RESPONSE OF WESTERN REDCEDAR TO RELEASE AND FERTILIZATION IN A MIXED-SPECIES STAND

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ABSTRACT

Western redcedar (*Thuja plicata* Donn ex. D. Don) is of high commercial value, is considered highly shade tolerant and occurs more commonly in mixed-species, uneven-aged stands than in pure stands. Successful maintenance of redcedar as a component of mixed-species stands to enhance diversity or to overcome the difficulties of establishing redcedar regeneration is dependent on its response to release and other silvicultural treatments. To assess the response of western redcedar to release and fertilization in a mixed-species stand, 74 western redcedar trees were selected to represent a wide distribution of diameter and crown classes in a stand in which the overstory had been recently removed in Capitol State Forest near Olympia, WA. Three types of competition indices were calculated for each study tree in order to quantify the extent of the release treatment as well as to characterize the current growing conditions. Pre-treatment values for the competition indices were calculated retrospectively using the number and size of stumps present. Half of the study trees were fertilized with urea at the rate of 200 kg of N/ha. Percent DBH growth increased significantly in response to fertilization every year for 3 years following fertilization with the greatest effect the first growing season after application. Percent height growth was more affected by the presence of overtopping trees following the release treatment than by fertilization. Of the competition indices modeled, the percent overlap of influence areas (based on tree size) was the most consistently effective at predicting percent diameter and height growth at all years when measurements were taken up to year 15. Western redcedar responded positively to removal of overtopping trees; thus, this type of release should be considered a viable management option. Response to fertilization was positive but short lived.

KEYWORDS: redcedar, release, fertilization, management, height growth, diameter growth

INTRODUCTION

Western redcedar (*Thuja plicata* Donn ex. D. Don) is a highly shade-tolerant tree species found in western North America and occurs more commonly in mixed-species, uneven-aged stands than in pure stands (Minore 1990, Klinka and Brisco 2009). Because of its shade tolerance, it can survive in the understory or midstory of forests, and thus, can be an important contributor to the structural diversity associated with old-growth stands (Old-growth Definition Task Force, 1986). It has been recommended that forest managers interested in wood production grow redcedar in relatively high density, pure-species stands because wood quality and growth will be reduced when redcedar is overtopped by faster growing trees (Oliver et al. 1988). Managers interested in wildlife habitat, biodiversity, accelerating the development of late successional characteristics, or maintaining visual quality, however, may be interested in managing redcedar as a component of more complex stands. Redcedar is difficult to regenerate in many locations due to browsing by deer and elk. For these reasons, it may be especially desirable to retain existing redcedar trees when harvesting the overstory, even if many of these trees may not be valuable for future timber harvest.

Substantial information is available on the tree and site factors which influence response of

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redcedar to release in the northern Rocky Mountains (Graham 1982) but very little has been reported for redcedar in the coastal portion of its range and some foresters have suggested that overtopped redcedar would not respond well to release as shade-formed leaves will not be able to function well in a higher light environment or root systems developed in a forest stand will not be adequate when the species is exposed to a more stressful environment. Redcedar has been shown to be responsive to fertilization (Devine and Harrington 2009, Walker et al. 1955, Weetman et al. 1988, Prescott 1996) and could possibly respond more quickly to release if fertilized with nitrogen. In this experiment, we followed the fate of redcedar trees for 15 years in a stand near Olympia, WA after overstory removal and fertilization. Because the stand conditions were irregular, we evaluated competition indices for their efficacy in reducing variation in tree growth response and used release and overtopping codes to further partition responses in a meaningful way.

MATERIALS AND METHODS

The study area is located in the northern portion of the Washington State Department of Natural Resources Capitol Forest near Olympia, WA, USA. It was in Unit 1 of the 'Poria' sale area (Fig. 1) which covered 11.3 ha; the unit is relatively flat and at an elevation of 180 m. The dominant soil type is Grove very gravelly sandy loam. In March 1995, the overstory was removed except for approximately 25 Douglas-fir trees per hectare and all western redcedar—primarily understory and midstory—was retained. We selected 74 western redcedar trees for the study which were free from obvious logging damage and represented a wide range in stem diameter and crown position. Diameter at 1.3 m (DBH) of selected study trees ranged from 0.8 to 24.8 cm and heights ranged from 1.6 to 18.3 m. Half of the selected trees were chosen on the basis of crown class, diameter and distance to other selected trees to be fertilized with nitrogen such that fertilized trees were approximately the size and crown position as the non-treated trees and were well distributed throughout the stand. All study trees were measured for DBH, height, height to live crown, and crown width soon after logging in 1995 (end of the 1994 growing season is year 0), prior to fertilization in the early spring of 1995 (year 1), and at years 2, 3, 4, 5 and 15.

