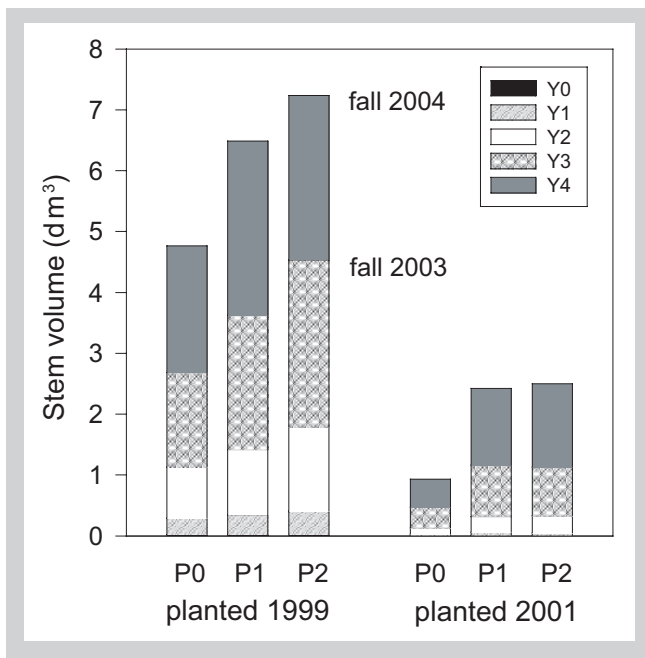
Figure 5—Four-year stem volume growth of red alder in relation to P treatment and cohort, multi-tree plot fertilization experiment.

An objective of the treatments is to maintain differing foliar concentrations of P, while maintaining adequate concentrations of other elements. In May 2001, P was added at rates of 0, 15, or 30 g P tree^{-1} as triple superphosphate and placed in dibble holes 15-30 cm from the tree. P has been added in subsequent years, based on projected rates of growth from year to year (determined from annual measurements), measured allocation of P to foliage (Brown 2002), and conservative assumptions of uptake of added P and rates of resorption of internal P prior to leaf senescence. Cumulative additions of P through 2004 (start of experiment year 4) in the P0, P1 and P2 treatments total 0, 41, and 88 g P tree^{-1} (0, 58, 124 kg P ha^{-1}), respectively.

Heights and diameters (basal in years one, two, and three; dbh in years three and four) were measured at the start of the experiment (spring of 2001, year one) and again in the fall of years one, two, three, and four. Foliage has been analyzed yearly as described above.

Similar to the relationship demonstrated earlier across sites, stem volumes of unfertilized seedlings one growing season after planting increased with soil Bray-P levels (fig. 4). Through four growing seasons, P additions have increased individual stem volumes by 56 % in the 1999 cohort and 156 % in the 2001 cohort (fig. 5); absolute increases due to P additions have been greater in the 1999 cohort. To-date, absolute effects of P addition have also increased each year since fertilization (fig. 5). Effects of P additions have been greater for dbh than for height in both the 1999 (24 vs. 16%) and 2001 (60 vs. 31%) cohorts.

Over the experiment, P additions have most consistently increased foliar concentrations of P and
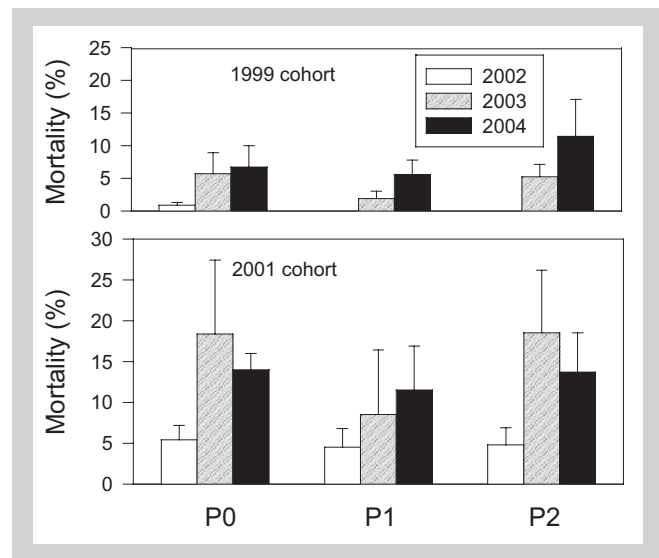

Figure 6—Mortality (% of initial number of seedlings per plot) of red alder in relation to cohort, P treatment, and year, multi-tree fertilization experiment. Vertical bars represent standard errors about the mean.
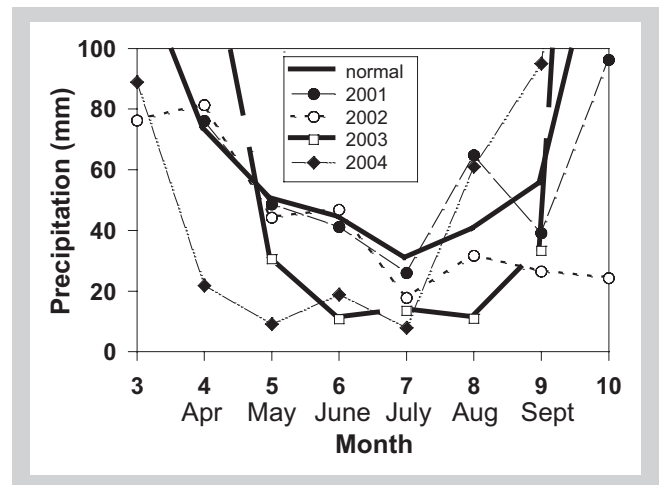

Figure 7—Precipitation, 2001–2004 growing seasons, multi-tree plot fertilization experiment.

decreased concentrations of Zn (table 3). Nonetheless, foliar P concentrations have decreased over time despite our refertilizing treatment plots. The foliar P concentrations are within the range of P concentrations felt to be deficient in both cohorts of seedlings. Concentrations of elements other than P and Zn have generally been unaffected by P additions during the study period and have been within ranges observed in the single-tree plot experiments.

Mortality in this relatively dry site has been significant through four years (fig. 6). Mortality has been greater in the fill-planted 2001 seedlings, possibly because of increased competition at the time of establishment, or because fill planting occurred mainly on poorer microsites. There is no clear evidence that P treatments have affected mortality rates. Mortality was greater in 2003 and 2004 than 2002 and may have been associated with drought during those growing seasons (fig. 7). A simple estimate of stand level

volume, based on individual stem volume responses and mortality rates suggests that P additions have increased volume by 2.1 (46%) and 2.5 m^3 ha^{-1} (56%) in the P1 and P2 treatments, respectively, through 4 years of treatments.

Discussion

Our studies suggest that the early growth of red alder on eastern Vancouver Island is limited by insufficient P supply. Deficiencies of other elements have not been clearly demonstrated, which might indicate that supplies of those elements are sufficient or additions of those elements were insufficient to increase growth.

The effects of P additions have been most pronounced at low soil Bray-1 P levels (< 12 mg kg^{-1}) and low foliar P concentrations (< 2 g kg^{-1}) and in plantations fertilized within one year of planting. Responses have been measured for up to three years following fertilization, but it is unknown how long growth responses might persist. In the sites studied, soil nutrient regimes classified as rich or very rich had low Bray-P concentrations. At this point, the relative effects of plantation age, stand history, and site characteristics on growth response to P additions are difficult to untangle, because the less-responsive older plantations were on drier sites with higher Bray-P concentrations and were planted on sites previously occupied by Douglas-fir, not red alder.

Growth responses in the multi-tree plot experiment discussed here have been largely consistent with results observed in the single-tree plot studies, as are first-year responses to 0, 30, and 60 g P tree^{-1} in a moist, very rich site near Powell River. Continued growth and soil measurements in these and similar newly-initiated multi-tree plot P fertilization experiments should provide insight into long-term effects of P availability on stand growth and soil development.

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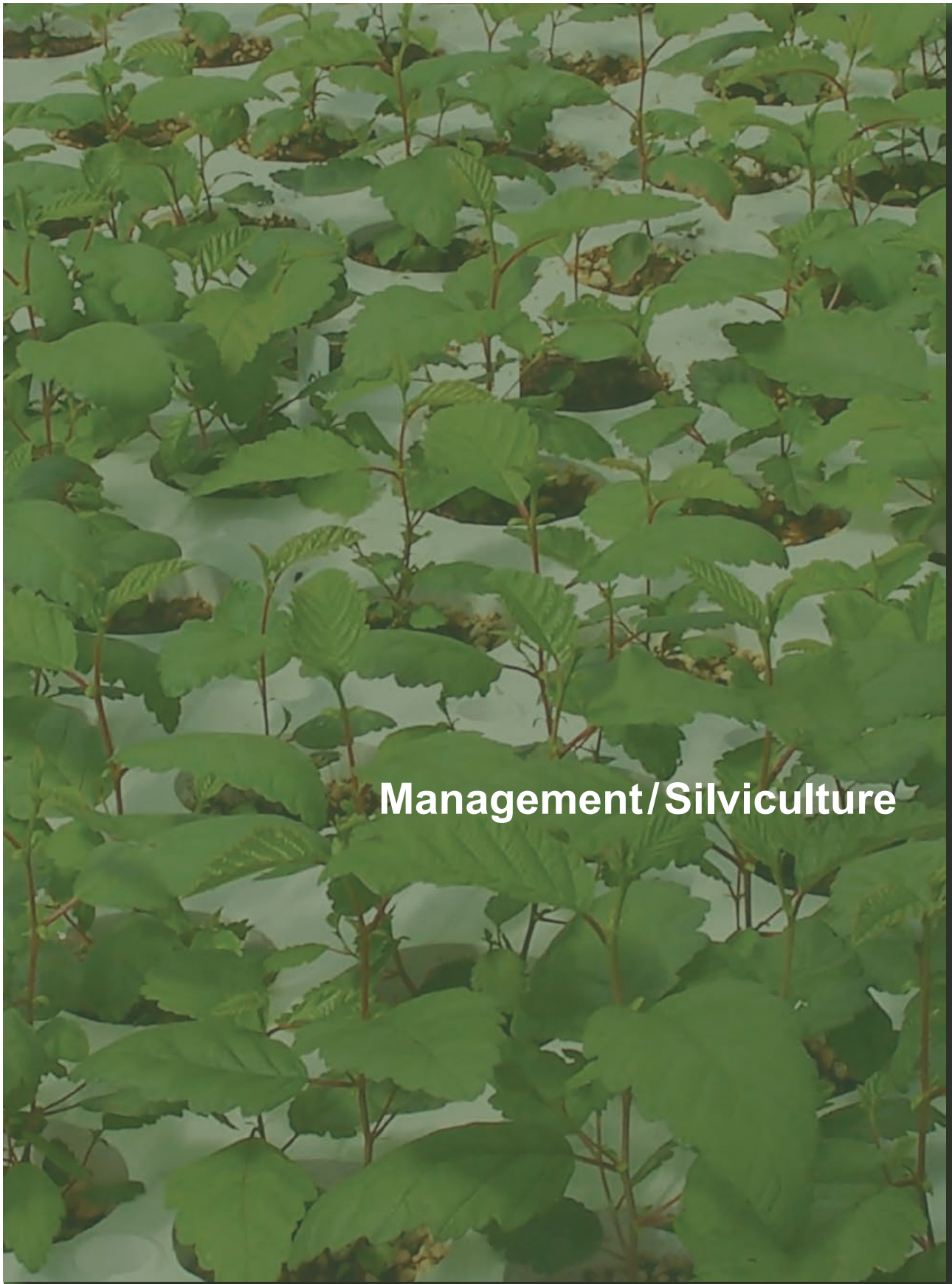
Management/Silviculture

Red Alder:
Its Management and Potential

Andrew A. Bluhm and David E. Hibbs[1]

Abstract

Red alder is now recognized as a valuable tree species in the Pacific Northwest because of recent increases in wood value, its fast growth and therefore its ability to produce sawlogs on short rotations. As compared to conifers, red alder has extremely fast juvenile growth rates but good growth is limited to a narrower range of site conditions. Red alder is also resistant to many of the diseases afflicting conifers, improves site productivity due to its nitrogen-fixing ability, and enhances wildlife and plant diversity across the landscape. Diameter and height growth of trees in managed plantations of red alder are greater than that of naturally regenerated stands. This apparent increase in growth is primarily due to the control of competing vegetation and planting density, and intermediate silvicultural activities (i.e. thinning). This faster growth results in a shorter time required to achieve trees of any given size. Tree form is also improved with management due to more uniform stocking. Results are presented here on the effect of initial planting density and various thinning treatments on twelve-year-old variable-density red alder plantations. Initial planting density influenced early diameter and height growth. Up through age 6, diameter growth increased with increasing density until a crossover occurred between ages 7 through 11. Diameter increment ranged from 1.4 cm/year to 1.8 cm/year. Height growth also increased with stand density except at extremely high densities. Height increment ranged from 1.1 m/year to 1.4 m/year. Optimal alder height and diameter growth was maximized around 1400-1500 tph until about age 10, at which time optimal diameter growth shifted to lower densities. Early stand volumes of close to 80 m^3/ha were achieved in the intermediate planting densities mainly as a function of absolute tree number and minimum merchantability limits. Thinning increased diameter growth response as compared to the control plots and thinning at age five resulted in greater diameters than thinning at age eight. By age 12, diameters were 21% and a 14% greater than the control for the early thinned and later thinned plots, respectively. Post thinning annual diameter increments were 25% and 38% greater for the early thin and the late thin, respectively. Thinning had no effect on tree height. Thinning increased individual tree volume 14% and 4% over the control plots for the early thin and the late thin, respectively. Thinning reduced the number of merchantable trees per hectare. Volume per hectare was greatest in the early thin plots (89.0 m^3/ha), followed by the control plots (81.2 m^3/ha) and the late thinned plots (68.0 m^3/ha). These results illustrate that the careful control of planting density and thinning regimes provide opportunities to achieve higher yields of better quality logs in a relatively short time.

Keywords: red alder, *Alnus rubra*, management, silviculture, planting density, precommercial thinning, tree growth, stand yield

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Introduction

> "What is a weed? A plant whose virtues
> have not been discovered."
>
> – Ralph Waldo Emerson (1803-1882)

Red alder (*Alnus rubra*; hereafter referred to simply as alder) is the major hardwood tree in the Pacific Northwest (PNW), comprising approximately two-thirds of the hardwood growing stock in the region. Although always present in the landscape, alder has historically been a low-value and under-utilized timber resource. The origin of most stands was accidental (natural regeneration after fire, logging or failed conifer plantations) and management efforts focused on eradication or conversion. This is changing rapidly due to the increased commercial value and recognition of its ecological benefits across the landscape.

Alder's easy regeneration, rapid growth rates and log price trends make it an attractive species to manage in the Pacific Northwest. However, this has not always been the case. Until recently, alder has been considered a "weed" by most foresters in the region. In fact, even recently, debate still surrounds the desirability of managing alder. For instance, the OSU Extension Service released, in the same year, two publications, "Managing Red Alder" (Hibbs 1996) and "Converting Western Oregon Red Alder Stands to Productive Conifer Forests" (Bondi and Emmingham 1996). While some were trying to grow alder, others were trying to get rid of it.

