

Western redcedar extractives: Is there a role for the silviculturist?

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Abstract

Understanding how silvicultural treatments and changes in the forest resource will affect wood quality characteristics, including heartwood natural durability, is a critical need for forest managers. Because heartwood properties can be affected by environmental disturbances, including silvicultural practices used to grow trees faster, we need to know if increased growth rates have associated tradeoffs with natural durability. In this study, the effects of thinning and fertilization were studied on 24 western redcedar trees that were part of a silvicultural trial. There was no consistent relationship between growth rate and extractive content within trees and the fertilization and thinning treatments had no significant effect on the average extractive levels of the trees. The physiological state of the tree, as represented by sapwood reserve levels, was weakly related to heartwood extractive concentration ($r^2 = 0.26$). Further studies to better understand the relationships between silviculture, heartwood extractives, and natural durability are discussed.

Heartwood durability is due, in large part, to the presence of non-structural “extractive” chemicals formed when the oldest portions of the sapwood are converted to heartwood. β -thujaplicin is one of a number of tropolones found in western redcedar. This extractive chemical has been a focus of much research because it is known to be a powerful antimicrobial agent (MacLean and Gardner 1956, Nault 1987, DeBell et al. 1999); however, western redcedar heartwood contains numerous other extractives, some of which have low toxicity and many that have not been identified (Jin et al. 1988, Ohira et al. 1994).

The heartwood component of the stem varies in proportion and quality, as trees grow older and larger. Sapwood thickness remains relatively constant over time, so the proportion of a tree stem that is heartwood increases in bigger trees (e.g., Yang and Hazenburger 1991). In addition, extractive concentration has been shown to increase with increasing distance from the pith (DeBell et al. 1999). Thus, the younger, smaller trees that are becoming increasingly important sources of forest products will have less heartwood that also has lower extractive levels than the older, bigger trees that were harvested in the past. This trend is of particular concern in a species like western redcedar, in which the quantity and quality of the heartwood is key to its value in naturally durable wood products. Another part of the current transition to harvesting younger and smaller trees is the use of intensive silvicultural practices to increase the growth rates of crop trees. This raises

the question of whether aggressive silvicultural practices will affect heartwood properties (such as decay resistance) of tree species such as western redcedar.

If silvicultural practices affect heartwood extractives, and thus natural durability, then it must do so by changing some aspect of the tree’s physiology. We have hypothesized that silviculture influences the energy storage levels in tree stems, and that these energy storage materials are the raw materials that are later used for heartwood extractive formation (Taylor et al. 2003).

Bryant et al. (1983) proposed a link between environmental conditions and the deposition of carbon-based storage and de-

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defensive compounds in the living tissues of small boreal plants. According to their “carbon-nutrient balance hypothesis,” carbon reserves either will be accumulated or depleted depending on the balance of nutrient absorption and carbon fixation (photosynthesis). Excess reserve compounds are then converted into carbon-based defensive compounds that make the leaves, buds, and twigs less palatable to the herbivores. Previous studies suggest that this carbon-nutrient dynamic may extend to trees and can be affected by silviculture, especially in cases where the “balance” is altered through fertilization (Sundberg et al. 1993, von Fircks and Sennerby-Forsse 1998, Viiri et al. 2001, Cheng and Fuchigami 2002, Li et al. 2002).

Because sapwood usually contains free sugar and starch reserves, whereas heartwood does not, it is generally assumed that these reserve materials in the sapwood are consumed in the heartwood formation process (Hillis 1987, Taylor et al. 2002). This argument is strengthened by evidence that the carbon stable isotope signature in the heartwood extractives and the cellulose of the same ring are often correlated (Taylor 2004). Heartwood extractives also are formed from carbon-based compounds imported from the inner bark (living phloem) of *Eucalyptus seiberi* (Hillis and Hasegawa 1963). Thus, it is possible that the levels of carbon-based reserves in the inner bark and sapwood could directly influence the resulting concentrations of carbon-based extractives in the heartwood.