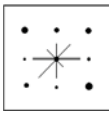
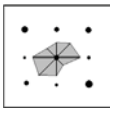
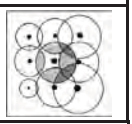
We evaluated three competition indices (CI's) for their efficacy in reducing variation in tree growth response and to help quantify conditions pre- and post-release. The CI's were calculated for each study tree both for past status (retrospectively, using stumps) and in their current status. The level of release was defined as the difference between the two values. Any tree or stump with a diameter at 0.3 m greater than 15 cm and within 10.3 m distance from the study tree was considered a competitor. Trees and stumps with a basal diameter 5.0 cm to 14.9 cm and located within a distance of 2.56 m were also considered competitors. In addition, study trees and surrounding trees and stumps were assessed post-harvest and used to estimate the tree's crown position both before and after the harvest. As a result, study trees were coded as either 'over-topped' or 'released'.

The three competition indices (CI's) used to quantify the extent of the release treatment and current growing conditions were 'sum line length', 'area', and 'percentage overlap'. Their calculation and descriptions are presented in Table 1 (see Brodie and DeBell 2004 for additional detail). For 'sum line length', the length of each line is proportional to the ratio between the DBH of the 2 trees. The competition index 'area', is similar to 'sum line length, but 'area' accommodates the differences in distribution of line lengths by going one step further to calculate the area enclosed by joining the endpoints of adjacent lines. For calculation of 'percentage overlap', each tree is considered to have a circular influence area estimated as ¼ of total height. The CI is the percentage of the study tree's area of influence that is overlapped by those of competitors.

In the early spring of 1996, urea at the rate of 200 kg of N/ha was manually applied to

individual trees in a circular area centered on the stem and with a radius equal to one-half of the tree height.

Table 1 -- Competition indices used in the study

Competition Index Name	Definition/Description	Representation
Sum Line Length	————	
Area	Area delineated by the endpoints of the lines defined by the CI 'Sum Line Length'	
Percent Overlap	———	

Where CI_i =competition index of subject tree *i*, DBH_i=diameter at 1.3 m of subject tree *i*, DBH_j=diameter at 1.3 m of competitor *j*, $DIST_{ij}$ = distance between trees *i* and *j*, and O_j=portion of the influence area of competitor *j* (radius=0.25 x height *j*) that overlaps influence of subject tree, and I_i = influence area of subject tree *i* .

Annual and periodic percent DBH and height growth were analyzed by a series of general linear models (GLM) using fertilization treatment, crown position, the CI's and initial size class as covariates (SAS Institute Inc. 2005).

RESULTS AND DISCUSSION

Residual Stand Damage

Selected study trees exhibited little or no damage from the removal of the Douglas-fir overstory either directly or as a result of the change in environment. Wind damage to the study trees during the course of the study was minimal. During the 15-year period, 4 trees were blown down or damaged by other blown down trees and two trees suffered broken tops. Excluding these trees from the study affected initial mean diameter and heights only minimally, so did not affect the overall study design. As a side note, in the months just prior to the last measurement, 3 of the study trees (and several others within the stand) were severely pruned by unauthorized bough harvesters. Generally, well over half of the crown was removed. The harvest of the overstory and subsequent crown development of the redcedar trees created a condition where the cedar boughs were not only more obvious, but more plentiful and may have subjected the stand to more damage of this type.

Response to Fertilization

Because of the wide range in initial diameter of study trees, growth response was expressed as percent DBH growth. Percent DBH growth increased significantly in response to fertilization every year for 3 years following fertilization with the greatest effect the first growing season after application (Fig. 2). Treated trees responded to fertilization with a 44% increase in percent DBH growth the first year, a 97% increase the second year and a 60% increase the third year. Trees did not respond differentially by initial size class. Height growth (figure 3) was much more influenced by the presence of overtopping trees following the release treatment than by fertilization (height growth response to fertilization not statistically significant). Over the first 5 years of the study, trees with an over-topping crown grew a mean of 0.57 m while those without the presence of an over-topping crown grew 1.24 m—a 118% increase. Long-term (15-year) response to fertilization was not statistically significant for either diameter or height growth, nor was the interaction between CI and fertilization significant.