Alder is not without its merits. It has always been a small component of the PNW conifer-based timber industry and has long been recognized as a desirable component in riparian systems. But as much as people used alder, the scientific understanding of this species lagged far behind that of its associated conifers. Recognizing the virtues of alder and the serious lack of silvicultural understanding, the Hardwood Silviculture Cooperative (HSC) was formed to improve the understanding, management, and production of alder. Due to the efforts of the HSC and other research organizations, the acceptance of alder is increasing along with (or due to) the growing knowledge base. This chapter describes the state of knowledge of managing alder plantations. Focus is primarily on four topics:

1) Characteristics of alder compared to conifers and other hardwoods

2) Reasons to manage alder

3) Differences between alder plantations and natural stands

4) Responses of alder to stand density management activities (initial spacing and thinning).

The HSC in brief

The Hardwood Silviculture Cooperative (HSC), begun in 1988, is a multi-faceted research and education program focused on the silviculture of alder and mixtures of alder and Douglas-fir (*Pseutotsuga menzeisii*). The goal of the HSC to improve the understanding, management, and production of alder. The activities of the HSC have already resulted in significant gains in understanding regeneration and stand management, and have highlighted the potential of alder to contribute to both economic and ecological forest management objectives.

To understand the response of alder to intensive management, the HSC has installed 26 variable-density plantations from Coos Bay, Oregon to Vancouver Island, British Columbia. The plantation distribution covers a wide range of geographic conditions and site qualities. At each site, cooperators planted large blocks of alder at four specific densities. Each block is subdivided into several treatment plots covering a range of thinning and pruning options.

Since the HSC was established, they (and many others) have learned a great deal about seed zone transfer, seedling propagation, stocking guidelines, identification of sites appropriate for alder, and the effects of spacing on early tree growth. Much of this information is available to the public and found on the HSC web-page http://www.cof.orst. edu/coops/hsc. Furthermore, the data set is now complete enough to begin analyzing the growth response of alder after thinning and/or pruning. However, much still needs to be accomplished. The ultimate goal is a better understanding of the effects of stand density on alder growth and yield and wood quality, and to develop a robust alder growth model.

How does alder stack up against conifers and other hardwoods?

There are obvious physical differences between alder and other conifers in the region, but perhaps the most important to managers is that there is relatively little knowledge about alder management as compared to conifers. This lack of information is a result of a combination of many factors, including inconsistent markets and the region-wide conifer-forestry mindset. Some of the important differences, with management implications, between alder and conifers are discussed below.

Alder is not what usually comes to mind when imaging the forests of the PNW. Conifers dominate the landscape, in abundance, size and stature. Hardwoods comprise only 12% of the growing stock in the region (Raettig et al. 1995) and pale in comparison to conifers in tree size and lifespan. However, alder has impressive juvenile height growth rates, accumulating more than two-thirds of its mature height by age 30 (Harrington and Curtis 1986, Worthington et al. 1960). This rapid growth is attractive to foresters. However, this fast growth dictates that management activities must

Height Growth Comparison

Legend:
- Alder   S127
- Douglas-fir   S130
- Hemlock   S126
- Redcedar   S118
- Sitka spruce   S129

Source: *Green and Klinka*, 1994

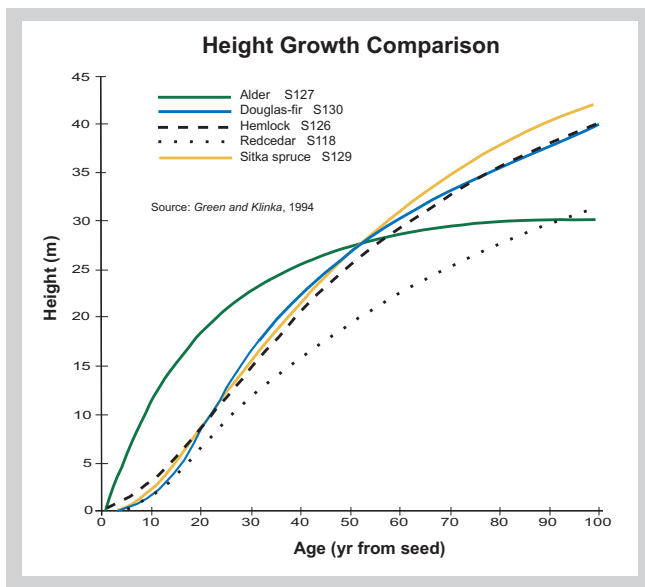Y-axis: Height (m)
X-axis: Age (yr from seed)

Figure 1—Comparison of height growth from seed to age 100 for red alder and associated coniferous species. Height curves and site index values are based on median values for conifers on Site productivity class II (from "Red Alder manager's Handbook for British Columbia," Peterson et. al. 1996).

be performed in a narrower time window and much earlier than in conifer stands for at least two reasons. One, stand characteristics are determined primarily by early stand conditions (i.e. diameter and height increment, live crown ratio). Two, vertical crown expansion is the primary means of crown response following thinning. Therefore early thinning is needed whereas thinning older stands (with minimal live crown) may not be beneficial.

Good performance of alder is limited to a narrower range of site conditions than most of its associated conifers. Despite the fact that alder is (incorrectly) perceived as a wet site species, it grows across a wide variety of sites. However, what is a good site for conifers may not be a good site for alder, and vice versa. For consistent, risk-minimizing management, species requirements (Harrington 1990) and proper site identification (Harrington 1986) is critical. Alder survival and growth is also more sensitive than conifers to small-scale, within-stand site variations.

At full stocking, alder usually has lower basal area than conifers (Puettman 1994), ranging from 20-30 m²/ha. Volume is likewise lower than conifer stands, ranging from 300-500m³/ha at 50-70 years. However, alder has similar rates of annual wood production as many conifers, with annual cubic volume growth rates of 21 m³/ha in pulpwood rotations of 10 to 12 years, and 14 m³/ha in saw-log rotations of 30 to 32 years (DeBell et al. 1978).

Today, alder is managed primarily for high-grade lumber/veneer. This fact means the quality of the resource (i.e. the log) is as important (or more so) than the quantity of the resource. Furthermore, unlike conifers, alder is a diffuse porous species. This trait allows uniform wood properties

and wood quality regardless of growth rate (Lei et al. 1997). These two traits have far-reaching impacts on management strategies.

Although alder is a minor component of the total timber volume in the PNW, it is, by far the most abundant hardwood in the region and comprises approximately 60% of the total hardwood resource (Raettig et al. 1995). It has a wide geographic range (1.9 million hectares) and a large volume of approximately 30 billion board feet (Glenn Aherns, personal communication). So while other hardwood species may be locally important, alder is the most important region-wide hardwood species.

A few factors other than the limited availability of other hardwoods favor the management of alder. Except for black cottonwood (*Populus trichocarpa*), alder growth rates far exceed other hardwoods of the region. Fast growth means short rotations. The only other region-wide hardwood species, bigleaf maple (*Acer macrophyllum*) has been found to be notoriously hard to grow. Alder seedlings are less susceptible to browsing than those of bigleaf maple. Furthermore, compared to many other hardwood species, living alder has surprisingly little decay. Allen (1993) indicates that merchantable volume losses to decay average 4% in alder 60-80 years old.

Why manage alder?

First and foremost, alder exhibits very rapid juvenile growth rates (Harrington and Curtis 1986, Nigh and Courtin 1998, Peterson et al. 1996) making it an appealing species to manage in short rotations. Through about age 25, alder height growth exceeds that of all associated conifers (fig. 1). Therefore, a primary management objective is to capture this difference. Although height growth rates decline rapidly after 20 years, a short-rotation, high-value crop can be achieved. With today's quick-return emphasis on plantation management, this short rotation length is economically appealing.

Although volume yields for alder are lower than those for conifers at typical conifer final rotation ages, alder volume is greater than the associated conifers at these short rotations (25-35 years). For instance, empirical data from natural stands in British Columbia indicate that for the first 25 years, the rapid volume growth of alder surpasses all other conifers. After age 25, well-stocked, undamaged (i.e. no weevil) Sitka spruce (*Picea sitchensis*) stands may surpass the alder. Western hemlock (*Tsuga heterophylla*) may catch up to alder by age 35, Douglas-fir by age 40, and western red cedar (*Thuja plicata*) not until age 75 (Peterson et al. 1996).

The resistance of alder to many diseases afflicting conifers offers another reason for interest. Although alder has diseases of its own, it is immune to two widespread diseases in the region. The high incidence of laminated root rot (*Phellinus weirii*) in the region causes untold amounts

of conifer growth losses. Conifer species show various levels of resistance, but all hardwoods are immune. On appropriate sites, alder is the species of choice in reforesting lands infected with laminated root rot (Nelson et al. 1978). Swiss needle cast, first observed in the Oregon Coast Range in the 1990's, affects approximately 50,000 hectares. In some heavily infected areas, it may cause up to 50% volume loss in Douglas-fir stands. Alder and western hemlock are alternative species to manage on lands heavily infected with this disease.

Alder produces more aboveground litterfall than do associated conifers. This litterfall has higher nutrient concentrations and decomposes more rapidly, resulting in improved nutrient cycling rates and leading to enhanced nutrient availability on a site. Furthermore, alder is a partner in a three-way symbiosis among roots, nitrogen-fixing actinomycetes in root nodules (*Frankia* spp.), and mycorrhizal fungi. This contributes to alder's rapid growth and positively influences soil structure and fertility. Rates of nitrogen fixation vary, but can range between 10-150kg/ha/yr (see table 1 in Bormann et al. 1994). Because nitrogen is the commonly limiting nutrient in the PNW, alder is likely to be important in the ecosystem productivity. Clearly, alder has the ability to improve soils not only for the next rotation, but long-term as well.

Studies in Alaska have shown that understory vegetation abundance, wildlife browse, songbird and aquatic invertebrate abundance, terrestrial arthropod abundance (Wipfli et al. 2002), and plant species richness (Deal 1997) increased with increasing proportion of alder in the stand. Furthermore, mixed alder-conifer stands provided greater complexity than stands dominated by either conifer or alder (Deal et al. 2004), enhancing the productivity and biological function of headwater streams (Wipfli et al. 2002).

Plantations vs. natural stands

The activities of the HSC have shown that managed plantations of alder can dramatically out-produce natural stands, resulting in a short-rotation, high-value crop. This apparent increase in productivity can be attributed primarily to three management activities: 1) proper selection of planting sites, 2) control of competing vegetation and initial planting density, and 3) intermediate stand treatments (i.e. thinning and/or pruning). Proper site selection and competition control are covered in other chapters. Planting density and thinning will be covered later in this chapter.

Perhaps the greatest advantage of managed stands of alder as compared to natural stands is the improvement in tree form. Most of the stems in older, natural alder stands have considerable lean and sweep, usually the result of uneven stocking, alder's high degree of phototropism, and differential growth rates (Wilson 1984). Such traits are considered defects and result in lower log value. Observations of planted stands indicate that the stems are much straighter than in unmanaged natural stands (Bormann 1985). Because the greatest value is in high-quality sawlogs, increases in log quality will result in direct increases in returns.

Alder plantations exhibit improved diameter and height growth rates across all site qualities and greater height growth across most planting densities except for extremely low densities. Research results indicate that the growth and yield of managed alder plantations will exceed that of natural stands (fig. 2). According to Worthington et al. (1960), 17 year old trees growing on site with a site index of 35 m would have a mean diameter of 15.3 cm. The mean diameter from one 17-year-old managed alder plantation of the same site quality was 23.3 cm, a 66% increase.

Height growth is also improved in plantations as compared to natural stands both across site quality classes and planting densities. Taking height growth data from 13 alder plantations, dividing into site quality class, and then overlaying these height growth curves on the site index curves from natural stands (Harrington and Curtis 1986) indicated that observed alder height growth in plantations was greater than predicted height growth across all site quality classes. Observed total height at age 12 was improved 1.4 m (9.3%) and 1.1 m (8.9%) for the high and low site quality classes, respectively (data not shown).

Alder growth is affected by stand density, and by controlling stand density it is possible to affect long-term stand trajectory. Figure 3 shows that observed tree height at year 12 was dramatically improved in all densities except of the extremely wide spacing (290 trees per hectare [tph]). Using the same data as the previous comparisons, observed height was improved 1.4 m (10.4%), 3.0 m (22.4%), and 2.0 m (14.9%) for the 680 tph, 1480 tph, and the 2800 tph densities, respectively, with the 1480 tph density approximating desired operational planting densities. However, tree height started to decline at extremely high densities (2800 tph). One would expect to see even greater declines in height growth with increasing density until it reached the levels of natural stands (which usually establish at very high densities).

So what are reasonable yield targets for managed alder plantations? Since no plantations have yet reached harvest age, one cannot say with absolute certainty. However, management of any species will increase yield. This pattern of increasing yield with management for Douglas-fir show that yields of intensively managed plantations can be double that of unmanaged natural stands. There is no reason to believe alder is any different.

Research results so far clearly indicate an increase in yield with alder management. Estimates of increased volume yield due to management range from 10-40% (Peterson et al. 1996, Puettman 1994) and increases in basal area of 14% (DeBell and Harrington 2002). Thinning can maintain diameter growth rates as much as 30-80%
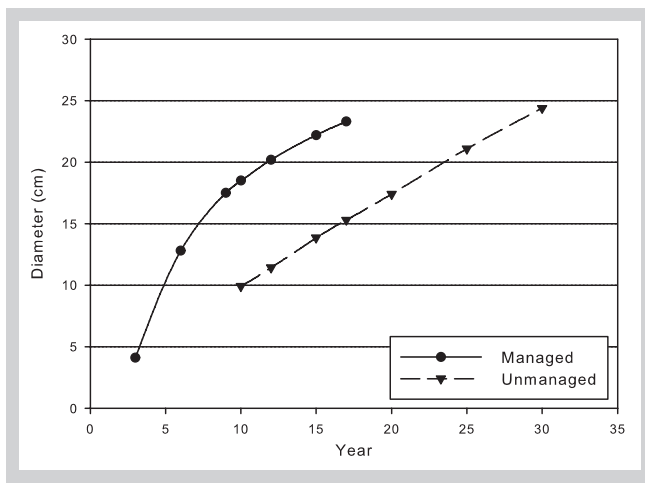
Figure 2—Comparison of diameter growth between an alder plantation (HSC Site #4201), planted at 1300 trees/hectare (tph) and thinned to 565 tph at age 4 with natural alder stands of the same site index (base age 50 years) of 35 m (from Worthington et. al. [1960]).

higher than those in unmanaged stands, at least until age 25. Thinning can maintain diameter growth rates of 0.75-1.0 cm/year for at least 10-15 years (Peterson et al. 1996). In another study, thinning increased the diameter growth of crop trees by 54% and net basal area growth was 60% greater, compared to unthinned stands (Hibbs et al. 1989).

Plantations would also have shorter rotations than natural stands. Managed stands are expected to attain an average diameter by 30 cm by age 30 years or earlier; an average natural stand would take 45 years (Peterson et al. 1996). Using the data from fig. 2 and assuming a constant diameter increment of 1.37 cm/year, the time required to produce a stand with mean diameter of 30 cm would be 22 years. DeBell and Harrington (2002) concluded that 20-year-old managed stands reached an equivalent basal area as that of a fully-stocked unmanaged stand of 27 years old. Other research (Barri Hermann, personal communication) has shown a halving of the time it takes managed plantations to reach the same yield (approximately 300 m^3/ha) as unmanaged stands (25 years vs. 50 years, respectively).