If one applies the model of the carbon-nutrient hypothesis to heartwood extractive formation, treating heartwood extractives as “carbon-based defensive compounds,” then one would predict that silvicultural manipulations that increase nutrient availability more than they increase photosynthate accumulation (e.g., fertilization) will lead to reduced heartwood extractive content. In contrast, if thinning results in increases in water or sunlight to the remaining trees, this would result in increased heartwood extractives if nutrients were constrained. These predictions have not been tested, despite the potential effects of such manipulations on the heartwood quality of naturally durable species.

The objective of this research was to evaluate the impact of thinning and fertilization on the extractive content of western redcedar heartwood.

Materials and methods

Sample selection

Plant material came from a silvicultural trial of western redcedar near Ozette on the Olympic Peninsula in the State of Washington (latitude 48° 9' N, longitude 124° 42' W, 100 m elevation). The site was a naturally regenerated stand of western redcedar that established after a clearcut in 1961. Thinning and fertilization treatments were applied to plots in the stand in a randomized block design. Tree growth was monitored over time (C.A. Harrington, personal communication), and the stand was studied by DeBell et al. (1999) as part of an investigation into the effect of silvicultural treatments on heartwood/sapwood relationships.

We sampled blocks containing each of three treatment combinations: unthinned, fertilized twice [F2]; thinned, fertilized once [TF1]; and thinned, fertilized twice [TF2] (Table 1). Two trees from each of four replicated blocks were randomly selected for sampling. A total of 24 trees were sampled (3 treatment combinations × 4 blocks × 2 trees per block).

Table 1. — Fertilization and thinning regimes applied to western redcedar trees evaluated in this study.

Sample group	Thinning	Fertilization (300 kg N/ha, 100 kg P/ha)	
		1980	1992
F2	No thinning (stocking left at ~5,900 stems/ha)	Yes	Yes
TF1	Thinned to 1,100 stems/ha	Yes	No
TF2	in 1980	Yes	Yes

Table 2. — Correlation matrix of the concentration of extractive components of heartwood samples of western redcedar (n = 269).

Extractive components	Degree of linear association (R) ^a					
	β-in	MT	TA	α-T	β-ol	GC
β-thujaplicin (β-in)	--					
Methyl thujate (MT)	0.49	--				
Thujic acid (TA)	0.41	0.76	--			
α-thujaplicin (α-T)	0.58	0.50	0.53	--		
β-thujaplicinol (β-ol)	0.40	0.41	0.33	0.59	--	
Total of all standards (GC)	0.63	0.78	0.95	0.72	0.47	--
ASTM extractives (ASTM)	0.31	0.24	0.16	0.36	0.38	0.27

^aValues (R) range from -1 to 1, where 0 corresponds to no linear association.

Increment cores (12 mm diameter) were taken at breast height through the pith from each tree in September of 2002, wrapped in plastic, transported in a cooler to the lab and then stored at -10°C until they could be analyzed. The cores were conditioned at 65 percent relative humidity and 20°C for 7 days, to produce a wood moisture content of approximately 12 percent.

Growth measurements

Fertilization or thinning treatments can affect tree growth, thus growth rate was considered to be an important covariate in this analysis. The width of each growth ring (nearest 0.001 mm) from the pith to the cambium was measured on each increment core, using a tree-ring measuring device consisting of a dissecting microscope mounted over a moving stage connected to a linear variable differential transformer (LVDT) displacement transducer (Acu-Rite Incorporated, Jamestown, NY). The increment cores were not sanded before being measured.

Extractive analysis

The increment cores, including heartwood and sapwood, were divided at each growth ring boundary using a razor blade. In cases where the growth rings were narrow, adjacent ring samples were combined to produce a bulk sample weighing at least 0.35 g (at 12% moisture content). The samples were ground to powder in a ball-type tissue pulverizer mill (Garcia Manufacturing, Visalia, California) for 2 minutes.

