Deterioration of wood from live and dead Alaska yellow-cedar in contact with soil

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Abstract

The deterioration of heartwood from live and dead Alaska yellow-cedar trees was evaluated by exposing ministakes in soils at field sites in Alaska and Mississippi for 2 and 4 year intervals. Southern yellow pine sapwood served as a control. The vastly greater deterioration, as measured by weight loss, in Mississippi compared to Alaska (60 and 10 percent after 4 years, respectively) was attributed to warmer temperatures, a longer growing season, and perhaps the presence of termites. The wood from Alaska yellow-cedar trees dead 26 years did not differ in deterioration from the wood from live cedar trees, but wood from cedar trees dead 81 years experienced an intermediate deterioration between these classes and the pine controls. Slow changes in heartwood chemistry following tree death probably explain these differences for Alaska yellow-cedar. The results from this and several related studies indicate that heartwood from dead Alaska yellow-cedar trees is suitable for many indoor and outdoor applications long after tree death, but wood from live or dead cedar trees does not perform particularly well in contact with soil.

Alaska yellow-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach), is a commercially and culturally important tree species in Alaska and British Columbia. Sometimes known as yellow-cedar or yellow cypress, the wood is prized for its strength, resistance to insects and decay (Rennerfelt and Nacht 1955, Barton 1976), and bright yellow color. The heartwood of Alaska yellow-cedar is listed as resistant or very resistant to decay (Forest Prod. Lab. 1999). Alaska yellow-cedar is often the most commercially valuable wood produced in Alaska and British Columbia, with the value driven by Asian markets, especially in Japan. Also, Native people have long used the wood and bark from Alaska yellow-cedar trees for many purposes including canoe handles, clothing, shelter, and artwork (Stewart 1984).

An extensive mortality problem (**Fig. 1**) known as Alaska yellow-cedar decline that occurs on about 500,000 acres in southeast Alaska (Wittwer 2004) and a smaller amount in nearby British Columbia (Hennon et al. 2005) complicates the management of this valuable tree. Concentrated tree death began in about 1880 to 1900 (Hennon et al. 1990a) and has continued to the present in the same forests. Alaska yellow-cedar trees can remain standing for up to a century after their death because of the heartwood's natural durability and superior strength. Standing snags accumulate in declining forests and can average about 65 percent of the Alaska yellow-cedar overall basal area (Hennon et al. 1990b). Thus, declining stands typically consist of long-dead trees, recently dead trees, dying trees, and surviving trees. Canopy level trees appear most vulnerable to the problem, but different ages and sizes of Alaska yellow-cedar trees are found in these dying forests (Hennon and Shaw 1997). The cause of Alaska yellow-cedar decline is not completely understood, and appears to be related to global warming, reduced snowpack, late winter dehardening, and spring freezing (Hennon and Shaw 1997, Schaberg et al. 2005, D'Amore and Hennon 2006, Hennon et al. 2006).

Recently, the strength of Alaska yellow-cedar wood from live trees in Alaska was tested and is now recognized with

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Figure 1. — Intensive forest decline of Alaska yellow-cedar in southeast Alaska. The extraordinary decay resistance and strength of Alaska yellow-cedar wood allow dead trees to remain standing for up to a century after death, offering a unique opportunity for potential salvage recovery of high value wood products.

new stronger design values (Western Wood Products Association 2005 Grading Rules). These new engineering values will likely place even higher demand on the Alaska yellow-cedar resource. A management strategy is being developed in Alaska (Hennon et al. 2006) which suggests emphasizing dead trees from declining forests as a source of timber, and, at the same time, favoring the regeneration and active management of Alaska yellow-cedar on sites where the forest decline does not occur.

The various properties of wood from dead Alaska yellow-cedar need to be evaluated before the declining forests can be used as a reliable source of timber. Thus, several years ago, several studies were initiated on the wood properties of dead Alaska yellow-cedar including mill recovery (volume and wood grades) (Hennon et al. 2000), strength properties (McDonald et al. 1997, Green et al. 2002), decay resistance (DeGroot et al. 2000), and heartwood chemistry (Kelsey et al. 2005). We use the same snag classification system (**Fig. 2**), originally developed for epidemiological studies of the forest decline (Hennon et al. 1990a), in each of these studies to integrate findings on various wood properties of dead trees (see discussion). Our approach has been to document changes in wood properties through time after tree death (e.g., using the snag class system) and to determine if, and when, properties began to change from those measured in wood from live Alaska yellow-cedar trees.