A serious concern for foresters is the lack of control one has over both density and stocking of natural stands. Of all the tools a silviculturist has, the manipulation of stand density holds the most promise; for density management provides opportunities to influence stand yield and tree size, form, and quality (Puettmann et al. 1993). Sawtimber yields and economic return can be greatly improved with management of most tree species—both alder and conifer—but the return for alder may be greater. With alder, management is needed to make the difference between good and poor results. The next section will describe experimental results of density management activities in alder plantations. Specifically, it will address the effect of initial planting density and thinning on individual tree and stand growth.
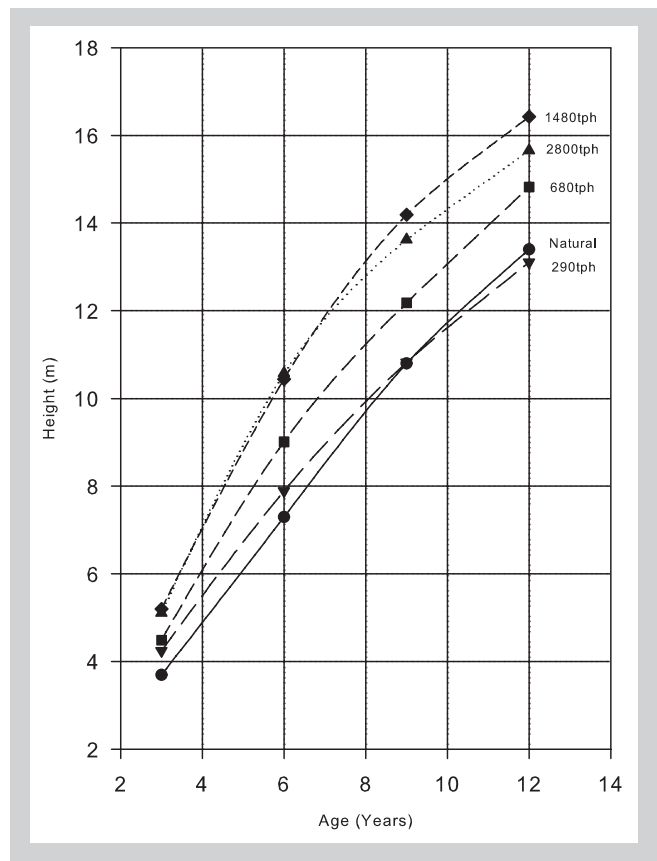

Figure 3—Comparison of height growth curves between managed plantations and natural stands of red alder. Plantation data is from 13 sites with a mean site index (base age 50 years) of 27.0 m (calculated from Harrington 1986). Height was calculated by planting density and was derived from the largest 247 trees per hectare. Natural stand data is from Harrington and Curtis (1986).

Density Management in Alder Stands

Methods

Site Description

The data in this analysis are from the 13 variable-density plantations of pure stands of alder in western Oregon and Washington that have reached 12 years old. The majority of plantations are in the Coast Range, with the remainder on the Olympic Peninsula, the Puget Trough, and the Western slopes of the Cascade Range (fig. 4). The climate is maritime and characterized by mild temperatures, wet, mild winters, cool, dry summers, and heavy precipitation (Franklin and Dyrness 1973). Soil types are silty loams, clay loams, gravelly loams, and cobbly loams. Elevation ranged from 46 m to 548 m, slopes ranged from 5% to 60%, and annual precipitation ranged from 115 cm to 330 cm.

Plantations were established on previously harvested sites of at least 6 ha and reasonably uniform ground

Figure 4—Location of Hardwood Silviculture Cooperative (HSC) pure alder plantations at least 12 years old.

conditions. Climatic (annual and growing season precipitation, length of growing season), and soils information was determined and site index was determined using the soil-site method of Harrington (1986). Mean site index (base age 50 years) was 30.9 m and ranged from 26-35 m. Treatment activities and data collection are administered by the Hardwood Silviculture Cooperative, Forest Science Department, Oregon State University, Corvallis, OR.

Measurements

At each site, blocks of inoculated, local alder nursery stock were planted with target spacings of 5.8 x 5.8 m, 3.8 x 3.8 m, 2.5 x 2.5 m, and 1.7 x 1.7 m (247, 568, 1297, 2967 tph). Site preparation methods used were the standard operating methods for the region and included normal competition reduction practices. Sites were planted using operational planting crews. Each treatment plot is 0.50 ha containing a 0.13 ha measurement plot. In addition to

the four control plots, thinning and pruning treatments are present at each site. Seedling survival was evaluated in year one and year two and plots were interplanted if mortality exceeded 30 percent. All invading trees and any overtopping shrubs were controlled

Two thinning treatments were performed on the two highest planting densities (1297 and 2967 tph). The first treatment was thinning when the tree crowns closed and lower branch mortality commenced (hereafter referred to as the "early thin"). The second thinning treatment was thinning when the average height to the live crown was between 4.5 and 6.0 m (hereafter referred to as the "late thin"). Residual target density for all thinning treatments was 568 tph. Leave trees were selected based on spacing, form, and dominance and marked with flagging. DBH was measured on all trees (both trees to be "cut" and "saved") and height and height to live crown was measured on all "save" trees. Measurements and thinning were done in the dormant season. Thinning was done with a chainsaw.

At age 3, 6, and 9, data on permanently tagged individual trees was collected in the dormant season. For every tree, stem diameter at 1.37 m (DBH), stem defect (fork, lean, sweep) and presence or absence of damage (animal, weather, etc) was recorded. Height was measured on a subsample of 40 trees spatially well-distributed over the plot that included the 10 trees of smallest diameter,10 of largest diameter, and 20 mid-range trees (based on diameter). Mean tree diameter was calculated as quadratic mean diameter. Plot means were calculated for diameter, height, and height to live crown for 1) the sample of trees on the plot that would represent the 247 trees per hectare with the largest diameter (used for initial planting density comparisons), or 2) all the trees on the plot (used for thinned versus unthinned comparisons). Actual density differed from target density and was calculated as the number of trees alive at age three, averaged across all sites. Individual tree volume was estimated from Skinner (1959) and volume per hectare was calculated by multiplying mean individual tree volume by the number of merchantable trees per acre (diameter greater than 15 cm).

Results
Planting Density

Early in stand development (through age 6), diameter increased with increasing density (fig. 5). After age 6, reduction of diameter with increasing density was observed primarily for the highest density. By age 9, DBH for the 2800 tph plots was 2.9 cm less (16% less) than the DBH in the lowest density (290 tph). DBH in the two intermediate densities was practically equal to the lowest density at age 9. Annual increment peaked at age 6 for all densities and then declined. At age 12, annual DBH increment ranged from 1.4 cm/yr to 1.8 cm/yr across all densities. By age 12, the typical reduction in DBH with increasing density was observed.
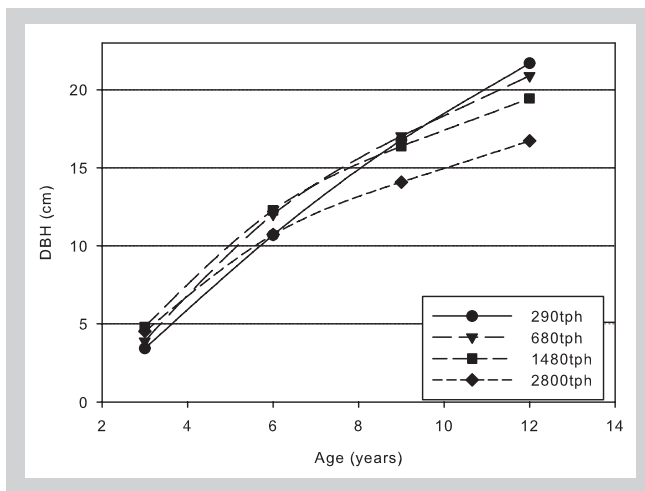
Figure 5—Comparison of diameter at breast height (DBH) by initial planting density for the 247 largest trees per hectare (crop trees). Data is derived from 13 red alder plantations throughout the Pacific Northwest with an average site index of 30.9 m (base age 50 years) calculated from Harrington (1986).
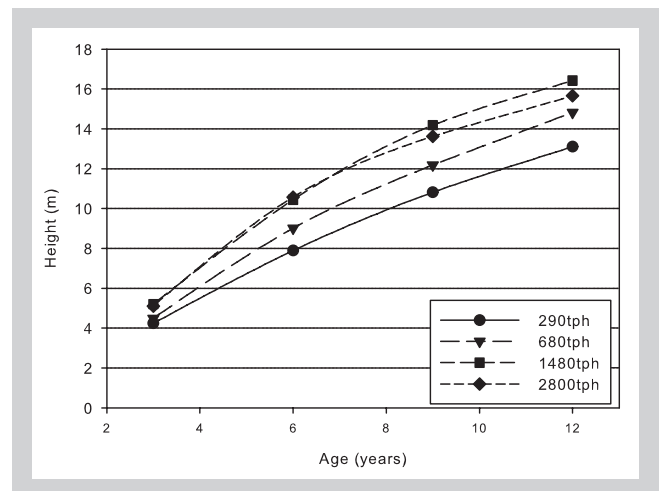

Figure 6—Comparison of total tree height by initial planting density for the 247 largest trees per hectare (crop trees). Data is derived from 13 red alder plantations throughout the Pacific Northwest with an average site index of 30.9 m (base age 50 years) calculated from Harrington (1986).

The influence of planting density on height was similar to that of DBH. Generally, height increased with density (fig. 6). This positive relationship was observed through age 6, after which height growth reductions were greater for the 2800 tph plots as compared to the 1480 tph plots. From age 6 through 12 the relative rankings did not change. As compared to the lowest density, total tree height increased 13%, 25%, and 19% for trees planted at 680 tph, 1480 tph and 2800 tph, respectively. For every measurement date, the lowest density (290 tph) had the shortest trees. By age 12, tree height in this density was at least 1.7 m less than the next closest planting density. At age 12, annual height increment ranged from 1.1 m/yr to 1.4 m/yr across all densities.

Across all densities, individual tree volume averaged 0.16 m³ and ranged slightly from 0.14 m³ to 0.18 m³ (data not shown). A pattern of decreased individual tree volume with increasing density was observed. The number of merchantable trees varied substantially by planting density (data not shown). The intermediate densities, 680 tph and 1480 tph, had two to three times (432 tph and 494 tph, respectively) the number of merchantable trees per acre than that of both the high (202 tph) and low (158 tph) extremes. The proportion of merchantable trees to total trees was 0.56 and 0.63 for the 290 tph and the 680 tph densities, respectively, then declined to 0.33 for the 1480 tph and dropped sharply to 0.07 for the 2800 tph density.

The sharp differences in the number of merchantable trees per acre accounted for large differences in volume per hectare. Volume per hectare for the 680 tph and the 1480 tph was 73.3 m³/ha and 81.2 m³/ha, respectively. These volumes were almost three times that of the two density extremes. Volume per hectare for the 290 tph and the 2800 tph was 28.5 m³/ha and 29.6 m³/ha, respectively The 290 tph density

had the largest individual trees; there were just not that many of them. The 2800 tph density had a lot of trees, just not many yet of merchantable size.

Live crown ratio, an important indicator of tree vigor, differed predictably by density. Figure 7 illustrates the decrease in crown ratio through time and with increasing density. Reductions in crown ratio commenced immediately and were of greatest magnitude in the highest density. Reductions occurred later and were of less magnitude as density decreased. No appreciable drop in crown ratio occurred in the lowest density through age 12. Although reductions in crown ratio are seemingly severe, it is important to note that even in the highest density, crown ratios of the crop trees are still greater than 50%. These results imply that although interspecific competition is undoubtedly occurring, dominant tree vigor remains high.

Thinning

Table 1 describes the tree and stand characteristics, both pre-and post-thinning, for all four treatments. In the 1480 tph density (both the early thin and the late thin treatments), thinning removed about half of the basal area and for the 2800 tph density, approximately two-thirds of the basal area. There were similar reductions in relative density.

Tree and stand responses to thinning are presented only for the 1480 tph densities with some comparisons to the 2800 tph densities. Two main factors affect tree and stand response to thinning; the timing and the intensity of thinning. Therefore, the similar response patterns observed between the two densities reveals a notable result, intensity (i.e. proportion of trees or basal area removed) has little effect on tree and stand growth following thinning at least within these timings and intensities. However, the timing of thinning noticeably affects tree and stand growth responses.

Table 1—Stand characteristics of thinned HSC plots.

Treatment	Early Thin		Late Thin	
	1480 tph	2800 tph	1480 tph	2800 tph
Age at thinning	5.09	5.27	8.73	8.20
Pre DBH (cm)	6.15	6.20	11.62	9.15
Post DBH (cm)	6.79	6.99	12.70	10.81
Post Live Crown Ratio	0.87	0.78	0.63	0.52
Pre Density (tph)	1332	2474	1371	2646
Post Density (tph)	555	573	584	624
% Density Removed	57%	72%	57%	76%
Pre Basal Area (m2/ha)	4.07	7.36	14.34	17.22
Post Basal Area (m2/ha)	2.09	2.26	7.43	5.78
% Basal Area Removed	48%	65%	48%	67%
Pre Relative Density	0.14	0.25	0.37	0.49
Post Relative Density	0.07	0.07	0.18	0.15
Relative Density Removed	0.07	0.18	0.19	0.34

Thinning increased diameter growth response as compared to the control plots; however, thinning at age five resulted in greater diameters than thinning at age eight (fig. 8). At age 12, diameters in the early thinned plots were 3.8 cm greater than the control while diameters in the late thinned plots were 2.3 cm greater. This corresponds to a 21% and a 14% increase, respectively. Annual diameter increments since thinning were 2.0 cm/yr and 1.5 cm/yr for the early thin and control, respectively and 1.3 cm/yr and 0.8 cm/yr for the late thin and control, respectively.

Thinning had virtually no effect on tree height (data not shown). At age 12, tree height ranged between 14.1 m and 15.0 m. Control trees were the tallest. There was only a 3% and a 6% reduction in tree height for the early thin and late thin, respectively.

Thinning increased individual tree volume. Individual tree volume at age 12 in plots thinned at age five was 0.19 m³, a 14% increase compared to unthinned plots (0.16 m³). The volume of trees thinned at age eight was only 4% greater (0.17 m³) than unthinned trees (data not shown). Thinning reduced the number of merchantable trees per hectare. There were 494 tph of merchantable size in the unthinned plots as compared to 469 tph in the early thin and 400 in the late thin (data not shown). The minor differences in individual tree volume and merchantable trees per hectare resulted in slight differences in volume per hectare. The greatest volume occurred in the early thin plots (89.0 m³/ha), followed by the unthinned plots (81.2 m³/ha) and finally the late thinned plots (68.0 m³/ha). This corresponded to a 9% increase in volume for the early thin and a 16% reduction in volume for the late thin compared to the controls.

Discussion

Planting Density

Contrary to conventional wisdom and much experience, the results presented here show that early diameter and height increase with stand density. Up through age 6, diameter growth increases with density until a crossover effect occurs between ages 7 through 11. Up through age 9, no penalty occurs with increasing density except at extremely high densities. Optimal diameter growth was maximized in the intermediate densities through about 10 years of age, after which optimal diameter growth shifted to the lowest density (290 tph). Only by age 12 was the pattern of decreasing diameter with increasing density observed. It could be argued that these results are not unique at all since the typical relationship of diameter and density did occur and (most likely) will continue and intensify as the stands age. Also, this crossover effect could be due to a combination of factors since early tree growth is a result of many factors in addition to density (Puettman 1994).