Samples of the wood powder (0.15 to 0.20 g) were weighed and enclosed in heat-sealable polyester filter bags (mesh size 25 microns, ANKOM Technology, Macedon, NY). Extractives were removed from the samples according to ASTM Standard D 1105-84 (ASTM 1996), which involves sequential extraction steps with toluene, ethanol, and hot water. The sample bags were then oven-dried at 103°C for 24 hours and reweighed. Total extractive content of the samples was calcu-

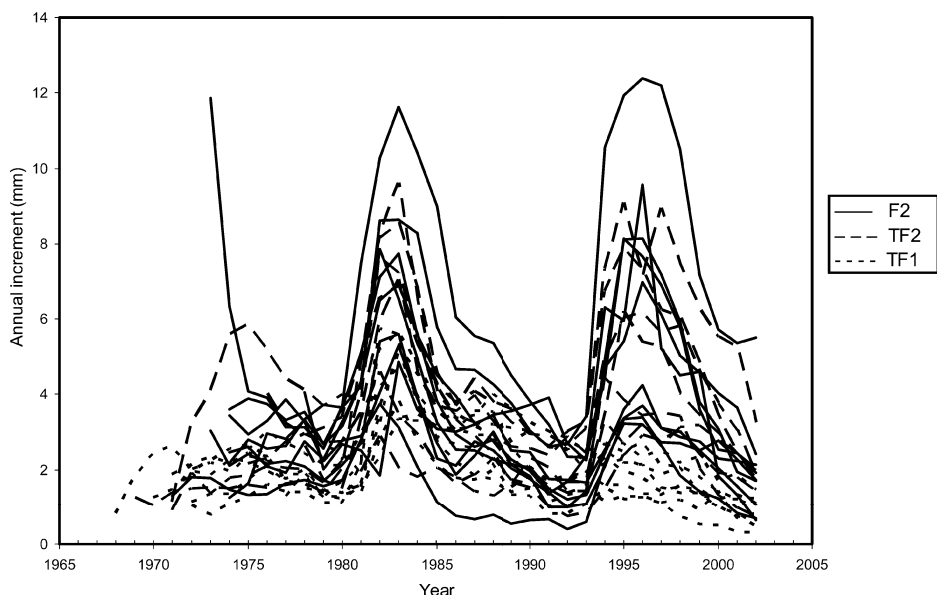


Figure 1. — Radial growth at breast height over time for western redcedar trees subjected to various thinning and fertilization regimes. Each tree shown individually. Fertilizer treatments were applied in 1980 and 1992.

lated as the mass lost from the sample, with a correction for the original moisture content.

The β -thujaplicin content of the wood powder was analyzed by gas chromatography, using a technique modified from that described by DeBell et al. (1999). Samples of the wood powder (0.11 to 0.14 g) were weighed into 2-mL centrifuge tubes. Acetone (1.0 mL) was added to the tubes, which were then capped, shaken, and allowed to stand at room temperature (20° to 23°C) for 18 hours. The tubes were then centrifuged for 10 minutes at 5,000 rpm, and 0.6 mL of the acetone/wood extract solution was pipetted into auto-sampler vials and the vials were capped. The wood extract solutions were analyzed on a Shimadzu GC-2010 gas chromatograph equipped with a flame ionization detector using He as the carrier gas (1.98 mL/min column flow). Then 2.0 μ L injections were made by auto-sampler onto a capillary column (Rtx-5: 15 m long, 0.25 mm inner diameter, 0.25 μ m thick, 5% diphenyl/95% dimethylpolysiloxane coating, Restek, Bellefonte, PA) using a 10:1 split ratio. The oven temperature began at 100°C, then increased at 5°C per minute to 130°C, held at 130°C for 3 minutes, increased by 30°C per minute to 250°C and finally remained at that temperature for 7 minutes. The injector and detector were maintained at 275°C. An external β -thujaplicin standard (CAS Number 499 to 44-5, Aldrich) was used to create a calibration curve to quantify the concentration of β -thujaplicin in each wood extract sample. The concentration of β -thujaplicin in the wood was then calculated by correcting for the mass of wood powder used in the analysis.

