GROWTH OF WESTERN REDCEDAR AND YELLOW-CEDAR

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ABSTRACT
Western redcedar (*Thuja plicata*) and yellow-cedar (*Callitropsis nootkatensis,* syn *Chamaecyparis nootkatensis*) are important tree species in both ecological and economic terms but relatively little information has been available on their growth rates under different stand and site conditions. We took a "data-centric" approach to ask: (1) which environmental variables are most related to site index (for redcedar), (2) what are the limits to growth (size-density relationships) for both species, and (3) how is growth related to stand conditions and site quality? Data was analyzed for over 50,000 trees on more than 3,000 plots throughout the range of both species. A wide range in tree age and stand type was sampled. Results include a classification tree predicting site index for redcedar using climate variables, maximum size-density relationships for both species, and a model for redcedar diameter growth using site and stand variables. Less data was available for yellow-cedar than redcedar but where comparisons across species were possible it appears that although maximum growth rates appear to be lower for yellow-cedar than redcedar, both species respond similarly to stand density.

KEYWORDS: redcedar, yellow-cedar, site index, height growth, diameter growth, size-density relationships

INTRODUCTION
Western redcedar and yellow-cedar are important species in northwestern North America but relatively little information is available on their growth rates (Klinka and Brisco 2009). We know that both species are tolerant of shade, have wide ecological amplitude, and are indeterminate in height growth (have no overwintered bud) (Minore 1990, Harris 1990). Some information is available for redcedar on within-season height growth (Walters and Sooes 1963) and diameter growth (Reukema 1965), and a density management diagram has been available (Smith 1989 and Farnden 1996 in Klinka and Brisco 2009) but most past analyses have used small data sets which have been limited geographically. In addition, very little information has been available for redcedar on topics such as effects of climate on site quality or the effects of stand and site variables on height and diameter growth and almost no quantitative information is available for yellow-cedar. For this project, we surveyed the literature, pulled together our own data sets and contacted several organizations to develop a data set of research and inventory plots where these species were present. We required measurements on fixed-area plots using standard protocols. Plots which had been remeasured were especially useful as they could be utilized to develop or evaluate growth functions, however, plots with only one measurement were also useful for a subset of our analyses. We compiled a data set with 3420 plots with 73,406 trees for redcedar (75% of the plots were remeasured) and 739 plots with 5897 trees for yellow-cedar (46% of the plots were remeasured). Although the two species occupy different ecological niches, we were hopeful that due to their shade tolerance and growth habits they might respond similarly for growth modeling. If so, this would allow us to develop information for redcedar based on a large data set and use it to guide stand management for both species.

METHODS
We analyzed climate variables associated with redcedar site index using a regression tree approach (De'ath and Fabricius 2000). There

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were 1606 observations from a wide geographic area. Climate variables used were from Crookston (2010) which included 15 variables that characterize monthly or seasonal temperature or precipitation; variables included monthly means, minimums, and maximum values as well variables related to time periods such as the frost free period. The classification tree was created using the "tree" package in R software for statistical computing (Ripley 2009).

Density management diagrams (first proposed by Reineke 1933) are used by many foresters to look at tradeoffs between number of trees and tree size (QMD or stem volume) and information taken from these diagrams is used in growth models to predict mortality and regulate stand density (Drew and Flewelling 1979). We developed maximum size-density relationships for both species by selecting plots where either redcedar or yellow-cedar was at least 50% of the basal area. We used this threshold for selecting plots to avoid reducing our data set too substantially. We plotted quadratic mean diameter (QMD) and number of trees per ha (in most cases only trees ≥ 2.5 cm DBH were measured) on a log-log scale. We fit the maximum density line to these points for redcedar using frontier analysis and compared the results to those for western hemlock (*Tsuga heterophylla*) and Douglas-fir (*Pseudotsuga menziesii*) by Weiskittel et al. 2009. Maximum Stand Density Index (Max SDI = number of trees on the line where QMD= 25 cm) was determined as first proposed by Reineke (1933). The Max SDI value and slope of the maximum density line were compared to the previous values for redcedar developed by Smith (1989) and Farnden (1996) (in Klinka and Brisco 2009) and recent values published for Douglas-fir and western hemlock (Weiskittel 2009), two common tree associates. We had to convert the earlier redcedar analyses from tree volume to QMD. We also plotted values over time for remeasured plots which experienced mortality in the BC Ministry of Forests and Range data set. In addition, the redcedar line was compared to the plot information available for yellow-cedar. We did not fit a separate line for yellow-cedar as we had insufficient remeasurement data to verify a separate line would be warranted.