As discussed earlier in this chapter, one goal of managing alder is to capture the difference in early growth between alder and conifers. Therefore it follows that a manager should then continue to capture the difference in early growth between alder densities. These early differences are important for at least three reasons. First, due to the short rotation ages predicted, 10 years old is about half to a third of a rotation. It would be unwise to ignore this phase of growth. Second, since thinning can maintain diameter growth rates and current research indicates the possible need to thin alder plantations before age 10, one could not only take advantage of the positive relationship
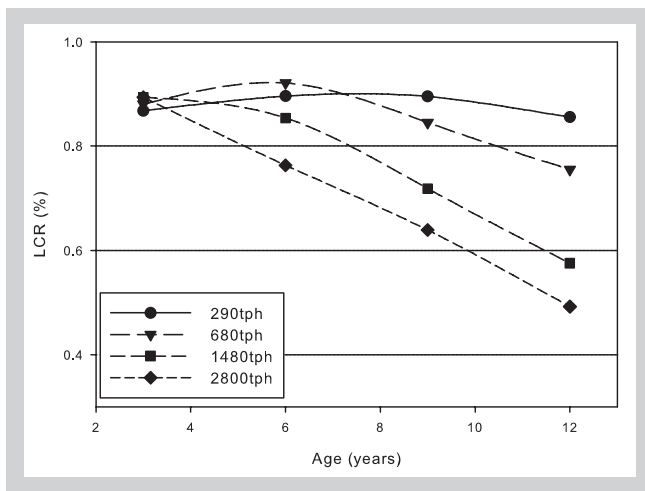
Figure 7—Comparison of live crown ratio (LCR) by initial planting density for the 247 largest trees per hectare (crop trees). Data is derived from 13 red alder plantations throughout the Pacific Northwest with an average site index of 30.9 m (base age 50 years) calculated from Harrington (1986).
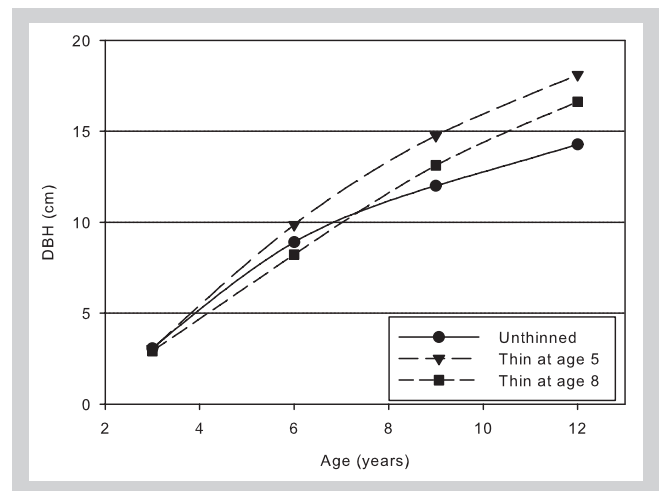

Figure 8—Comparison of diameter at breast height (DBH) for unthinned (control) trees, trees thinned at age 4 and trees thinned at age 8. All plots were planted at approximately 1480 trees per hectare (tph) and thinned to approximately 570 tph. Data is derived from 13 red alder plantations throughout the Pacific Northwest with an average site index of 30.9 m (base age 50 years) calculated from Harrington (1986).

between diameter and initial density, but possibly continue to build off of these increased growth rates. Third, since no penalty is incurred with increasing density but a huge improvement in tree form occurs with increasing density, log quality and thus value is maximized.

Mean annual diameter growth rates reported here (1.64 cm/yr, averaged across all densities) compare favorably to those reported in DeBell and Harrington (2002). They report annual diameter growth rates of 1.2 and 1.0 cm/yr for 20-year-old trees grown in a plantation on a comparable site. Across their lowest density plots (within the range of densities presented here and potential operational planting densities), the similar pattern of decreasing diameter increment with increasing density was detected.

Comparisons of the results presented here with other spacing trials are difficult due to the natural regeneration origin of previous spacing studies as well as the extremely high (outside the range of operational forestry) densities used. However, in a review of density management studies, Puettman (1994) reported annual diameter growth rates between 0.6 and 1.2 cm/yr. He then extrapolates that under optimal management regimes "good" sites could average trees 38 cm in diameter in approximately 27 years. Using these same assumptions and the mean diameter increment across all densities (1.64 cm/yr) reported here, it would take only 23 years to attain trees of comparable size.

Contrary to conventional wisdom, dominant height growth was not independent of stand density. Generally, height increased with stand density except at extremely high densities. Trees were consistently shorter in the lowest density plots. Will the crossover effect occur for height as it did for diameter? It did for the highest density but looking at the height growth curves of the three lower densities, it remains unclear. All curves seem to have parallel trajectories at age 12 and since height growth for alder decreases

dramatically around age 20, one could conclude that early differences in tree height due to planting density may maintain themselves through an entire rotation.

The rapid decline in height growth for only the densest plots raises an interesting question about potential differences in height growth patterns between plantations and natural stands. All published height growth curves are based on natural stands and natural stands usually establish at densities equal to, or more often, much higher, than 2800 tph. Height growth reductions of the lower plantation densities were less than the highest density and seem to remain fairly constant. These results further indicate tree growth in plantations is distinct from that of natural stands and elucidates the need to draw new height growth curves for plantation-grown trees.

The negative effect of density on diameter combined with the positive effect on height resulted in similar mean individual, merchantable tree volume across all planting densities. However, the number of merchantable trees per acre varied considerably, mainly as a function of the absolute number of trees per acre and minimum merchantability limits. Trees in the lowest densities were generally larger in diameter than the other densities and therefore had a very large percentage (but not number) of merchantable trees. Conversely, the densest plots had lots of trees but few above the merchantable diameter limit. At this time, the best balance between tree size and number is found in the intermediate densities. Stand volume was considerably greater at intermediate densities as compared to the two density extremes.

Individual crop tree volumes reported here (0.16 m³) were comparable but slightly greater than that reported by Hibbs et al. (1989) for 14-year-old individual crop

tree volumes found in a natural stand (0.15 m^3). Per hectare volumes of the two intermediate densities in this study (approx. 77.3 m^3/ha) was much greater than what Worthington et al. (1960) predicted for 15 year-old unmanaged alder of equivalent site productivity (31.4 m^3/ha).

These volume estimates are only a snapshot during stand development. Using these values at age 12 to predict volume at final rotation age is unwise for multiple reasons. First, as the stands age, growth rates change in different patterns for the different planting densities. These differential diameter and height growth rates are not accounted for and will result in major errors in extrapolation. Second, these are merchantable volume estimates (trees greater than 15 cm DBH). Not accounted for are the trees just below this limit that would become merchantable in the future. Third, stand growth (and thus volume) will be affected by any changes in site or stand growing conditions. Precipitation, storm events, insects, etc. all affect final stand volume.

The growth patterns observed here are unexpected results according to current theory (Grey 1989, Smith et al. 1997). Density-dependent height growth has been observed for southern pines (MacFarlane et al. 2000, Quicke et al. 1999) and for Douglas-fir (Scott et al. 1998). For alder, this effect has either not been observed (Bormann 1985, Smith and DeBell 1974) or observed for alder planted at extremely high densities (DeBell and Harrington 2002, Hurd and DeBell 2001), well outside the range of operational planting levels.

This research agrees with previous research (Bormann and Gordon 1984, Cole and Newton 1987, DeBell and Giordano 1994, Hibbs et al. 1989, and Knowe and Hibbs 1996) that optimum height growth is maintained at intermediate levels of density and reduced at either extreme. But a word of caution is needed when attempting to compare natural stand growth with plantation growth. Puettman (1994) recognized that site index curves are based on natural stands and natural stands come in at very high initial densities. This would result in reductions in potential height growth and an overestimation of productivity when applied to plantations. Furthermore, will this enhanced height growth continue to final rotation? Regardless, it is apparent that just the simple act of planting trees at lower densities than those found in natural stands can increase diameter and height growth through at least age 12.

Log quality is extremely important in determining value for alder since clear wood has much greater value than unclear wood. Perhaps what is more important than the differential effect of density on growth is the effect of density on tree form. Figure 9 illustrates the stem form differences found across planting densities. Increasing planting density reduces multiple stems, tree lean and sweep and increases the length of the branch-free bole;

resulting in increased log quality. This research and others has found that long-term diameter growth will be reduced somewhat at these higher densities. Wide spacings, however, lead to large branches on the lower bole that reduces 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), and then thinning once a desired branch-free bole is obtained. This research indicates planting at intermediate densities maximizes tree form with minimal deductions in growth. Furthermore, a clear understanding of the effect of live crown ratio on tree growth and log quality is absolutely essential in choosing and timing silvicultural treatments.

Thinning

The crossover effect observed in diameter due to planting density begs the question of whether or not to thin alder plantations (and if one should, then when and to what residual density). Clearly, diameter growth rates are optimized in intermediate densities through age ten, then they start to decline. This leads to the question; can these declines in diameter (and by extension, volume) growth be prevented with thinning? This question will be discussed in the framework of four issues: intensity of the thin, timing of the thin, tree vigor, and stem form.

Although not specifically tested in this project, it seemed that the intensity or magnitude of removal with thinning had little effect on tree growth response. As mentioned earlier, thinning 2800 tph plots to the same residual density as the 1480 tph plots (i.e. a much heavier thin, see table 1) resulted in the same patterns of individual tree response. However, stand responses would differ in that the leave trees in these denser plots would be smaller than the intermediate plots, would have reduced diameter increments, and would thus take longer to reach equivalent size. Secondly, it has been observed that alder is susceptible to weather damage following thinning, especially with drastic reductions from very high densities. The experimental design here had all thinning treatments to one residual density (approximately 570 tph). Therefore, until more research is done testing specific residual densities, specific recommendations on the intensity of precommercial thinning cannot be accurately made. However, within the range of the densities used in this project, thinning resulted in increased diameter response, had no effect on tree height, and thus increased individual tree volume regardless of pre- or post-thinning densities.

Results presented here indicate that thinning elevated diameter increment levels as compared to not thinning. Furthermore, thinning early offset or prevented the gradual decline in diameter increment with age and thus resulted in greater diameter increment when compared to thinning later. At age 12, the mean diameter of plots thinned at age five (on average) was 1.5 cm greater than plots thinned at age eight. This increase would likely be maintained throughout the
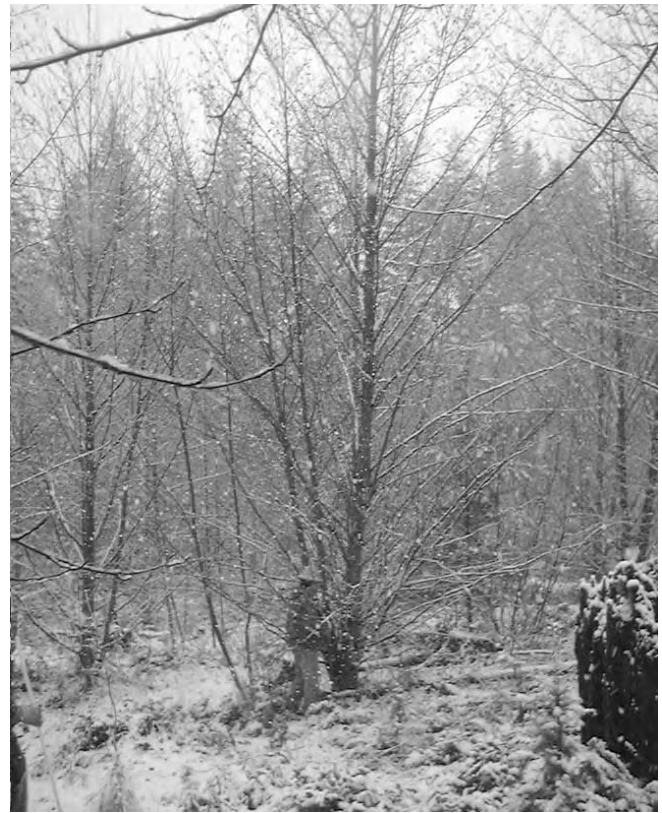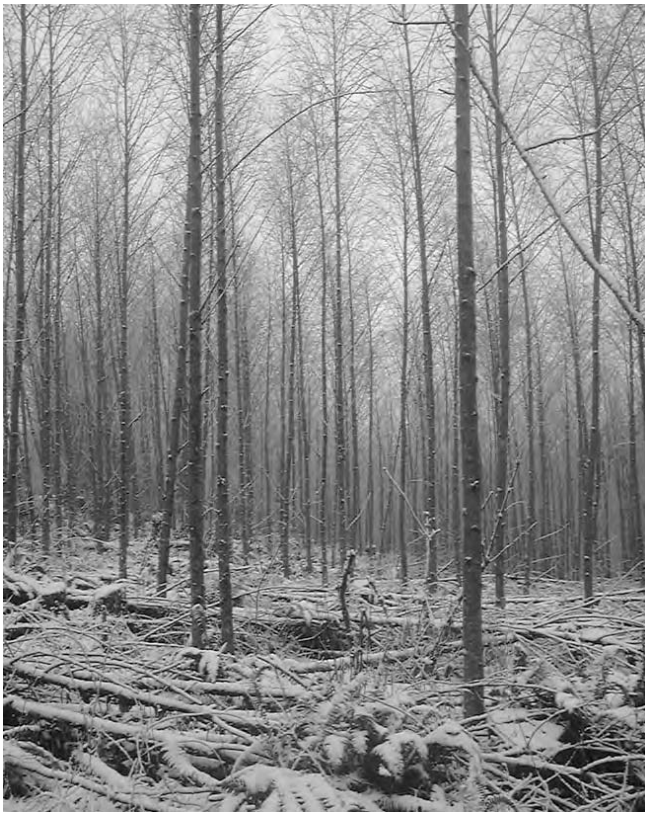
Figure 9—Comparison of tree form between trees planted at planted at 1480 trees per hectare (left) and planted at 290 trees per hectare (right). Both photos taken on the same day, from the same plantation, from the same location.

rotation as seen by the apparent parallel diameter trajectories of the thinned plots illustrated in fig. 8.

The question of when to thin can also be addressed by using this data and placing it into the context of relative density. Relative density was calculated for each of the four planting densities and plotted in relation to the density management guide (Puettman et al. 1993) in fig. 10. Line B (relative density of 0.65) is the average maximum or the "self-thinning" line that stands approach as trees grow and mortality reduces their numbers. Line C (relative density of 0.45) is the operating maximum which is the line above which considerable mortality occurs. Line D (relative density of 0.25) is the competition threshold which is the line below which the site resources are not fully utilized. The zone between lines D and C is considered the recommended management zone because 1) below line D individual tree diameter growth is maximized but stand productivity is reduced and 2) above line C substantial mortality and reduction in tree growth occurs. This management zone compromises individual tree growth and stand yield.

Therefore, according to the diagram, trees in the 1480 tph density would start suffering growth losses (i.e. competition) at age six and significant mortality at age ten. This timeframe of the management zone underlies the importance of early management and illustrates the narrow

"window" of management activities of alder stands as compared to conifers. However, the data used here implies that diameter growth reductions may occur even before age 6 (i.e. Line D) and waiting until age ten (i.e. Line C) would result in not only mortality but significant losses in diameter growth.