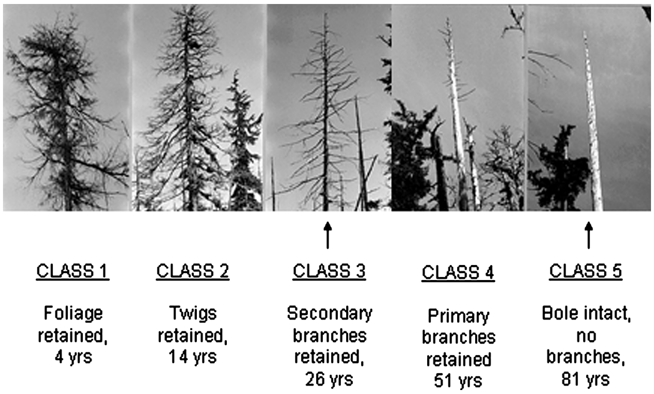

Figure 2. — Characteristics and mean time-since-death (see Hennon et al. 1990a) for the 5 dead tree (snag) classes of Alaska yellow-cedar. Wood from snag classes 3 and 5 (arrows) were used in this study. In addition, wood from live Alaska yellow-cedar trees was used as a standard and wood from southern yellow pine served as a control.

Several previous studies have direct application to the present study on wood deterioration. In a laboratory study, DeGroot et al. (2000) reported that Alaska yellow-cedar wood from live trees and two snag classes experience rapid decay when challenged with wood-decaying fungi. Only the Alaska yellow-cedar wood from the oldest snag class experienced appreciable decay when challenged with an aboveground fungus, however. In another laboratory study, Formosan subterranean termites (*Coptotermes formosanus*) preferentially fed upon Alaska yellow-cedar sapwood, or fungus-stained heartwood, but all termites that fed upon unstained Alaska yellow-cedar heartwood died (Morales-Ramos et al. 2003). Wood from dead trees was not included in that study. Alaska yellow-cedar heartwood of live trees invaded by black-staining fungi (Smith 1970) had smaller concentrations of the defensive compound nootkatin, and thus lower decay resistance (Smith and Cserjesi 1970). Finally, Kelsey et al. (2005) quantified the concentration of various Alaska yellow-cedar heartwood compounds from live trees and each of the five snag classes. Several important compounds (e.g., carvicol, nootkatin, and nootkatol) had similar concentrations in live trees and class 1 and 2 snags, showed initial decline in class 3 snags, then progressively lower concentrations in class 4 and class 5 snags. Kelsey et al. (2005) suggested that the reduced concentration of nootkatin and carvacol may be responsible for diminished decay resistance in the wood from older class 5 snags reported by DeGroot et al. (2000).

The objective of the current study was to document the extent of deterioration due to outdoor exposures in soil contact in two different environments, as measured by weight loss, in Alaska yellow-cedar wood from live trees and two classes of dead trees (dead 26 and 81 years). A secondary objective was to evaluate if wood from trees of different sizes or wood from different radial positions in the tree differed in deterioration.

Methods

Wood collection

The wood used in this study was collected at the same time as wood used in testing strength properties reported by Green et al. (2002) where more sampling details can be found. Briefly, live trees, those dead approximately 26 years (class 3), and those dead approximately 81 years (class 5) (**Fig. 2**) were selected for destructive sampling in a declining Alaska yellow-cedar forest near Wrangell, Alaska, (56°16′44″ N. 132°19′49″ W.) in 1996. Aging from trees sampled in the same forest for a previous study on wood strength (McDonald et al. 1997) indicated that most of our sample trees would have ranged from about 200 to 400 years old. Wood was sampled from two diameter classes of trees: small, 30 to 41 cm (12 to 16 in), and large, 43 to 53 cm (17 to 21 in), measured at breast height to determine if tree size had an influence on wood decay, as was found in an *in vitro* test (DeGroot et al. 2000). As trees were cut, bole sections beginning at breast height and

Table 1. — Number of ministakes used in the study by radial position in sample tree, exposure time, tree condition class, tree diameter class, and exposure location.

			Exposure time							
			2 years				4 years			
			Radial position[a]				Radial position[a]			
Tree condition class[b]	Tree diameter[c]	Exposure location	I	II	O	OO	I	II	O	OO
			(n)[d]							
Live	Large	AK	19	19	18	17^1	19	19	18	17
		MS	19	19	18	17	19^2	19	18	17
	Small	AK	19	19	18	15	19	19	18	15
		MS	19	19	18	15	19^1	19^1	18	15
Snag class 3	Large	AK	9	9	9	9	9	9	9	9
		MS	9	9	9	9	9	9	9	9
	Small	AK	10	10	10	8	10	10^1	10	8
		MS	10	10	10	8	10	10	10	8^3
Snag class 5	Large	AK	9	9	9	9	9	9	9	9
		MS	9	9	9	9	9^1	9	9^1	9
	Small	AK	10	10	10	7	10	10	10	7
		MS	10	10	10	6	10	10	10^1	7^1
Control		AK	10	--	--	--	10	--	--	--
		MS	10	--	--	--	10^2	--	--	--

[a] Radial position of the ministake as it was taken from the sample tree: I = innermost, II = inner innermost, O = outermost, OO = outer outermost.
[b] See Figure 2 for snag classes.
[c] Sample trees were either large diameter, 43 to 53 cm (17 to 21 in) or small diameter, 31 to 41 cm (12 to 16 in).
[d] Value in superscripts refer to the number of missing stakes in that group.