One analysis was performed per wood sample. The coefficient of variation of the method was 5.8 percent, as judged by repeated analysis of the same wood powder samples. Subsequent to the β -thujaplicin analysis, standards of α -thujaplicin, methyl thujate, thujic acid, and β -thujaplicinol were obtained (provided by Dr. R. Daniels, Forintek Canada Corporation). Retention times (i.e., peak locations) for these substances were determined under the same chromatography conditions, and the concentration of each of these compounds in each

sample was estimated from the original datasets by applying the same calibration curves developed for β -thujaplicin. Correlations (“R” values) among the values of individual extractive components within each sample were calculated using computer software (S-PLUS 6.1 for Windows. Lucent Technologies, Inc. Murray Hill, NJ).

Comparison of growth and extractive trends over time

To assess the relationship between growth patterns and extractive content, we assumed that a new ring of heartwood was formed each year (Nobuchi et al. 1984, Magel 2000). Therefore, the growth increment in a given year was compared graphically with extractive levels from heartwood rings that were assumed to have converted from sapwood to heartwood during the same year. We used the number of rings in the sap-

wood for a given sample at the time of harvest as the offset for these comparisons (Taylor et al. 2003). When comparing growth rate to total extractive or β -thujaplicin content in trees over time, 5-year moving averages were calculated for both the growth ring width and extractive content to isolate the general trends from background variability.

Whole-tree average values for radial growth rate, total extractive concentration, and β -thujaplicin concentration of the increment cores were calculated by weighting the sample values by their relative contribution to the total mass of the increment core. Basal area-weighted averages were calculated by weighting the values for each sample by their relative contribution to the area of a circular cross section, based on the radial distance contained within the growth ring(s) sampled.

Results and discussion

Silvicultural treatments and growth rate

Measurements of the radial annual ring increments in the increment cores indicated that fertilization increased tree growth in the years after treatment (Fig. 1). Trees that were fertilized twice (groups F2 and TF2) showed two distinct periods of rapid growth, whereas those that were fertilized once had only one growth spike (group TF1).

Thinning appeared to have relatively little effect on the growth of the sampled trees: the thinned-and-fertilized-twice (TF2) group did not grow faster on average (mean growth increment = 3.59 mm, standard deviation [SD] = 1.11 mm) than the unthinned-and-fertilized-twice group (F2) (mean = 3.38 mm, SD = 1.11 mm). Trees in the thinned-and-fertilized-once group (TF1) grew more slowly on average (mean = 2.13 mm, SD = 0.42 mm) than the trees in the other two groups, both of which received an additional fertilizer treatment in 1992.

Silvicultural treatments and extractive content

Radial patterns in total extractive content were inconsistent (Fig. 2) but increased with distance from the pith in about half

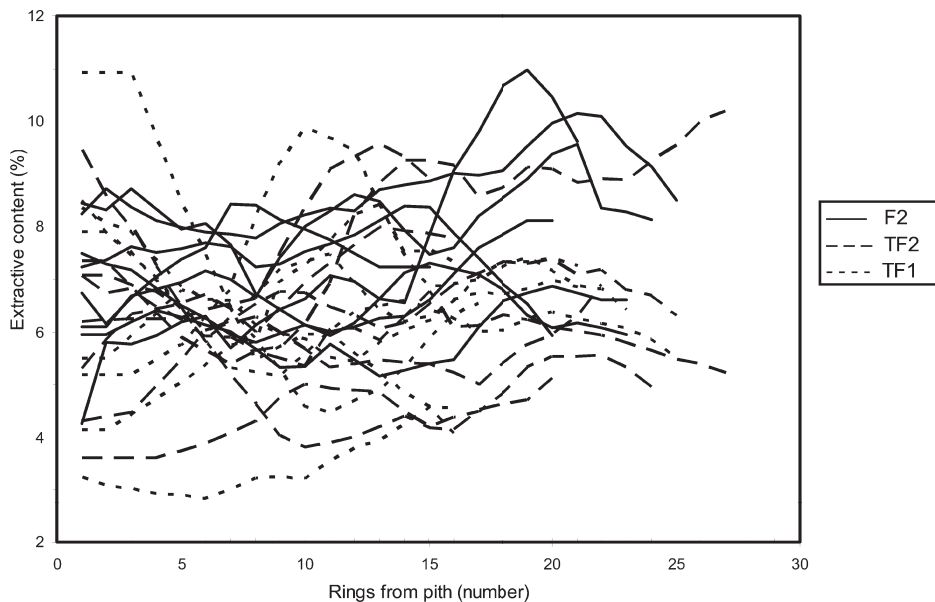


Figure 2. — Radial changes in heartwood total extractive content at breast height for all trees, with each tree shown individually.