According to Puettman et al. (1993), the location of the competition threshold (Line D) was determined not only by diameter growth reductions due to competition but also by the observation that some stands thinned below this line showed reductions in height growth (also see Hibbs et al. 1989) and that trees growing in stands with densities below this line had poor height growth and stem form. Therefore, the recommendation is not to thin below a relative density of 0.25. The results presented here are contrary to this recommendation. First, as stated above, it seemed that substantial diameter growth losses in plantations occurred near or even below Line D. Second, no reductions in height growth after thinning occurred in any of the four thinning treatments, all of which reduced relative density far below Line D. Third, trees in these stands had already achieved desirable stem form and form did not deteriorate after thinning. The discrepancies between what was observed here and the recommendations from the stand density diagram (thin earlier and heavier) emphasize the need for more research on tree growth in plantations versus natural
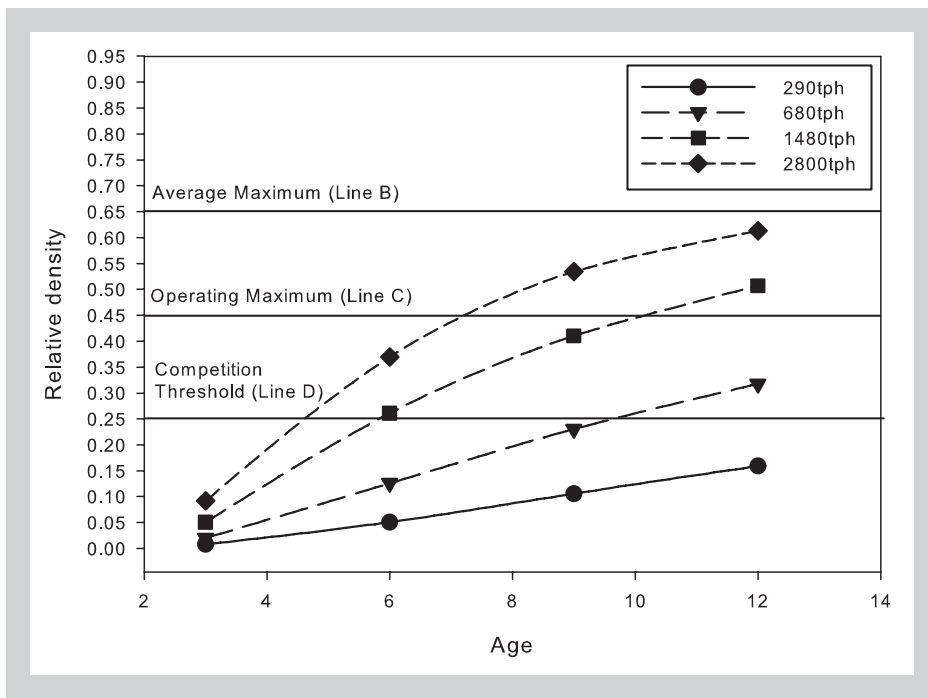
83

Figure 10—Relative density by initial planting density. Data is derived from 13 red alder plantations throughout the Pacific Northwest with an average site index of 30.9 m (base age 50 years) calculated from Harrington (1986). Lines B, C, and D are taken from the density management guide developed by Puettman et al. (1993).

stands, underscore the benefits of stand management and illustrate the importance of tree vigor and stem form in determining when to thin.

When alder is planted at densities high enough to rapidly occupy the site and (as shown earlier) to maximize early tree growth, crown recession occurs rapidly. Thus, it would seem that thinning early is crucial since thinning must favor trees with good growth potential (i.e. large crown size). Thinning early will capture the early rapid growth phase and maintain a good live crown ratio but reduce stem quality because of the presence of branches on the lower stem. Trees thinned late would have better wood quality but reduced vigor (as indicated by reduced crown ratios) and thus, less growth response following thinning. Therefore, as with all species, the goal of thinning is to balance the maintenance of vigorous individual tree growth with overall stand growth and, more exclusively with alder, optimal stem quality.

Thinning in alder plantations increased individual tree diameter with minimal effect on height growth. Volume data at age 12 indicated that the reduction in stand density through thinning is offset or will be overcome by the increased diameter growth rates associated with thinning. Furthermore, the accelerated diameter growth rates would result in shorter rotations because the remaining trees would reach commercial size sooner. However, the long-term effects of the time and intensity of thinning on plantation yield and wood quality are still unknown.

Conclusion

Red alder (*Alnus rubra*) is the major hardwood tree in the Pacific Northwest yet, until recently, management efforts have been practically non-existent. However, the rapid growth rates and the recent increase in alder prices have resulted in increased interest in managing alder.

Due to a number of biological factors, managing alder is different from managing conifers. First, alder has impressive juvenile growth rates. It is not until about age 40 that the associated conifers surpass alder in height. This not only reduces rotation lengths but creates a narrower window in which to perform management activities. Second, good performance of alder is limited to a narrower range of sites than most conifers. For instance, alder is very susceptible to summer drought stress as well as unseasonable frosts. This makes site selection and site preparation an extremely important first step in alder plantation establishment. Third, alder is resistant to many diseases that afflict conifers such as laminated root rot and Swiss needle cast. Fourth, alder is an important element of healthy forests and biodiversity. Alder fixes nitrogen (improving site productivity), furnishes wildlife habitat and is an important component in aquatic food webs. Fifth, alder is not a commodity product; it occupies a special niche due to its uniform wood properties. This places special emphasis on log quality as well as overall yield.

Previous research has indicated that managed stands of alder can out-perform natural stands. Not only are growth rates increased, but tree/stem form are improved as well. This improvement is mainly due to proper site selection, control of competing vegetation and planting density, and silvicultural treatments.

When deciding on whether, when, and how much to thin, a manager must weigh individual tree growth and vigor, stand yield, and log quality. Regardless of specific ownership objectives, it is recommended that precommercial thinning should be done early in stand development. Thinning too early negates the growth benefits associated with higher densities and would reduce stem quality due to branches. Thinning too late results in improved wood quality (due to self-pruning) but the trees are smaller with reduced vigor and thus do not respond well to the thinning.

More research into the long-term effects of initial plantation density and the timing and intensity of thinning treatments on alder tree growth, wood quality, and stand yield is needed. Once this is achieved and an alder growth and yield model is developed, alder can contribute to both economic and ecological forest management objectives.

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Red Alder Plantation Establishment: Site Selection, Site Preparation, Planting Stock, and Regeneration

Alex Dobkowski[1]

Abstract

The information to be presented is based on research results from experimentation done on red alder (*Alnus rubra* Bong.) from 1987 to 2001 by Weyerhaeuser Company, and anecdotal evidence from almost 20-years of experience growing red alder at an operational-scale on Weyerhaeuser lands in western Washington.

As with any tree species, the keys to successful red alder plantations establishment are: (1) site selection; (2) quality planting stock; (3) site preparation; (4) out plant timing; and (5) planting quality. However, red alder is generally less forgiving of sub-optimums for these factors than other commercial tree species grown in the Pacific Northwest.

Frost, very poor soil drainage, drought stress and exposure can negatively affect establishment success, site productivity and wood quality (from top-breakage and sun-scald) of red alder plantations. Sites with these characteristics are not suitable for growing of red alder commercially. Frost/cold is the number one killer of planted red alder—avoid frost prone sites and within-site frost pockets. Generally, the best sites biologically for growing red alder are also some of the best sites for growing Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco).

All stock types have been used to establish red alder plantations successfully. Seedling morphological characteristics and physiological readiness at time of planting, and site conditions over the first 3-years, determine field performance success. Seedling survival and early growth is predicted by the following factors: (1) stem basal caliper (measured 25-mm above the root-collar); (2) height; (3) height on the stem to the lowest healthy bud; (4) percent of the stem with healthy buds; (5) total vegetation ground cover in years 1 and 2; and (6) root system fullness. Basal caliper appears to be the most significant factor for seedling survival and growth—presumably because more stored carbohydrates are available for new root growth early in the growing season. This allows the tree to develop an active root system before the demands from rapid leaf growth begins. Seedlings with a basal caliper of 6-10 mm, height of 60-90 cm, a root mass that is dense enough to indicate a good balance with the shoot, and with abundant *Frankia* nodules throughout the root system will survive, grow fast and capture the site quickly.

Weed competition > 30% cover decreases growth and > 90% decreases survival. Currently there are few selective herbicides for release of planted red alder from weed competition—most broadcast vegetation control must be done prior to planting.

The spring planting period begins when the probability of a killing frost is low and ends before there is an appreciable seasonal drying of the soil. The recommended planting window for western Washington, at elevations less than 300 meters, is mid-March to mid-April.

Red alder plantation establishment can be very successful on "the right sites," when the "correct" silviculture is practiced. Establishment success and subsequent tree growth can be highly variable on "sub-optimal" sites, or when sub-optimal silviculture is practiced.

Keywords: Red alder (*Alnus rubra* Bong.), site selection, planting stock, site preparation and planting.

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Introduction

Red alder (*Alnus rubra* Bong.) is a valuable hardwood tree species that competes with many other hardwoods in the marketplace (Western Hardwood Association 2005). Red alder is used principally for the production of lumber and veneer—high-grade lumber for fine furniture, cabinets, and turnings; lower-grade lumber for furniture frames/interior parts and pallets; face veneer for cabinets; and core veneer for high-quality paneling. When red alder is compared to other important North American hardwoods—yellow birch (*Betula alleghaniensis* Britton), black cherry (*Prunus serotina* Ehrh.), sugar maple (*Acer saccharum* Marshall)—its workability index reflects that it is very competitive for finishing, machining, sanding, polishing, color uniformity and gluing, and it has the lowest specific gravity/strength. A very important characteristic of red alder is that the wood readily accepts stain enabling red alder to mimic more expensive woods very convincingly. Lower grade alder logs have value as a desirable pulpwood species.

Because of the expectation of a continuing strong hardwood industry in the Pacific Northwest, some landowners are investing in growing red alder saw-logs to provide future raw material for that industry. This paper will focus on what we know about the requisites for successful red alder plantation establishment. The information presented is based on results from experimentation, and anecdotal evidence from almost 20-years of research and operational experience in red alder tree growing. The intent is to provide a practical guide to assist landowners in growing red alder plantations successfully.

As with any tree species, the factors to successful red alder plantations are: (1) site selection; (2) quality planting stock; (3) correct site preparation; (4) proper out plant timing; and (5) planting quality. The exception for red alder is that the species is generally less forgiving of sub-optimums for these factors than other commercial tree species grown in the Pacific Northwest.

Site Selection

Site selection for red alder requires evaluation of site characteristics relative to the risk of plantation failure from environmental factors, red alder productivity potential, and the need for herbaceous weed control. The objective is to exclude from consideration planting units that will have obviously low red alder productivity potential and/or obviously high risk of plantation failure due to poor soil drainage, frost, drought or inability to control weed competition.

Risk of Plantation Failure

Some characteristics of the better sites for red alder management are (Harrington 1986, Harrington et al. 1994):

Elevation – Less than 300 m;

Physiographic position – Flood plain, terrace, bench, lower slopes;

Aspect – West to east slopes;

Slope – 10-30%;

Soil drainage –Well drained;

Soil texture – Silt loam, silty clay loam, clay loam, silty, clay;

Soil depth – Greater than 75 cm;

Depth to summer water table – 2- to 3-meters; and

Parent material – Sedimentary, sedimentary/volcanic, and volcanic.

Planting units with a combination of the following site characteristics are probably undesirable candidates for red alder production (site productivity will be low and the risk of plantation failure will be high):

- Bog or marsh areas;
- Upper slope positions;
- Ridge tops;
- S to SW exposures;
- Frost pockets (within site & "macro" cold air drainage);
- Exposed and windy sites;
- Droughty sites - sandy, excessively drained, soils;
- Poorly drained soils;
- Depth to summer water table less than 1-meter or greater than 4-meters.
- Highly weathered/leached soils.
- Elevation greater than 450 meters.
- Sites with expected very high levels of weed competition that can not be adequately controlled to low levels—i.e. salal (*Gaultheria shallon*).

Foresters need to use their judgment when determining the suitability of a site for growing red alder. Any single characteristic that would result in a high risk of plantation failure may be sufficient to exclude a unit from consideration for red alder production (e.g., a severe frost pocket). If a unit has an "undesirable" characteristic that does not increase the risk of mortality, it may still be acceptable for red alder production depending on the combination of other factors (e.g., S to SW Exposure). A site with multiple "undesirable" characteristics is probably unacceptable as a red alder management unit (e.g., S to SW exposure and excessively drained soils).

Select sites with a low risk of regeneration failure. Poor soil drainage, frost, drought and difficult to control weed communities can hinder successful plantation establishment considerably.

Although naturally occurring red alder can tolerate poorly drained soils, careful examination shows that it occupies only the better drained micro-sites within the irregular topography of a wet site. The establishment of a well-stocked plantation is significantly hindered on wet sites because suitable micro-sites occur infrequently and are poorly distributed.

Newly planted seedlings are adversely affected by poor drainage. Where saturated soils persist into the growing season, poor drainage induces seedling mortality and also severely restricts root growth of those seedlings that survive periodic soil saturation. The diminished root system can predispose newly planted seedlings to later summer drought stress. Given the heavy herbaceous weed communities that can develop on these sites and limited site preparation options, drought stress effects can be compounded, resulting in considerable seedling mortality. Red alder is a riparian and upland site species—not a wet-site species.

Areas of high frost hazard should not be regenerated to red alder. These sites are associated with topographic features having a high probability of cold air drainage from higher elevations in the spring and fall seasons (fig. 1). Vegetation condition and topographic features can be used to assess the likelihood that a site is in a cold-air drainage. Red alder and other naturally occurring woody vegetation can show evidence of previous frost events. Areas where fog hangs for long periods indicate potential for a frost pocket. Valleys exhibiting a gentle gradient from high elevation areas or topographic features that form blockages tend to slow the flow of cold air and be more frost-prone. Frost risk is increased if there is a cold-air dam such as a ridge of mature trees downhill or downwind (a planting unit that is surrounded by timber can create a frost pocket).

There is evidence that soils with a high summer water table may be more prone to frost risk. These soils provide a good supply of late-growing season soil moisture—prolonging red alder growth well into the early fall. Alder in this de-hardened state are very vulnerable to early frost. This type of an effect is usually very clustered within a plantation. Exposed sites in the Cascade foothills, that are prone to east-winds in the winter, also have a high risk of freeze related mortality and damage. The effects of cold associated with normal seasonal weather can be mitigated a considerable amount through site selection. However, young red alder plantations will always be vulnerable to the effects of arctic outbreaks in the early-autumn because red alder tends to grow late into the growing season and is usually not hardened-off by early-autumn.

Summer drought and heat stress contribute significantly to reduced performance of newly planted red alder

Figure 1—Shown is an example of how topographic conditions can be evaluated to judge the risk of cold damage—"Dw" has a high risk of frost—cold air accumulation; "Ll" on mid- to upper slope positions has enough "air" drainage to prevent serious frost. Note photograph plantation failure from cold damage on "Dw" and vigorous, well-stocked plantation just upslope on soil "Ll".

seedlings. Regeneration difficulties have been particularly noted on droughty sites typified by south-southwest aspects, steep slopes, and coarser textured soils. Units with heavy textured soil that have been seriously compacted from ground-based logging tend to have excessive alder mortality on logging trails—root system development seems to be seriously impeded and moisture stress results as the crown foliage mass continues to develop.

There may be portions of a planting unit that is unsuitable for red alder—frost, wind, or drought prone. If these micro-sites are large enough to be identified and flagged-out, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) or some other species should be planted. An example of this would be units in the Cascade foothills. The mid- and lower-slopes can be ideal for red alder and the ridge-top slope position unsuitable. Steep southwest slopes in a unit with predominantly moderate slope and favorable aspect are another example.

Red Alder Site Productivity

Site productivity for red alder is an important consideration for commercial production. Site index based on the heights of an appropriate sample of trees near index age (i.e., base-age 20 or 50-years for red alder) is a common practice for making this determination. Most often site index can not be estimated directly from tree height measurements because the tree species of interest is not presently growing in even-aged stands, of the correct age, in the vicinity of

sites to be regenerated. A useful estimate of red alder site productivity (base age 50-years, Worthington 1960) can be obtained in the absence of site trees to measure following the procedures given in, "A Method of Site Quality Evaluation for Red Alder" (Harrington 1986).