127 cm (50 in) long were removed. These were then sectioned longitudinally once, and one of the half bolts was shipped to the Forest Products Laboratory in Madison.

Two radially cut boards from each section of the tree boles of 38 live trees, and 19 each of Class 3 and Class 5 snags were reserved for this study. These boards were then processed so that each durability exposure location would have specimens from both inner and outer heartwood of each tree. The small stakes were prepared by first planning the boards to a thickness of 19 mm. Then, two adjacent 19-mm-wide strips were cut from both the innermost (pith) edge of the board and the outermost edge of the board nearest the sapwood. The 19- by 19-mm (0.75 in) strip was then cut into 17-mm (7 in) lengths. The 177-mm lengths were numbered in sequential order within the 19-mm beams. The identity of each 177-mm length was retained to account for tree, radial position and sequential order within the 19- by 19-mm units. The presence or absence of black stain in each ministake was noted.

Ministakes were then conditioned at 27 °C (80 °F) and 30 percent relative humidity until they reached a stable weight. Reference (control) stakes (19 by 19 by 177 mm) of southern yellow pine (*Pinus elliotii* Engelm., *P. palustris* Mill., *or P. taeda* L.) sapwood were also conditioned to a constant weight. The control beams were cut from any available southern pine sapwood that had not been chemically treated and had a rate of growth between 2 to 6 growth rings per cm (5 to 15 rings per in). **Table 1** gives the individual counts of ministakes per exposure group.

Field study

The ministakes were exposed at sites in Alaska and Mississippi. A recent clearcut site (56°16′44″ N. 132°19′49″ W.) south of the city of Wrangell on Wrangell Island was chosen for the site in Alaska. This site was approximately 1 km (0.6 mi) south of the declining forest where the wood was originally collected. The clearcut site was well drained, at approximately 150-m (500-ft) elevation, and had a gentle 5 percent west-facing slope. Shrubs and forbs were mowed before deploying the ministakes. Weather data from 1949 to the present from the nearby city of Wrangell indicate an annual mean temperature of 6 °C (43 °F) and annual precipitation of 190 cm (79 in), spread somewhat evenly throughout the year (Western Regional Climate Center 2005). The mild maritime climate at this latitude produces a short growing season with just 5 months of mean daily maximum temperatures greater than 10 °C (50 °F).

The Mississippi field exposure site was located within the Harrison Experimental Forest (HEF) in Saucier, Mississippi. The area was partially cleared of trees before the ministakes were installed; ground cover was mostly wiregrass during the study. The HEF has a slope of 5 to 12 percent, soil that is Poarch fine sandy loam with a pH of 4.85, and an average annual precipitation of 160 cm (62 in) (Crawford et al. 2000). Mean annual minimum and maximum temperatures in nearby Jackson, Mississippi, are 12 °C (53 °F) and 24 °C (76 °F), with no mean monthly temperature below 10 °C (50 °F) (Southern Regional Climate Center 2005).

Two stakes from each sampled position in a beam were exposed at each site and were partially randomized for position in the plot. Odd-numbered ministakes of each 19- by 19-mm beam were exposed in HEF, and even-numbered ministakes of each 19- by 19-mm beam were exposed in Alaska.

The field plot design allowed for the ministakes to be placed in evenly spaced rows 1 m (3 ft) apart with 15 cm (6 in) between each ministake within a row unless an obstacle increased that distance, with no more than 28 ministakes in each row. A total of 582 yellow-cedar ministakes and 20 southern yellow pine control ministakes were installed at each site. The small stakes were immersed nearly full length into soil, setting the bottom to a depth of 15 cm (6 in) (Englerth and Scheffer 1955), and left there for several years. Exposures of two and 4 years at both locations were based on the rate of attack observed on the "IUFRO" stakes (1 by 1 by 18 inches) that are exposed at the Harrison Experimental Forest. After 2 years of exposure, the ministakes in the odd number rows were removed and those in the even number rows were removed after 4 years. Once the ministakes were removed from the ground using pliers, they were soaked in water to remove excess dirt and debris, blotted dry with paper towels, then shipped back to FPL where they were reconditioned to a constant weight at 27 °C and 30 percent relative humidity before weight loss determinations were made. Percent weight loss was used as our indicator for lack of resistance to decay.