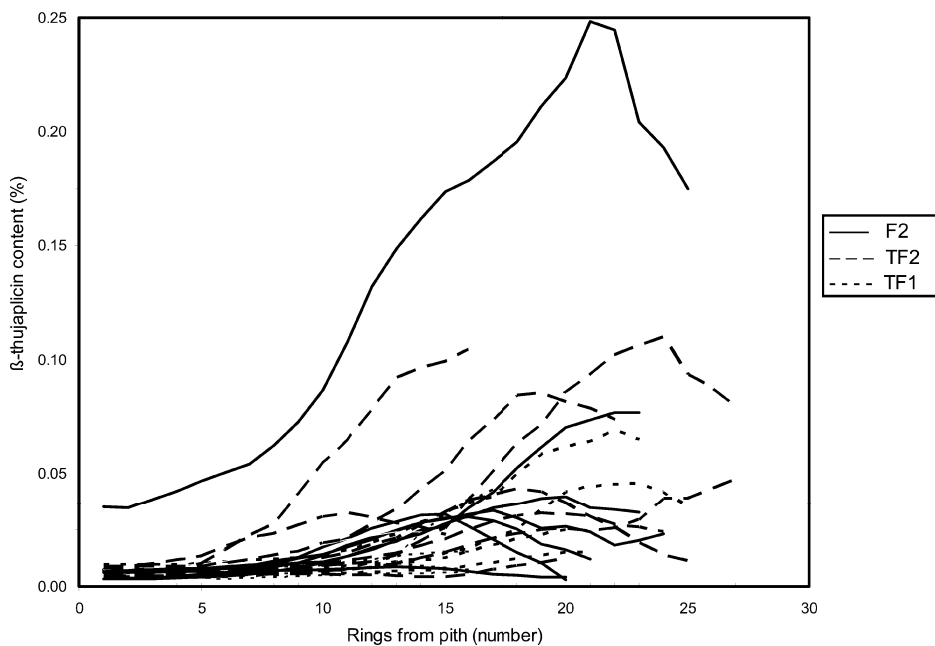


Figure 3. — Radial changes in heartwood β -thujaplicin content at breast height for all trees, with each tree shown individually.

of the trees (Fig. 2). β -thujaplicin levels were generally low in all trees, but showed a relatively consistent trend of increasing concentration with distance from the pith (Fig. 3), similar to that observed by Nault (1987) and DeBell et al. (1999).

There was no consistent relationship between patterns of radial growth rate and heartwood total extractive content. Visual inspection of graphs of the data for each tree suggested a positive association between the fertilizer-related spikes in growth rate and total extractive content in 6 of the 24 trees (Fig. 4A). This is consistent with trends observed in Douglas-fir (*Pseudotsuga menziesii*) in response to thinning (Taylor et al. 2003). There appeared to be no relationship between the fertilization and extractive content curves in 12 trees (Fig.

4B). A negative relationship between fertilizer-induced growth and extractive content had been predicted, but was suggested in only six of the trees (Fig. 4C). There was no consistent difference between the treatment groups in terms of patterns of growth and total extractive content within the trees.

The relationship between growth rate and β -thujaplicin content within trees was also analyzed. β -thujaplicin content in all trees showed no consistent association with radial growth rate (data not shown). Overall, growth rate spikes from fertilization did not appear to coincide with consistent changes in total heartwood extractives or β -thujaplicin content.

There was no significant difference between the treatment groups in whole-tree average extractive content, nor was there any apparent correlation between average growth rate and total extractive content (Fig. 5). This was true in the case of β -thujaplicin content as well as total extractives, using both average values or “basal area-weighted” average values (data not shown).