The evaluation process requires that the user score soil-site factors that pertain to geographic/physiographic characteristics, soil moisture/aeration, and soil fertility/ physical properties. Applying the site quality evaluation method requires the soil survey/soil series profile descriptions, long-term meteorological data, local knowledge and on-site observation.

Soil survey and soil series profile descriptions provide information on the following: 1) elevation; 2) physiographic position; 3) aspect and slope; 4) soil texture; 5) soil depth; 6) soil rock and gravel content; 7) soil parent material; 8) soil pH; 9) soil organic matter, and 10) soil bulk density. Published long-term meteorological data from the recording station closest to the planting unit is used to determine growing season precipitation (April 1 through September 30). Local knowledge is used to assess special hazards (frost pockets, exposure, wind, etc.), internal soil drainage, and approximate depth to the summer water table.

On-site observation is required to: 1) confirm the soil-site factors taken from the soil survey; 2) determine site specific special hazards; 3) verify internal drainage and summer water table depth assumptions; 4) evaluate the character of red alder growing in the vicinity of the unit (frost or heat damage, health, stem form, etc.).

Experience has shown that this approach classifies sites accurately as to good, intermediate or poor sites for growing red alder. The accuracy of the method can be increased by giving more of a deduction in site-points for droughty sites, exposed windy sites, frost pockets, and when pH in the surface soil is 4.0 or less.

Lands selected for growing red alder should be good sites and have a very low risk of poor establishment success. Generally, the best sites biologically for growing red alder are also some of the best sites for growing Douglas-fir.

Planting Stock

All stock types (containerized plug, bare-root, plug+1/2 transplant) have been used successfully to establish red alder plantations (Radwan et al. 1992, Dobkowski et al. 1994). Research trials have shown that survival and early growth of bare-root seedlings is predicted by the following morphological characteristics and other factors: (1) basal caliper (measured 25mm above the root collar); (2) height; (3) height to the lowest healthy bud or lateral branch; (4) percent of the stem with healthy buds or branch laterals; (5) total vegetation ground cover in years 1 and 2; and (6)

root system fullness. Root System fullness for bare-root seedlings is classified as follows:

Good (fig. 2)—An abundance of fibrous, flexible, heavily branched roots, and an absence of heavy, stringy, non-branched roots; root mass is dense enough to indicate a good balance with the shoot; abundant *Frankia* nodulation present.

Fair (fig. 3)—One or several heavy, woody, non-branched roots, but a portion of the root system is fibrous and well-branched, shoot appears proportionately heavier than the root system (i.e., shoot and roots are not "well balanced"); *Frankia* nodulation present.

Poor (fig. 4)—Root systems are predominately composed of heavy, woody, non-branched roots, or if there are fibrous roots, they are too few to support the tree; the root system is clearly out of balance with the shoot. *Frankia* nodulation is rare.

Basal caliper appears to be the most significant factor for seedling survival and growth—presumably because more stored carbohydrates are available for new root growth early in the growing season. This allows the tree to develop an active root system before the demands from rapid leaf growth begins.

Figure 5 gives an example from one experiment showing the relationship between the probability of achieving an age-1 plantation-height target and seedling root system, basal caliper and height (A. Dobkowski, unpublished data 2004). This result from a logistic regression analysis indicates that seedlings with a good root system, basal caliper of 6 mm or more, and height of 60 cm has a 0.80 probability of achieving the age-1 height target.

Results from this and other field experiments, coupled with operational experience, suggests the following specifications for bare-root seedlings (Ahrens 1994, Dobkowski et al. 1994, Molina et al. 1994, Kendall et al. 2003):

- Height—range 45-100 cm—with approximately 70% of the seedlings between 60 and 70 cm;

- Basal caliper (measured 25 mm above the root collar)—5 mm minimum caliper—with approximately 70% of the seedlings between 6 and 9 mm;

- Root systems characterized by an abundance of fibrous, flexible, heavily branched roots, and an absence of heavy, stringy, unbranched roots, root mass dense enough to indicate a good balance with the shoot; many Frankia nodules;

- Healthy branches or buds along the full-length of the stem; and

- Free from disease and top-damage.

Figure 2—Shown are bare-root seedlings (1+0)—height and basal caliper suitable for out-planting—"Good" root systems.

Figure 4—Shown are bare-root seedlings (1+0)—height and basal caliper suitable for out-planting—"Poor" root systems.

Figure 3—Shown are bare-root seedlings (1+0)—height and basal caliper suitable for out-planting—"Fair" root systems.
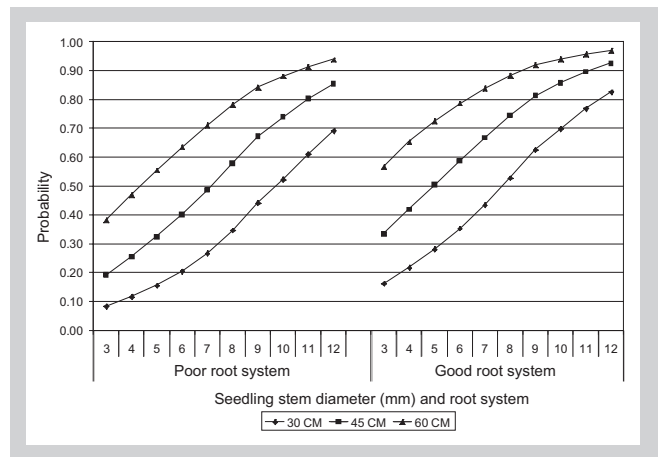

Figure 5—Shown is the probability of bare-root seedlings, with poor or good root systems, achieving 1-meter in height one growing season after planting.

Bare-root seedlings with these attributes, when planted on good sites and with proper site preparation, will achieve survival and height-age targets most of the time. Generally, large seedlings (large caliper, balanced height and caliper, good root systems and *Frankia* nodulation) are preferred—even when taking into consideration that the logistics of handling and planting large stock is more problematic and can incur more cost. Smaller stock types and seedlings generally have a much greater risk of poor performance.

Weed Control

Heavy first and second-year weed competition, particularly grass and herbaceous plant life-forms, has been shown to be detrimental to red alder survival and growth (Figueroa 1988, Dobkowski et al. 1994). Weed competition

thresholds based on first-year cumulative ground cover of grass/sedge, forbs ferns, and woody plants:

- Minimal Effects – Below 20%;
- Growth Impacts – 30% to 80%; and
- Survival Impacts – Greater than 90%.

Weed competition occurring late in the first growing season, and in the second growing season, can have serious impacts on rapid tree growth. Effective control of weed competition can often be the difference between plantation success and failure (fig. 6).

Figure 7 (A. Dobkowski, unpublished data 2004) shows the probability of achieving plantation height age targets by seedling basal stem diameter and height at time of planting with heavy (80%+ cumulative vegetation

ground cover) and very-low weed competition (10%-15% cumulative vegetation ground cover). This result indicates that even seedlings with larger basal caliper (7 to 9 mm) do not perform satisfactorily under heavy weed competition. Conversely, most seedlings large enough for operational out-planting (basal caliper greater than 5 mm and height of greater than 45 cm) perform well under low weed competition.

Weed control prescriptions need to consider weed communities that existed in the under-story of the harvested stand as well as weed invasion by forbs, grasses, and woody shrubs into newly harvested areas. There are currently a very limited number of herbicides for site preparation and the release of planted red alder from weed competition. For practical purposes, all broadcast herbicide control measures must be taken prior to planting. Atrazine 90 WSP™ (active ingredient, Atrazine; Helena Chemical Company 2005; Washington State only), Accord Concentrate™ (active ingredient, glyphosate; Dow AgroSciences 2005), and Escort™ (active ingredient, Metsulfuron methyl; DuPont 2005) are registered/labeled for use in red alder site preparation. Atrazine 90 WSP can be broadcast over the top of dormant red alder as a release treatment. Accord is labeled for the release of hardwoods from weed competition, but only as a directed spray—not as a broadcast application.

> **Check regulations before applying these or any herbicides—read and follow herbicide labels very carefully when applying herbicides.**

Cumulative vegetation ground cover in the first growing of less than 10-15% is desirable for rapid stand establishment and growth and to maintain ground cover in the second growing season below competition thresholds for red alder survival and growth. If ground cover of herbaceous weeds is expected to exceed 30-40% in year two, it is advisable to use herbicides in late-winter/early-spring, when red alder are still dormant and weeds are active. A broadcast application of Atrazine 90 WSP™ in late-winter and/or a directed spray of Accord Concentrate™ applied in early-Spring can be effective as a release treatment.

Anecdotal evidence suggests soil scarification that exposes mineral soil (when combined with weed control) can increase survival and growth when heavy slash/forest floor is present.

Planting

Out-plant Timing

A planting date should be selected to balance the risks of freeze damage and drought stress. The spring planting period begins when the probability of a killing frost is low and ends before there is an appreciable seasonal drying of the soil.

Figure 6—This photograph shows an example of the effects of through weed control on first year field performance for red alder (pre-plant application Atrazine and Glyphosate on the left vs. no weed control on the right). Meter-stick shown for reference.
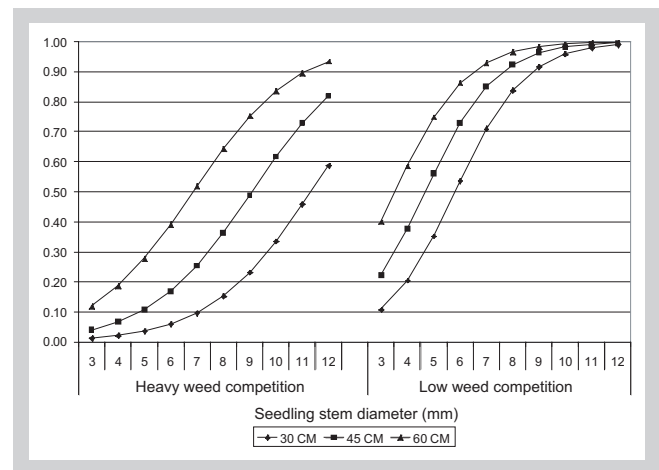

Figure 7—The probability of bare-root seedlings with "good" root systems achieving 1-meter height, one growing season after planting, given high and low levels of weed competition.

The recommended planting window for elevations less than 300 m, is mid-March to mid-April. Planting in November through February can result in serious freeze damage (top-kill and diminished root growth potential). Planting in late April to mid-May may not allow enough time for an adequate root system to develop before the onset of summer drought stress. It is advisable to begin planting in early March (at sites with minimal risk of spring frost) rather than planting into late April or early May.

Other considerations at time of planting

Red alder seedlings should be lifted from the nursery beds or styro-blocks/plugs in early January, freezer stored (-2°C) until the spring planting time is reached. Seedlings should be defrosted slowly under cover at approximately 4 to 5°C. Once the seedlings have thawed they should be cooler stored (2°C) until planted. It is advisable to keep seedlings frozen until just before the planting date—minimizing cooler storage to a week or less. Because red alder can de-harden very rapidly when removed from cold storage, seedlings stored in the field on the day of planting need to be protected from heat to prevent premature de-hardening. On-site daily storage under an insulated truck

canopy or in the shade of standing timber covered with a heat shield (i.e., Mylar™) seedling protection tarp is recommended. Take only the number of seedlings that can be planted in one-day from cold storage to the field.

Red alder seedlings are brittle and prone to breakage. Planting crews accustomed to handling conifers need to be cognizant that alder seedlings require more care. Careless loading of seedlings into planting bags can result in considerable breakage to roots and stems. Care needs to be taken when closing the planting hole to assure that the stem is not wounded by the planter's boot.

To partially offset the effects of heat and drought on newly planted seedlings, deep planting (ground level approximately 25-50 mm above the root collar) is recommended. Minimizing the scalping of forest floor during the planting process can reduce heat girdling; exposed mineral soil at the base of the stem from scalping acts as a heat-sink, and the thin bark of alder is readily damaged. Similarly alder planted directly against logging slash or stumps is easily damaged by sun-scald and/or mechanical abrasion—make certain that the planting spot is clear of surface slash for approximately a 30-cm diameter around the stem.

Conclusion

It is essential that "Best Management Practices" for site selection, plantation establishment and silviculture be followed in order to achieve successful red alder plantations. Achieving uniform stocking and rapid early growth, so that the stand "captures the site" within the first 3-years, is critical. It is essential that early intensive silviculture be practiced in order to assure rapid site occupancy. Rapid site occupancy by the crop promotes full stocking, rapid growth and good stem quality.

Red alder can be difficult to grow successfully in plantations – generally the species is "less forgiving" than conifers when planted on the "wrong" sites, and/or with improper silvicultural practices. For example; planting frost-prone sites or ineffective herbaceous weed control may reduce growth of Douglas-fir, but can result in extensive mortality and very poor growth of red alder. Effective weed control is more difficult for red alder because of the limited number of herbicides available for use on red alder, particularly for release treatments following planting. Also, the planting window is much narrower for red alder than for Douglas-fir (March 15–April 15 for red alder, vs. early-winter to early-spring for Douglas-fir). The consequence of planting red alder too early or too late can be excessive mortality.

Though the risks of failure and difficulty of growing red alder may be higher than growing conifers, we have learned how to mitigate the risks (through site selection, nursery practices and silviculture). The uncertainties of growing red alder must be weighed against the demand for red alder in commercial applications in the world-wide lumber market. Plantation-grown red alder can produce quality saw-logs in a relative short rotation of 25 to 30 years (compared to 60-years plus for other important North American hardwoods). Some landowners think that red alder will continue to have increasing value potential because of its desirable commercial wood properties and relatively short rotation for saw-logs.

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Response of Young
Red Alder to Pruning

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Abstract

Red alder (*Alnus rubra, Bong.*) is the most common hardwood in Washington, Oregon and British Columbia. It is used for a variety of products including firewood, pulp, and solid wood products such as furniture, cabinets and musical instruments. Pruning may be a viable management technique for increasing clear wood and, thus, value in managed stands but little information has been available. To determine the biological effects of pruning red alder, we selected 530 trees in 3-, 6- and 10-year-old plantations. Sample trees were from plots that had different previous silvicultural treatments, providing a range of growth rates. Pruning removed one third of the live crown, was performed on seven dates throughout the year, and included both live and dead branches as well as a sub-sample of intentionally damaged collars around dead branches. The rate of branch occlusion (healing) was well correlated with tree growth at breast height and with distance from the base of the live crown. Live branches occluded more rapidly than dead branches and dead branches occluded more rapidly if the branch collar was intentionally wounded during pruning.

The number of epicormic branches induced by pruning was minimal, but increased with tree age and where trees were growing in an open condition. No stem breakage or sunscald was observed as a result of treatment. Six years following pruning, 91% of pruned branches less than 1 cm in diameter and 80% of branches 2–3 cm in diameter had completely occluded. Those that had not occluded by that time were on trees with low growth rates. Time of year of treatment had little effect on tree growth rates, occlusion rate, epicormic branch formation, and damage. Pruning young trees did not result in any damage or loss of growth. To maximize the amount of clear wood it would be best to prune as soon as logistically possible. Thus, if economic incentives are present for clear wood, landowners and managers may want to consider pruning young trees, taking into account the possible need for multiple lifts.