ORGANON is a growth and yield model developed by David Hann and others at Oregon State University (http://www.cof.orst.edu/cof/fr/research/organon/). It models tree diameter growth as a function of tree diameter, basal area (BA), basal area in trees larger than the subject tree (BAL), crown ratio, and site index. Very few of our plots had crown data and only a subset had site index (SI) values. We predicted site index for our plots using the regression tree. We developed a model using an ORGANON-type growth equation (i.e., using the same equation form as in ORGANON) based on tree diameter, BA, and BAL, and SI.

We did not model height growth but we did evaluate height increments for redcedar from remeasured plots by plotting them on the same scale as the commonly used site index curves for redcedar (Kurucz 1985). We determined the percentage of the plots which had height increments close to (± 25%), greater than (>25%) and less than (<25%) the predicted slope for that age and site index. This was done for two large datasets: the BC Ministry of Forests permanent sample plot network and the Continuous Vegetation Survey plots from national forests in WA and OR. There were very few plots with remeasured heights for yellow-cedar so this comparison was only possible for redcedar.

We also determined years from 0.1 m to breast height (1.3 m) from stem analysis data from 10 trees from each of the 19 naturally regenerated sites in BC, WA and OR sampled by Radwan and Harrington (1986) and compared those field values to the ones that would be predicted from the equations in Mitchell and Polsson 1988).

RESULTS AND DISCUSSION

The most important climate variables in the regression classification for redcedar site index were: mean maximum temperature in the warmest month, minimum temperature in the

coldest month, day of year to accumulate 100 degree days > 5°C (a measure of how mild the winter is), and growing season precipitation (Fig. 1b). These variables separated site index values into 6 classes. Looking at the plots spatially (Fig. 1a,c), we can see the sites with the lowest site index are mostly in southeast AK (which is not too surprising). However, the regression tree does provide interesting insights into the geographic separation of sites with moderate or high values for site quality. The greatest site index values were predicted for areas in OR, WA and southern BC that are moderately warm (winter and summer) and have relatively high growing season precipitation. Coastal sites in northwest Oregon, western WA, and BC appear to be limited in productivity by summer temperatures when compared to sites further inland.

Comparisons of height growth increments against Kurucz (1985) site index curves indicated an interesting difference between the 2 redcedar data sets (Fig. 2a,b). The BC data was relatively balanced in terms of the breakdown of percentage of plots with greater (21%) and lower (28%) slopes for the height increments than would be predicted for that age and site quality. On the other hand, in the OR-WA data set, the breakdown in percentage of plots (slopes of height increments compared to the SI curves) was 69% of plots with greater slopes and 15% with lower values. Since the curves under-predict growth for the majority of the OR and WA sites, this could indicate that the curves under predict height growth in warm environments and a future research topic could be the development of new curves for redcedar across a wider range of environments.

The number of years to breast height for redcedar varied within sites (Fig. 3) but did not differ across our range of sampled site index (mean= 4.7 years). This compares to the mean value of 9.5 years as calculated from the equation in Mitchell and Polsson (1988); the M&P equation values differ by SI but the range is quite small. We assume the highest values in Figure 3 would represent trees which were damaged by browsing or other factors early in their life. The lowest values shown on the graph indicate that early height growth can be quite good under favorable conditions.

We developed an ORGANON-type equation for predicting diameter growth of redcedar and compared it to an existing model for Douglas-fir. We used moderate SI values for Douglas-fir (37 m) and redcedar (25 m). With these SI values, the models predict similar growth rates for redcedar and Douglas-fir (Fig.4a) when they are grown with minimal competition. Although the two species are well matched in this example, their growth rates could differ substantially if the SI for either species was changed. However, in all the comparisons we made growth rates are reduced much more sharply for Douglas-fir than redcedar when basal area is increased (Fig.4b). This trend was especially pronounced when BAL increased (Fig. 4c) as diameter growth of redcedar was predicted to be considerably greater than that of Douglas-fir in dense stands and when trees are in poor competitive positions. There was not enough remeasured plot data to fit a similar type of growth equation for yellow-cedar. On plots where both cedars were present (at least 2 of each species) and mean diameter for the 2 species was ± 10 cm, mean growth of yellow-cedar was about 25 to 30% slower than that of redcedar (but relative growth rates were variable, see Fig. 4). In the absence of more data for yellow-cedar, models developed for yellow-cedar could be adjusted downward by 0.3 or could be adjusted based on local information.