There were no consistent effects of silvicultural treatments on total extractives among trees or on the patterns of heartwood extractive accumulation over time within trees. This suggests that there is little relationship between the carbon-nutrient balance dynamic and the accumulation of heartwood extractives in young western redcedar trees. The sample size may have been insufficient to account for natural variability, but the relatively consistent reaction of heartwood extractives to thinning that Taylor et al. (2003) observed in Douglas-fir was absent in these western redcedar trees. The heartwoods of Douglas-fir and western redcedar are quite different in their chemistry and natural durability, which may reflect larger differences in growth strategies. Such ecophysiological differences could also produce different heartwood responses to silvicultural treatments. These differences illustrate the importance of understanding tree response before applying silvicultural regimes from one species to another.

Along with species-specific growth responses, there may also be a “juvenile” period in relation to heartwood formation. Nault (1988) and DeBell et al. (1999) observed that extractive contents in old trees continued to increase with number of years from the pith (or “cambial age”). Unlike the pattern with other juvenile-to-mature wood property transitions such as

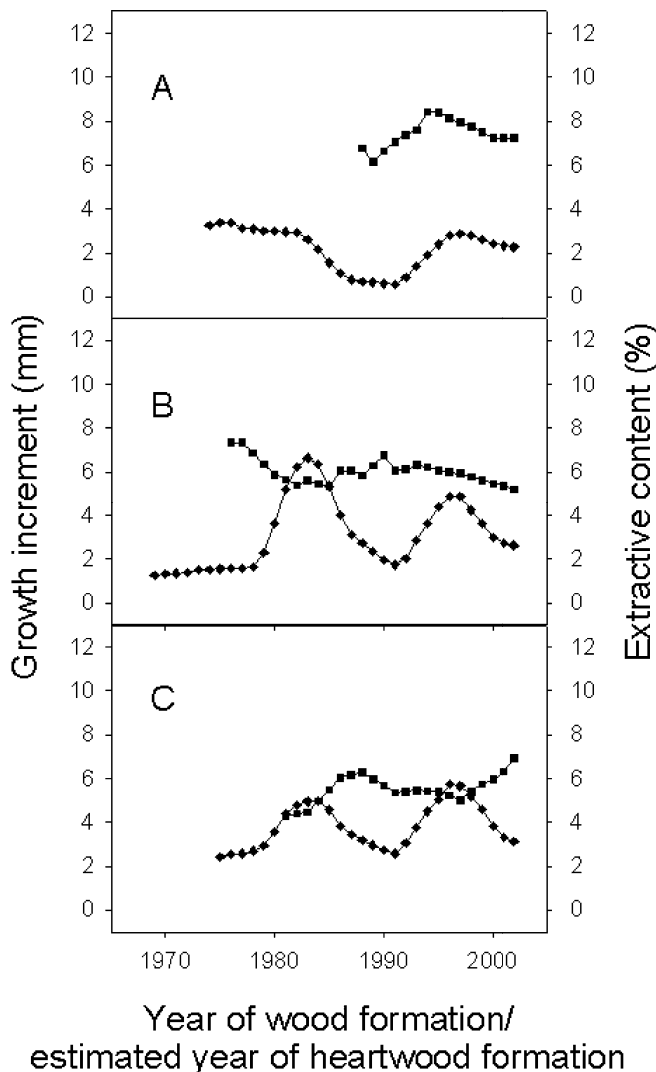


Figure 4. — Growth rate (-◆-) and heartwood total extractive content (-■-) over time for three trees. Panel A is tree 266 from the F2 treatment, showing a positive association between the fertilizer-related spikes in growth rate and total extractive content. Panel B is tree 25 from the TF2 treatment, showing no association between the fertilizer-related spikes in growth rate and total extractive content. Panel C is tree 32 from the TF2 treatment, showing a negative association between the fertilizer-related spikes in growth rate and total extractive content.

cell length (Zobel and Sprague 1998), the extractive content did not level off with number of years from the pith. Such observations suggest that a lower extractive level in heartwood nearer the pith is not a “juvenile-wood” phenomenon in the normal sense. Still, young trees such as those sampled in this study may respond differently to silvicultural manipulation than older trees in terms of heartwood formation.