These findings concur with the findings of previous studies where western redcedar has been shown to be consistently responsive to nitrogen additions in relatively even-aged stands during the years immediately following treatment (as opposed to the more erratic response of western hemlock) (Harrington and Wierman 1985, Weetman et al., 1987, Weetman et al. 1989, Weetman et al., 1993, Devine and Harrington 2009). Significant differences were found in diameter and height growth (although in those studies the presence of over-topping trees was not a factor) and it was suggested that early response to thinning alone would be quite small in comparison to thinning and fertilization

combined, as this study suggests as well. Also similar to other studies, the increase in periodic growth rate produced by the addition of nitrogen was not sustained over a longer period of time (Weetman et al. 1989, Devine and Harrington 2009), dissipating sometime between 4-10 years after treatment (Blevins et al., 2006).

Competition Index Evaluation

For each measurement interval, an analysis of variance was performed for percent DBH and height growth using crown position, fertilization treatments, and 1 of the 3 CI's as covariates. Of the 3 CI's, 'Percentage Overlap' most consistently produced the highest R^2 values and was used to quantify levels of competition in further analysis.

We believe that the other 2 CI's did not perform as well in an unevenly spaced, mixed-species stand for several reasons. The CI 'sum line length' did not account for the spatial distribution of tree size in the area immediately adjacent to the study tree; in its calculation, it could not give value to a group of smaller trees to one side providing a gap for the study tree. Although the calculation of the CI 'area' did take the spatial distribution of competitor trees into account, it could not quantify the amount that competitors' effects overlapped. By contrast, the value of 'percent overlap' has no upper limit. If a smaller competitor is slightly more distant from the study tree than a larger competitor, the influence of both is quantified. Although 'sum line length' and 'area' may work well in evenly-spaced stands where trees are similar in size, the CI 'percent overlap', with its higher sensitivity, performed better as a modeling tool within this more variable stand.

Response to Competition and Release

Percent DBH growth and percent height growth were both significantly increased by the release treatment (Figs. 4 and 5). Two factors contributed to the growth response to treatment. First, and most significant ($p<0.05$), was the reduction of competition within the immediate area (as quantified by 'percent overlap'). Once percent overlap reached approximately 125, further increases in competition level had little or no effect on either DBH or height growth.

The second factor contributing to response was crown position (over-topped or released). Although not as significant as 'percent overlap', crown position was significant at $p<0.10$. The response of released trees to their crown position was dependent on the level of competition present after treatment (Figs. 4 and 5, inset graphs). If competition in the immediate area remained high (percent overlap greater than 125), the trees did not respond to the removal of crowns directly above. If competition in the immediate area was low, there was greater differentiation in growth between those trees that remained over-topped in contrast to those that had been released.

A related study in southwest Washington (Deisenhofer, 2010) found similar results although in that study, height growth response to release was slower and less pronounced than that of diameter growth. Redcedar's response to release in the northern Rocky Mountains (Graham, 1982) was highly dependent on several site factors including aspect, initial tree size, and soil and foliar characteristics. Although this study did not evaluate all site factors, initial tree size was not a statistically significant predictor of response to release.

CONCLUSIONS

Anecdotal information suggests that western redcedar may suffer from 'thinning shock' as has been documented for Douglas-fir on poor sites resulting in short-term height growth reduction (Harrington and Reukema, 1983). Such was not the case in this study. The trees responded well to release from over-topping crowns and a reduction in the number of competitors in the immediate area, thus these treatments represent viable management options. Although diameter growth responded well to fertilization, the response was not sustained in the long-term, however, fertilization my still be a valuable silvicultural tool depending on the short-term management objectives.

Figure 1 -- The study site in 2000 (year 6 of the study). The overstory had been removed except for approximately 25 Douglas-fir trees per ha.