Keywords: red alder, *Alnus rubra*, pruning, branch occlusion, silviculture

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Introduction

It is well known that initial density affects diameter growth. We can produce larger diameter trees more quickly if they are grown at wider spacings than if they are grown at narrower spacings. Associated with wide spacings, however, is the production and retention of large diameter branches, especially on the lower bole of the tree. These branches reduce the log grade and consequently reduce the products (and values) for which the log can be used. Some foresters have speculated that the lowest-cost option to produce quality wood would be to grow the trees at spacings close enough to cause natural death and abscission of the lower branches. However, this strategy assumes that dead branches will be shed soon after the abscission process is complete and that stem breakage will occur at a point close to the tree bole. It will also either increase the time required to produce trees of a specified size or require thinning after branches have naturally abscised. An alternative strategy would be to plant at wide initial spacings and plan to artificially prune the trees. While pruning can be an expensive process, the costs may be justified if increases in log quality can be transformed into increases in log value.

Pruning red alder has not previously been examined in a comprehensive manner. The only published report is that of Berntsen (1961) where 21-year-old trees were pruned, then examined 22 years later to see what the effects were on wood quality. Bernsten concluded that pruning did increase the amount of clear wood produced, but warned that epicormic branches could result in defects such as knots or blemishes. No other information is available specific to alder, however, much information is available in the forestry or horticultural literature on the effects of pruning on plant growth and on methods for pruning (O'Hara 1989). In addition, there is substantial information in the botanical literature on the physiological responses of plants to wounding (i.e. the removal of live branches).

Studies on the time of year of pruning are generally limited to only a few dates and do not include information on the phenological status of the trees. In addition, the results differ by species and the response variable considered. For example, Krinard (1976) concluded that summer pruning of eastern cottonwood was better than spring pruning because it resulted in fewer and shorter epicormic branches. McQuikin (1950) recommended pruning eastern hardwoods (except red maple) in late winter or early spring to achieve fastest wood occlusion; he recommended pruning red maple in late spring or early summer to reduce excessive bleeding (sap exudation). Neely (1970) reported May-pruned eastern hardwoods healed more quickly than July- or March-pruned trees. October-pruned trees healed much more slowly than trees pruned at the other three dates. Childs and Wright (1956) reported higher incidence of infection in Douglas-fir spring-pruned wounds than fall-pruned wounds. Shigo (1976) reported different decay mechanisms invaded eastern

hardwoods depended on the time of the wounding. Leben (1985) concluded that spring wounding of red maple resulted in less dieback around the wounds and less decay than fall wounding. Puritch and Mullick (1975) reported water stress substantially slowed formation of an impervious layer in grand fir seedlings. Biggs and Cline (1986) reported irrigation to speed up formation of the impervious layer at some sampling dates. Given the range of responses reported in the literature, we could not predict the time of year or growth conditions that would be optimum to prune red alder.

Most pruning studies have dealt with the removal of live branches, but a few have also examined dead branches. Shigo (1986) indicates that branch collars should not be damaged when live branches are pruned, but recommendations are contradictory on the treatment of dead branches. It appears that injuring the branch collar when removing the dead branches will greatly speed up filling in the cavity at the base of the branch, however, Shigo et al. (1979) suggests that this will increase the amount of decay associated with the dead branch. Casual observations have noted that occlusion rates over dead branches on red alder can be slow.

We designed a study to determine the biological effects of pruning young red alder. The study focused on four questions. Are there any negative effects, such as sunscald, sap exudation, or production of epicormic branches, associated with pruning young red alder? If there are negative effects, do they vary by time of year of pruning? What effects do factors such as tree age, growth rate or height on the bole have on the rate of occlusion? Are there positive or negative effects of wounding the collar area around dead branches? A second study (DeBell et al. 2006) quantified internal decay rates associated with a subset of treatments.

Materials and Methods

Alder plantations established at the Washington State Department of Natural Resources' Meridian Seed Orchard near Lacey, Washington and at the Centralia Mining Company—now owned by TransAlta Corporation—near Bucoda Washington, were selected to represent a variety of age groups and silvicultural regimes. The Meridian Seed Orchard included both thinned and non-thinned areas (at 1- and 2-m spacings respectively) from 3-year-old plantations established in 1989, and areas that had been previously irrigated and non-irrigated in 6-year-old plantations established in 1986. Trees selected at TransAlta were in 10-year-old plantations that had been established in 1982; these trees had been planted as part of a spacing trial and included a range of spacings from 2 to 4 m. Initial diameter at 1.3 m and total height are given in table 1. Mean annual precipitation at both locations is 1245 mm with 150 mm falling as rain from June 1 through September 30. Mean annual, mean January minimum, and mean

Table 1—Initial d.b.h. and height, and mean diameter growth from 1991 to 1997.

AGE	Treatment	Mean d.b.h. 1991 (cm)	Mean ht 1991 (m)	D.b.h. growth 1991-1997 (cm) Min	Max	Mean
3	Thinned	4.8	4.7	2.1	12.5	7.5
	Not thinned	4.1	4.1	0.5	6.5	3.3
6	Irrigated	11.6	11.6	1.2	10.6	5.0
	Not irrigated	9.5	9.5	0.8	12.0	4.6
10	n/a	13.3	10.5	1.4	10.3	4.6

August maximum temperatures are 10.1, 0.1 and 25.1 °C, respectively, at the Lacey site and 10.6, 0.6, and 25.3 °C at the Bucoda site (Daly, 1994. http://www.ocs.orst.edu/prism).

The time-of-year portion of the study examined trees pruned on seven separate dates selected to cover the range in tree phenology. The dates (and general phenological condition) were: May 1 (budbreak and leaf expansion), June 15 (active height and diameter growth), August 1 (active diameter growth, height growth primarily over), September 15 (diameter growth continuing but some leaf abscission beginning), November 1 (leaf abscission almost complete), January 1 (deep dormancy, cold temperatures), and March 1 (trees still dormant but temperatures moderating). The first five dates were in 1992 and the last two were in 1993.

On each treatment date 20 trees from the 3-year-old plantation (10 thinned and 10 not thinned); 20, 6-year-old trees (10 irrigated and 10 not irrigated); and 20, 10-year-old trees were pruned to examine the effects of time of year, growth rate, and bole height on response. Pruning was done with a handsaw and the pruners were instructed to not wound the branch collars of either dead or live branches. Furthermore, at the May 1 pruning date, 40 additional 10-year-old trees and 60 additional 6-year-old trees were pruned at the same two sites. This second group of trees had the live branches pruned in the same manner as described above, however, half of all trees at each site had dead braches pruned by removing the entire branch collar (i.e., the swelling around the base of the branch, particularly on the lower side). Removing the entire branch collar (cutting the branch flush with the stem) considerably increased the size of the wound created for all but the smallest branches which had minimal branch collars.

Prior to pruning, all trees to be pruned were marked at 0.3 m on the bole and then every 1 m up the bole until pruning height was reached. Trees in the time-of-year portion of the study were pruned up to a point representing one-third of the existing live crown. For most trees this was approximately a height of 3.3–5.3 m, although 1 tree was pruned up to 7.3 m. All trees in the damaged-branch-collar portion of the study were pruned to 3.3 m. Each pruned branch was tallied by stem section from which it was removed (0–0.3 m, 0.3–1.3 m, 1.3–2.3 m, etc), whether it was alive or dead, and by 1-cm diameter class. Epicormic branches present before pruning were also tallied by stem section and then removed (usually with hand clippers).

After the 1992 growing season, all study trees were measured for stem diameter at 1.3 m, total height, and height to live crown. Diameter at 1.3 m, total height, and number and length of new epicormic branches was remeasured after each growing season from 1993 to 1997. Percent occlusion of all pruning wounds was also measured after each growing season from 1993 to 1997 by visually estimating the percent of the wound area that had been covered by callus (tissue formed over and around a wound). Each tree in the 10-year-old plantation was coded for proximity and direction of adjacent openings that might induce epicormic branching. These codes were not based strictly on spacing of adjacent trees, but also if the opening was sufficiently large to cause a discontinuity in crown closure and allow light to fall upon the bole of the edge tree. Form was assessed after the 1994–1997 growing seasons by measuring stem diameter at 0.3, 1.3, 2.3, and 3.3 m heights on the pruned study trees and on unpruned trees in the same plantations with 1992 diameters similar to those of the pruned trees.

Results and Discussion

Damage to pruned trees

Following pruning, no problems were encountered with sap exudation (bleeding), sunscald, stem lesions, top breakage, excessive production of epicormic branches, or damage by red-breasted sapsuckers on trees from any pruning date. Top breakage and sapsucker damage have been observed on red alder trees operationally pruned when 50% or more of the live crown was removed (C. Harrington, personal observation) but removal of 33% of the live crown in this study did not predispose the trees to damage.

The frequency of epicormic branches increased immediately after pruning (table 2). However, by 1997, the 3-year and 6-year old trees had less than 1 epicormic branch per tree and most of these branches were short and small in diameter. There was a reduction in the percent of trees with epicormic branches in all the plantations throughout the study period. The mean number of epicormic branches per tree remained relatively the same in the 6- and 10-year-old

Table 2—Frequency, mean number and size of epicormic branches at the time of pruning (1992 and 1993) and after the 1994 and the 1997 growing seasons.

Age	% Trees with epicormic branches			Mean number of epicormic branches per tree			% Epicormic branches with a length >=15 cm	
	1992-1993*	1994	1997	1992-1993*	1994	1997	1994	1997
3	41	69	29	1.2	1.9	0.7	0	36
6	5	27	19	0.1	0.8	0.5	3	27
10	33	91	89	0.8	7.4	7.3	65	80

*At time of pruning

plantations and decreased by 37% for trees from the 3-year-old plantation. No relationship was found between the time of year that pruning took place and the number of epicormic branches produced.

Epicormic branches were more likely to be present in a more open environment. At the time of pruning, 56% of the trees in the thinned portion of the 3-year-old plantation—the more open environment—had epicormic branches, compared to only 27% in the non-thinned portion (although both portions had a mean of less 2 small epicormics per tree). By the end of 1994, the crowns had closed in the thinned portion and the number of trees with epicormic branches and the mean number of epicormic branches per tree in the thinned and not thinned portions of the plantation were not significantly different. Although most areas in the 10-year-old plantation had a closed canopy, there were some openings sufficiently large enough to cause discontinuities in crown closure throughout the study period. Trees that had an opening directly adjacent to them (n=50) generally had more epicormic branches per tree than trees with no opening present within 2 rows (n=58), unless the opening was to the north side of the tree (fig. 1, a). If an opening was present 1 row away (n=41), it did not increase the number of epicormics formed unless the opening was in a southerly direction (fig. 1, b).

Berntsen (1961) suggested that production of epicormic branches could be a problem when pruning red alder; however, closer examination of the data from his study (Rapraeger 1949 report on Cascade Head pruning and thinning study, data on file, Olympia Forestry Sciences Laboratory) indicated that the stem sections he examined came from a 21-year-old red alder stand that was heavily thinned (two-thirds of the stems removed) and the large overstory conifers were girdled at the same time as pruning. Thus, the red alders were exposed to a major change in their light environment at the same time as pruning. Even so, the trees at Cascade Head had fairly low numbers of epicormic branches 10 years after these treatments were imposed

(14 per tree on the 5-m section that had been pruned) and most (75%) were less than 0.1 cm in diameter. Thus, both the Cascade Head study and our observations confirm that although red alder does produce epicormic branches following pruning, it is not particularly prone to doing so. The results from the Cascade Head study are also consistent with our observation that epicormic branches are more likely to form and persist on older trees.

Growth Rate and Stem Form of Individual Trees

Stem form appeared to be very slightly altered by pruning in all the plantations; however, the differences were not significant ($p \leq 0.05$). The differences in form were most pronounced in the 10-year-olds and although differences between stem form in pruned trees in comparison to trees not pruned was greater in year 5 than in year 2 (fig. 2), it was still not statistically significant. From year 2 (1994) to year 5 (1997), the mean diameter of the bole at heights closer to the base of the live crown, once pruned, increased at a rate greater than the rates at sections lower down on the bole. If this trend continues, it appears the boles of pruned trees will become more cylindrical.

The rate of branch occlusion at various heights up the bole also indicates greater rates of diameter growth closer to the base of the live crown. For example, after 3 growing seasons (trees pruned in May, 1992), mean percent occlusion of live branches 2 to 3 cm in diameter pruned in sections at 1-m intervals (starting at 0.3) up the bole of the trees were 51%, 56%, 60%, 61%, 77%, and 95% (ending at 5.3 m height), respectively. Separated into tree age groups, all 3 ages showed the same trends, although it was more difficult to discern in the 3-year-olds due to smaller branch sizes, reduced number of sections, and more rapid percent diameter growth.
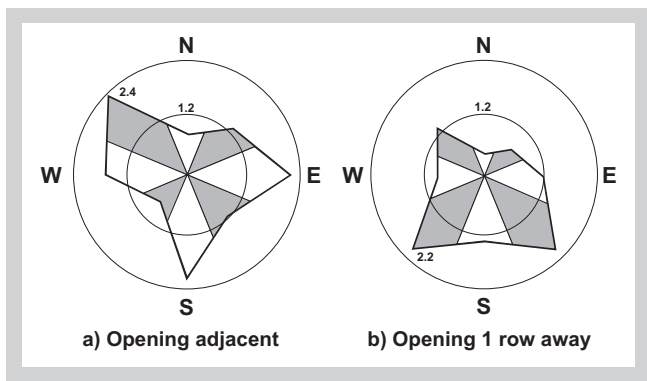
Figure 1—Mean number of epicormic branches in 1994 present on 10-year-old trees that a) had an adjacent opening and b) had an opening 1 row away. Trees with no opening within 2 rows had a mean of 1.2 epicormics per tree and are represented by the smaller inner circle.

Figure 2—Stem diameter at 0.3, 1.3, 2.3 and 3.3 m height within the 10-year-old plantation on both pruned and non-pruned trees in years 2 and 5.

Factors affecting branch occlusion

There were substantial statistical differences in the degree of branch occlusion by initial branch size, tree size, tree age, and overall growth rate of the tree. For example, 2 years after pruning, mean percent occlusion of branch wounds in the 3-year-old and 6-year-old plantations ranged from only 67% (non-irrigated portion of the 6-year-old plantation) to 94% (thinned portion of the 3-year-old plantation) (fig. 3). Silvicultural factors that affected the rate of diameter growth, such as thinning or irrigation, also had an effect upon the rate of occlusion. Differences in rates of occlusion between the different tree ages can be attributed to both the initial differences in branch size by plantation and to tree growth rates. For example, branches 1 cm in diameter or smaller were 97%, 74%, and 45% of the branches pruned in the 3-, 6-, and 10-year-old plantations respectively.