The maximum size-density relationship we developed for redcedar (n = 1688 plots) had a maximum density line with a lower slope (-1.29 vs -1.77) and a higher Max SDI (2170 vs 1780) than that previously developed by Smith (1989), but our model was similar to more recent information (Farnden, 1996 as presented in Klinka and Brisco, 2009 had slope = -1.44, Max SDI = 2046) (Fig. 5a). We had a wider range in diameters and larger sample size than was available to Smith. Max SDI was higher than that reported for Douglas-fir (1462) and western

hemlock (1582) (Weiskittel 2009). Reineke (1933) proposed a slope of -1.605; our slope of -1.29 is significantly lower (95% confidence intervals = -1.34 to -1.24). The high Max SDI and lower slope may reflect the ability of this shade-tolerant species to grow in multilayered stands. Remeasured data from the BCMF data set fit the maximum size- density line very well (Fig. 5b). The data cloud for yellow-cedar appeared to fit the line developed for redcedar (Fig. 5c) and values associated with the redcedar line would probably be adequate for yellow-cedar until more data is available to fit a separate line for each species.

CONCLUSIONS

In summary, redcedar productivity is quite sensitive to climate variables with the best sites having warm summers, mild winters, and high summer precipitation; thus, the factors which limit growth differ geographically. Redcedar and yellow-cedar have shared characteristics such as the capacity to develop very high stand densities and good survival in the understory. Although the species differ in their ecological niches, they appear to respond similarly in terms of stand density-tree size relationships. Most of our data was from natural stands and many of these stands were unmanaged. We recognize that management activities can have a major impact on tree growth (e.g., use of genetically improved stock, control of browsing, fertilization); however, until more data is available (e.g., genetic multipliers for growth models, juvenile height growth curves for managed stands), incorporation of our results into growth models and silvicultural guidelines should result in better management of these neglected species. The limited data available for yellow-cedar means managers will need to use relationships developed for redcedar or use knowledge based on local stand conditions.

ACKNOWLEDGEMENTS

We thank the following for their assistance: Tara Barrett, PNW Research Station, for assistance in processing FIA data (FIA = USFS Forest Inventory & Analysis program); Jim Menlove, Rocky Mountain Research Station, for providing FIA plot data for Idaho and Montana; Ron Planden, Forest Analysis & Inventory Branch, BC Ministry of Forests and Range, for providing data from the BC permanent sample plot network; Jane Reid, PNW Research Station, for providing FIA plot data for Alaska; Robin Lesher and Cindy McCain, US Forest Service, for providing data from Region 6 Ecology plots; and Bob Brown, USDA Forest Service Region 6, for help with accessing the CVS data.