The silviculturist’s role

Our results suggest that increasing growth through thinning or fertilization does not reduce the extractive content of young western redcedar heartwood. It would be valuable to further assess the relationship between silviculture and heartwood properties in other species, and in older redcedar trees growing over a range of environments, to ensure that gains in growth rate do not come at the expense of natural durability.

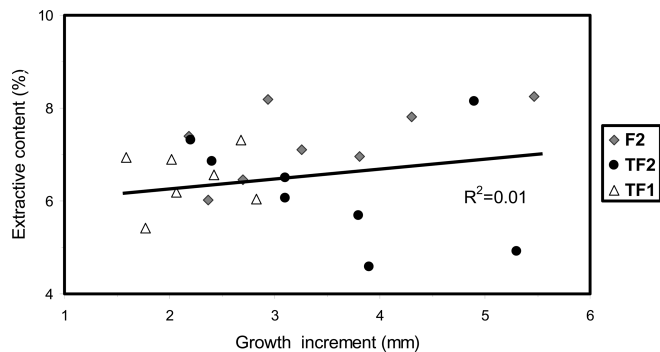


Figure 5. — Relationship between average growth rate and average heartwood total extractive content for all trees.

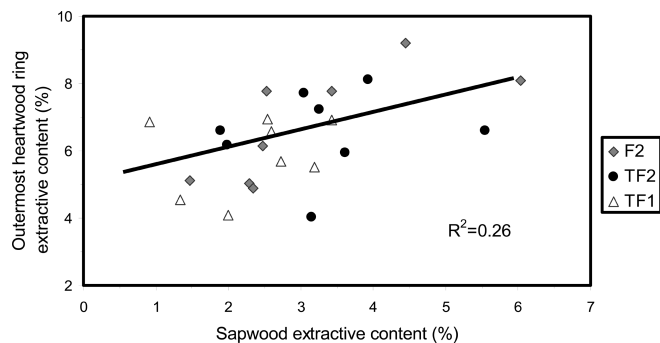


Figure 6. — Heartwood total extractive content as a function of the concentration of reserve materials in the adjacent sapwood for all trees. Sapwood extractive content is the weighted average of total extractive values from all the sapwood rings in each tree.

These data did not support the concept of a relationship between carbon-nutrient balance, environmental manipulation, and heartwood extractive levels; however, there was weak evidence that higher amounts of reserve materials in the sapwood (presumably starch, free sugars, and lipids) were associated with higher total extractive levels in the adjacent heartwood ($r^2 = 0.26$, Fig. 6). This suggests some support for the hypothesis of a positive relationship between carbon reserves in the living tissues and extractive concentrations in the nearby heartwood. In this case, however, the connection between fertilization and tree response may be more localized to those rings formed during the response, which will not become part of the heartwood for many years. It would be useful to analyze which sources of carbon contribute the most to the formation of heartwood extractives in western redcedar, because recent work involving carbon stable isotope analysis has suggested that, in Douglas-fir, extractives within senescing sapwood rings are a primary source of carbon for the heartwood extractives that form within that same ring (Taylor 2004).

The absence of a correlation between silvicultural treatments or the resulting growth rate differences and sapwood extractive levels (data not shown), suggests that it would be useful to investigate further the link between silvicultural practices and sapwood extractives in western redcedar. Such connections have been shown in other species (e.g., *Pinus taeda*, Gebauer et al. 1998), so it would be useful to understand why a similar dynamic was not observed in these trees.

Conclusion

Correlations between sapwood and heartwood extractive concentrations imply that the physiological status of the tree can influence heartwood properties. Fertilization treatments on western redcedar trees produced no consistent changes in the levels of heartwood extractives that are crucial for the natural durability of wood. Increasing the growth rate of young western redcedar trees through silvicultural treatments is not expected to affect natural durability in western redcedar. However, more work is required to test this prediction for different tree ages and growing conditions.

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