Mean percent occlusion was also closely related to both branch size and basal area growth (fig. 4). Stem diameter growth varied significantly by age and treatment, as well as by initial tree size (table 1). Diameter growth as a percent of initial diameter prior to pruning (1991) to the end of the 1994 growing season was 49% for the 3-year-olds, 21% for the 6-year-olds, and 17% for the 10-year-olds. These age trends in growth rate as a percentage of initial diameters are also reflected in the mean percent occlusion by 2-cm diameter growth classes. For example, live branches 2 to 3 cm in diameter pruned in the 3-year-old plantation had a mean percent occlusion of 65%, 94%, and 100% for a d.b.h. (diameter at 1.3 m) growth of 0 to 2 cm, 2 to 4 cm, and 4 to 6 cm, respectively. For the same branch diameter and the same dbh growth classes, the mean percent occlusion was 59%, 70%, and 94% for the 6-year-old plantation and 31%, 46% and 51% for the 10-year-old plantation. So, for any given amount of d.b.h. growth, the younger trees grew more in respect to their initial diameter and occluded wounds at a faster rate.
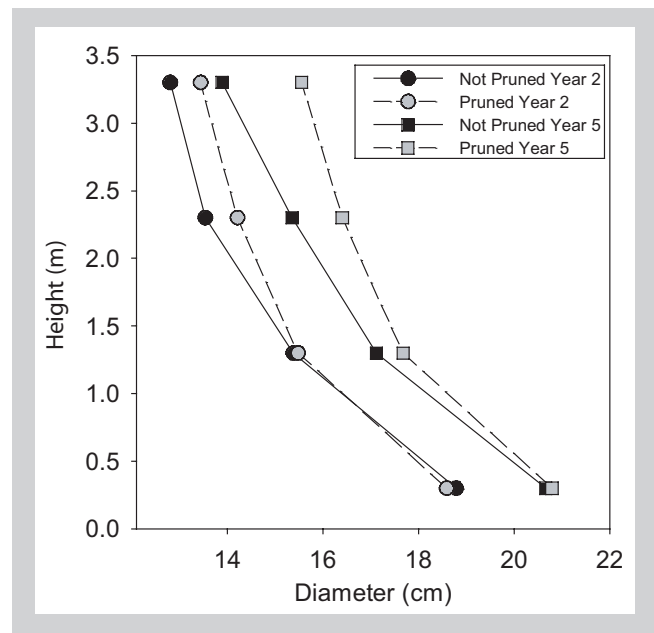
As expected, at the time of the first occlusion assessment at the end of the 1994 growing season, the branches that had been pruned at the earlier pruning dates showed greater occlusion. For example, the percent of live 2 to 3 cm-branches that had reached 90% occlusion or greater was 16% for the May 1, 1992 pruning date, 14% for the June 15, 1992 pruning date, 2% for the August 1, 1992 pruning date, and 1% for the 4 subsequent pruning dates (September 15, 1992; November 1, 1992; January 1, 1993 and March 1, 1993). By the end of the 1995 growing season, the early spring treatments (May '92 and March '93) exhibited slightly slower than expected occlusion rates, but branches of all size classes for all the pruning dates reached 90% or greater mean occlusion by the end of the 1997 growing season (fig. 5).

Occlusion of live vs. dead branches and effect of branch collar treatment

We compared the rates of occlusion for pruning live branches without wounding the branch collar, dead branches pruned without wounding the branch collar, and dead branches pruned by removing or damaging the branch collar. For each of the smallest branch size classes (the size classes where n>100), differences among the three categories were small at the time of the first assessment in 1994 and even smaller in 1995, but two consistent and statistically significant patterns were present. First, the mean rate of occlusion was greater for live branches than for dead branches that were pruned without wounding the branch collar (fig. 6). Second, even though damaging or removing the branch collar during pruning increased the
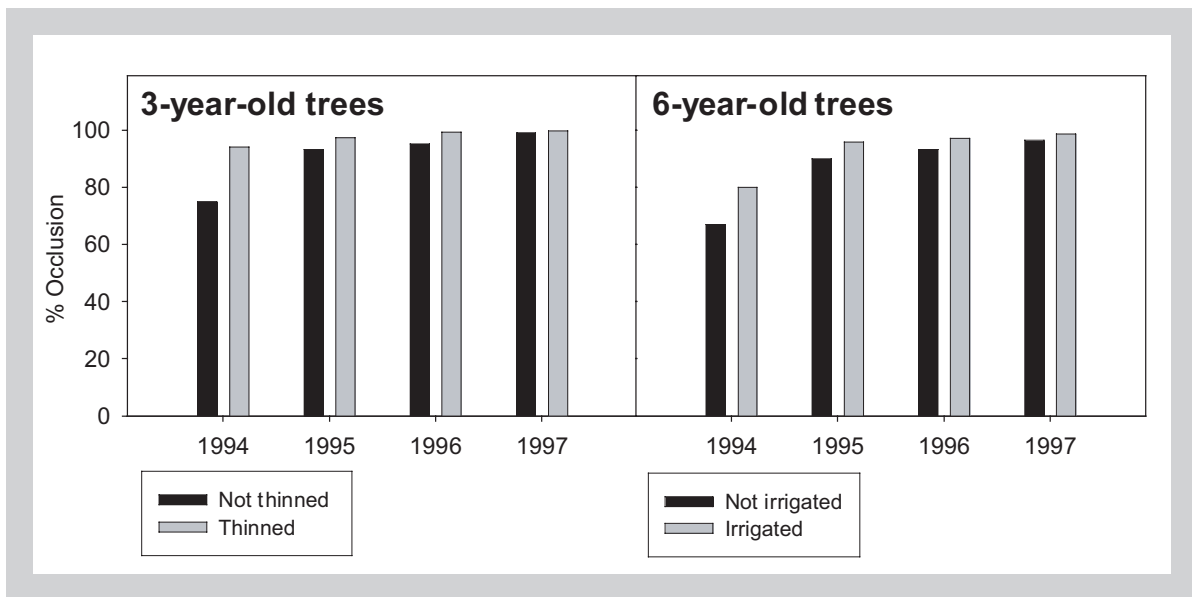
Figure 3—Mean percent occlusion of all pruned branches in the 3- and 6-year old plantations 1 to 5 years following pruning (dependant upon time of pruning).
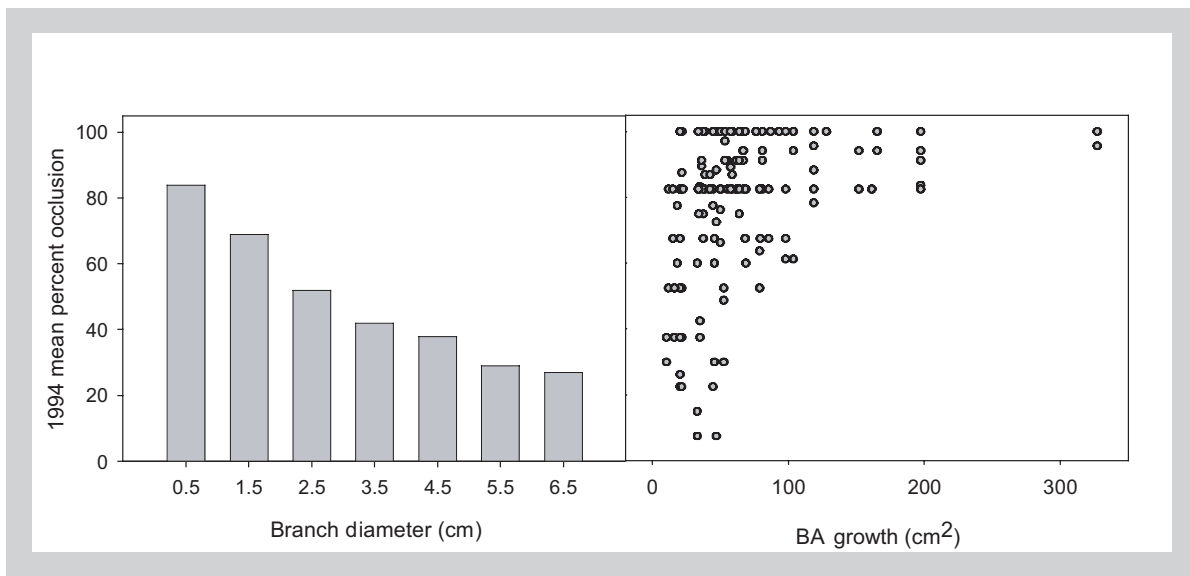

Figure 4—Relationship between percent occlusion of branches pruned in 3-, 6-, and 10-year-old red alder stands by diameter of pruned branch and basal area growth measured at 1.3 m.

size of the wound to be occluded, wounds associated with damaged branch collars occluded more quickly than those associated with undamaged branch collars. Although this difference in occlusion rates between injured and uninjured branch collars is unlikely to be of practical importance, it indicates that pruners do not need to be especially careful to avoid injuring branch collars. Additional examination of the wood around these wounds also indicated no difference in the amount of internal decay associated with damaged or undamaged branch collars or the time it took to form clear wood (DeBell et al. 2006).

Red alder wood decays rapidly after the death of the tree; thus, in past years some foresters have speculated that alder might not be a good candidate for thinning or pruning because of the potential damage associated with these activities. More recent evidence, however, has shown that living red alder trees are quite effective in compartmentalizing decay (Allan 1993). Allen's study on Vancouver Island showed decay volumes to be small and most decay associated with natural breakage did not spread outward beyond the location on the bole where damage was sustained. Additional assessments of decay
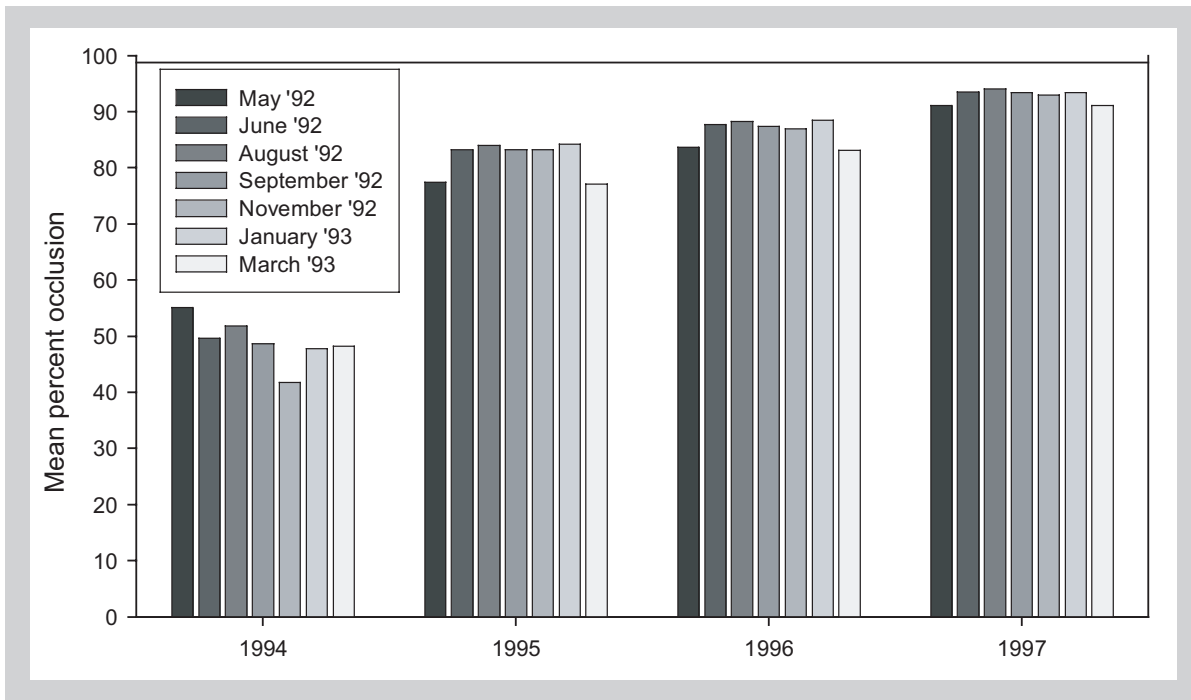
Figure 5—Mean percent occlusion for all branches sizes at all pruning dates at 4 successive assessment years.
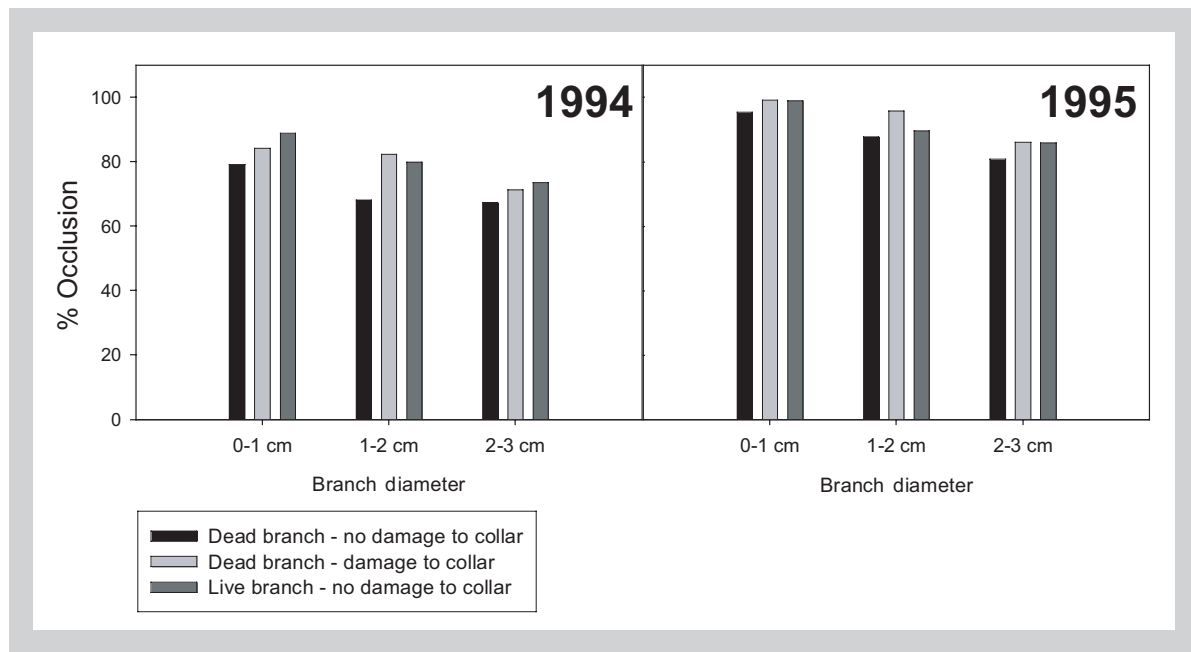

Figure 6—Comparison of occlusion rates by branch size classes and year for live branches pruned without damaging the branch collar and dead branches pruned with and without damaging the branch collar during pruning.

associated with pruning were made in the Cascade Head pruning study (C.W. Jacobs memo dated Feb 28, 1947 on rot found in alder stands, on file Olympia Forestry Sciences Laboratory). The wood in and near 25 knots on 6 pruned trees was assessed for signs of decay 10 years after pruning by sampling with an increment borer. On 24 of the 25 knots, the decay was found to be confined to the knot area; on

the 25th knot, the rot extended to the pith and about 25 cm below the branch, but did not extend into the wood formed after pruning. The companion study to our young-stand pruning (DeBell et al. 2006) also found minimal amounts of rot associated with the branch scars. Thus, there is no evidence that decay will be a problem after pruning young red alder.

Conclusions

Pruning at plantation ages 3, 6, or 10, did not have negative effects on the incidence of decay or defects within the tree bole, production of significant numbers of epicormic branches, or growth of the tree. Contrary to reports for several other species, the results were consistent across all seven pruning dates; thus, time of year of pruning had little or no effect. Differences in rates of occlusion could largely be accounted for by the differences in growth rate due to tree age or other management activities (such as thinning or irrigation). Although our study examined the effects of wounding the branch collars only on dead branches, we suspect that incidental damage during the pruning operation to branch collars of live branches should not be a source of concern. However, because there was no practical benefit from removing the branch collar, and it would take more time and effort to do so, we would not recommend it as a standard practice.

Because both small and live branches occlude more quickly than large or dead branches, pruning at an earlier age would not only result in a smaller knotty core, but would produce straight-grained clear wood more quickly after pruning. In addition, if epicormic branches are a concern, pruning young stands appears to result in the lowest number of epicormic branches. Epicormic branch production was also most closely tied to the presence of openings on the south side of the tree, thus, trees north of stand boundaries or gaps are the poorest candidates for pruning. From a biological standpoint, there appear to be no obstacles and several benefits to pruning red alder at an early age; thus, the decision of timing of pruning should be based on economic factors.

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