Figure Captions

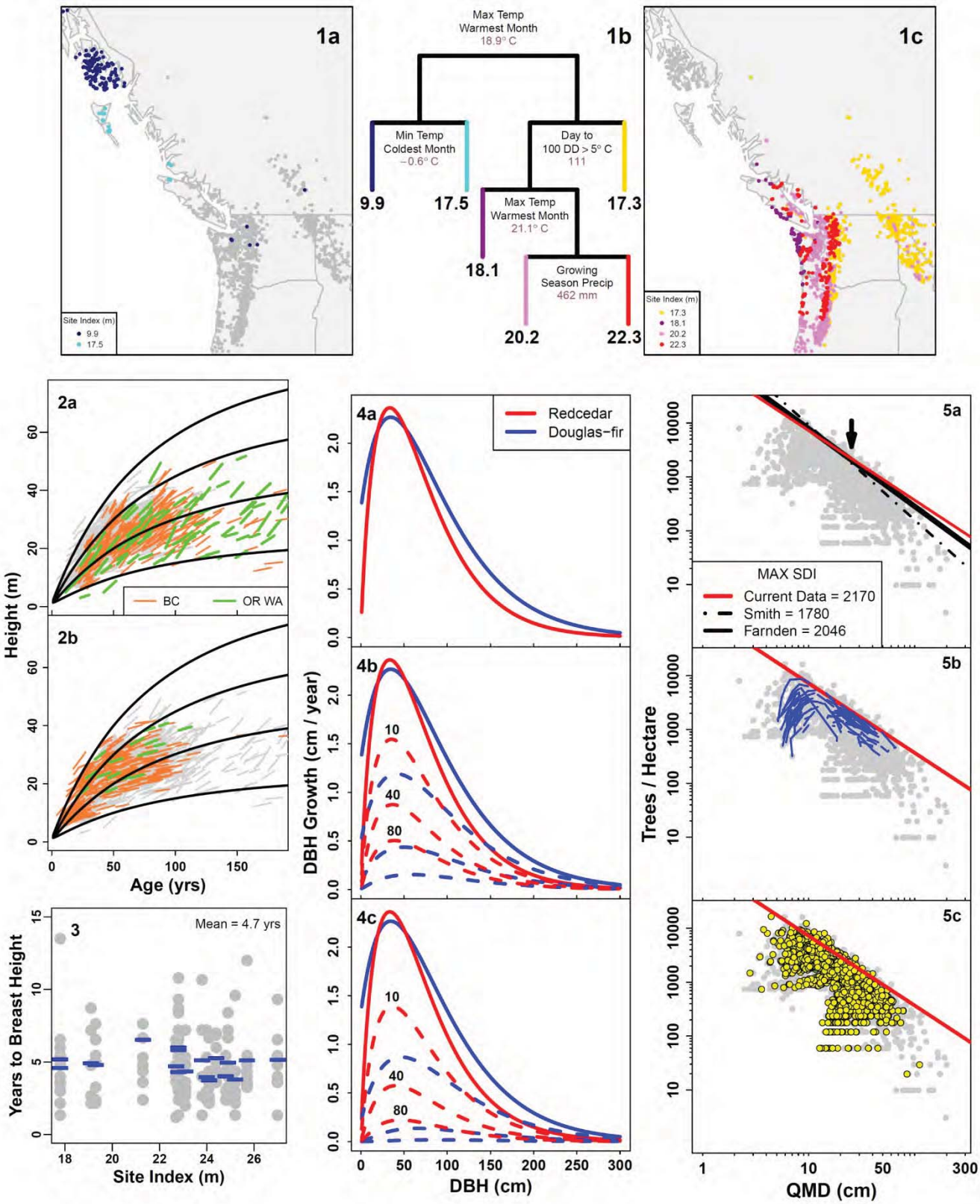
Figure 1 -- Regression tree to predict redcedar SI based on climate variables. The regression tree (b) divided the observations into two “cold” groups (a) and four “warm” groups (c).

Figure 2 -- Height growth increments of dominant and codominant trees from the BC and OR WA CVS datasets compared with the expected height trajectories from Kurucz (1978) site index curves. Height increments with slopes that are 25% greater than the site index curve (a) and 25% less than the site index curve (b) are color-coded by data source.

Figure 3 -- The average number of years to reach breast height across a range of site index for redcedar. Each grey point represents a single tree; the blue bars show the mean for each stand that was sampled.

Figure 4 -- Comparison of new diameter-growth model for redcedar (red lines) with an equation used in ORGANON for Douglas-fir (blue lines). Diameter-growth rates were predicted to be about the same for both species when they are open-grown (a). Predicted growth was compared for stand basal areas of 10, 40, and 80 m^2/ha and for trees in superior competitive positions (b; 75% of basal area in smaller trees) and inferior positions (c; 75% of basal area in larger trees).

Figure 5 -- Fit of a maximum stand density line for redcedar (red) compared with lines presented by Smith (1989) and Farnden (1996).


1a
Site Index (m)
9.9
17.5
1b
Max Temp
Warmest Month
18.9° C
Min Temp
Coldest Month
−0.6° C
Day to
100 DD > 5° C
111
9.9
17.5
Max Temp
Warmest Month
21.1° C
17.3
18.1
Growing
Season Precip
462 mm
20.2
22.3
1c
Site Index (m)
17.3
18.1
20.2
22.3
2a
2b
Height (m)
BC
OR WA
Age (yrs)
3
Mean = 4.7 yrs
Years to Breast Height
Site Index (m)
4a
4b
4c
Redcedar
Douglas−fir
DBH Growth (cm / year)
DBH (cm)
5a
5b
5c
MAX SDI
Current Data = 2170
Smith = 1780
Farnden = 2046
Trees / Hectare
QMD (cm)

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