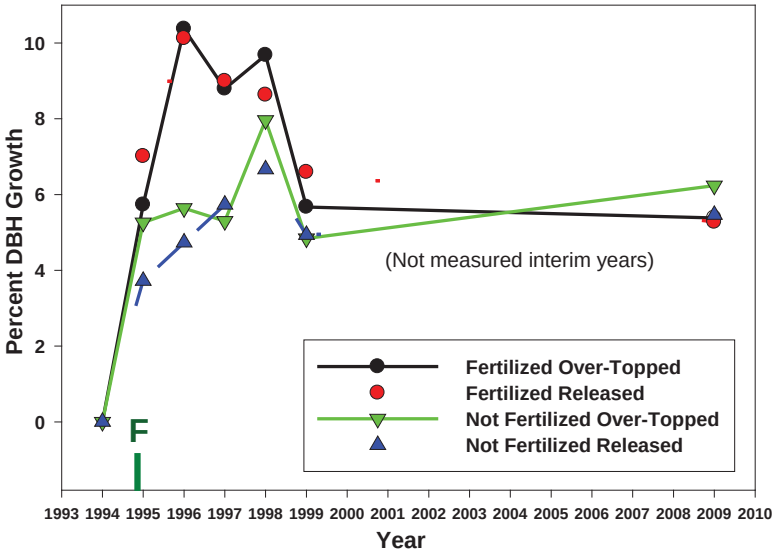


Figure 2 -- Mean annual percent DBH growth by treatment and crown position.

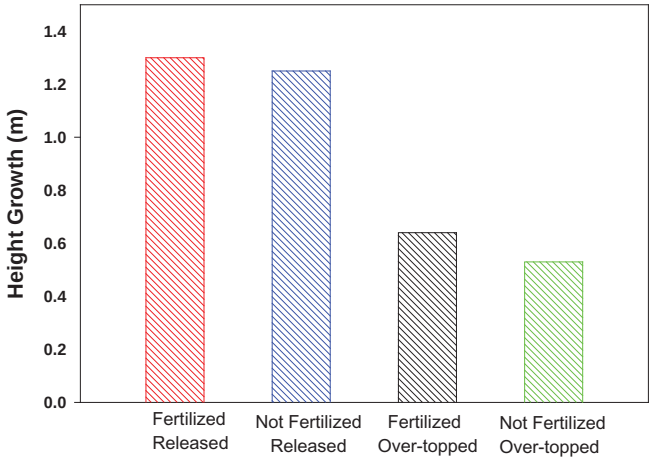


Figure 3 -- Mean height growth from 1994-1999 by treatment and crown position

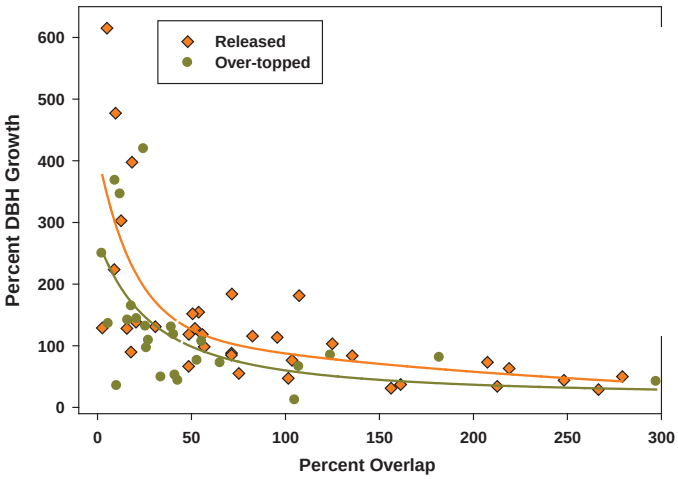


Figure 4 -- Percent DBH growth per tree by the CI, "overlap" and crown position. Note that the release was ineffective at high CI levels. Note: Percent Overlap may exceed 100% where multiple influence areas overlap.

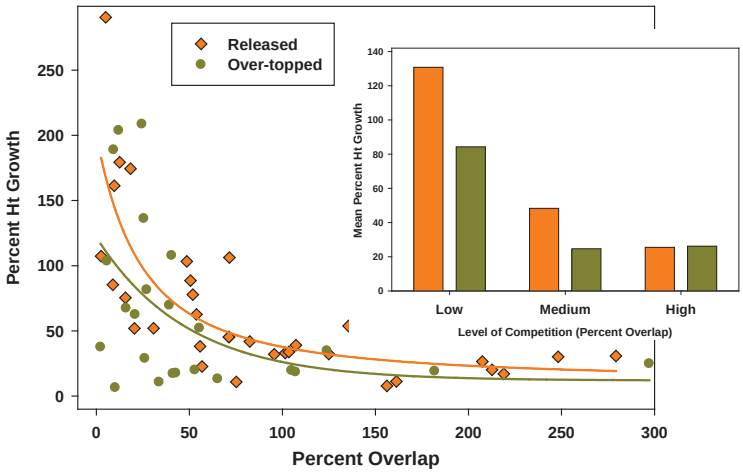


Figure 5 -- Percent Height growth per tree by the CI, "overlap" and crown position.. Note: Percent Overlap may exceed 100% where multiple influence areas overlap.

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