Experimental design and data analysis

The percent weight loss of ministakes of Alaska yellow-cedar was compared based on the factors of tree condition class, tree size, stake position within tree, exposure location, and years of exposure. There were three tree condition classes (live trees, snag class 3 (dead 26 yr), and snag class 5 (dead 81 yr)), two tree diameter classes (small and large), four stake positions within a tree (inner, inner-inner, outer, and outer-outer), two exposure locations (Alaska and Mississippi) and two exposure periods (2 and 4 yr). The southern yellow pine controls were assumed independent without tree condition class, tree size, or positional nesting.

A strip-split-plot type of analysis was used with exposure location and years of exposure as one set of strip-plot factors and tree species, tree condition class (within species) and tree size (within species) as another set of strip-plot factors, and stake position (within species) as a subplot factor. Using SAS V9.1 (SAS Institute 2004), a mixed effect analysis (with random effects, with Kenward-Rogers approximation for denominator degrees of freedom in hypothesis testing) was conducted on the logarithm of percent weight loss. The antilogarithm transform provided estimates in terms of median percent weight losses for graphical display. Means in the percent scale were estimated for assumed homoscedastic groups based on summations of random effect estimates and residual estimate. Although both estimators are biased, large sample sizes and small variances were assumed to reduce bias effects. Additionally, approximate confidence intervals were constructed for both medians and means by multiplying the median or mean by the corresponding function of the standard error, $\exp(z_{\alpha/2} \times \mathrm{se}(\ln\%))$ for the lower confidence limit and $\exp(z_{1-\alpha/2} \times \mathrm{se}(\ln\%))$ for the upper confidence limit, where z is the standard normal deviate and se(ln%) is the standard error given on the logarithmic scale (Gilbert 1987). The standard error for the mean confidence interval listed in the tables is based on Cox's method (Zhou and Gao 1997).

Differences in least squares means of the log-transformed percent weight losses were evaluated on a multiple comparison basis, using Holm adjustments (Westfall et al. 1999). The adjustments were applied to a family of 43 comparisons. One stake exposed in Alaska for 2 years was lost and assumed missing at random; several ministakes exposed in Mississippi for 4 years and one ministake exposed in Alaska for 4 years were reported missing and assumed completely destroyed. Different imputations of this data were evaluated to determine the sensitivity of the analyses to these assumptions.

Table 2. — Fixed effect analysis for factors associated with estimated weight loss from ministakes placed in the ground. Factors include species (Alaska yellow-cedar, southern yellow pine), tree condition class (live cedar, dead class 3 cedar, dead class 5 cedar), tree size diameter class (small, 30 to 41 cm (12 to 16 in) and large, 43 to 53 cm (17 to 21 in), exposure location (Alaska and Mississippi), exposure period (two and 4 yr). Not shown are primary factors or interactions where p > 0.10.

Type 3 tests of fixed effects				
Effect	Num DF[a]	Den DF[b]	F Value	Pr > F
Species	1	793	60.34	<0.0001
Tree condition (species)	2	99	12.21	<0.0001
Tree condition × tree diameter (species)	1	98	3.16	0.0468
Exposure location	1	75	1312.19	<0.0001
Wood species × exposure location	1	846	9.99	0.0016
Exposure time	1	75	174.02	<0.0001
Tree condition × tree diameter × exposure time (species)	2	771	2.91	0.0552
Species × exposure location × exposure time	1	846	13.48	0.0003

[a] Numerator degrees of freedom is the number of independent hypotheses simultaneously tested with the associated factor.

[b] Denominator degrees of freedom is the Kenward-Roger approximated (SAS 2004).

Results

Exposure location had a dominant influence on deterioration; ministakes in Mississippi experienced significantly greater weight loss than those in Alaska (**Table 2**). Species of wood and exposure period (2 and 4 yr) also had significant effects on deterioration. The interaction of tree condition and tree diameter had a borderline significant effect ($p = 0.047$). Wood from older class 5 snags cedar trees, with large diameter, had significantly greater deterioration than wood from other snag classes, but not significantly different from wood from the smaller diameter class 5 snags. The radial position of the wood in trees did not have a significant effect on percent weight loss and was not evaluated further. Also, the presence of black stain in the wood of ministakes had no detectable influence on deterioration ($p = 0.45$).

Disregarding location and exposure time, Alaska yellow-cedar wood from live trees and class 3 snags did not differ, but wood from the larger, older class 5 snags had significantly greater deterioration (**Table 3**). The wood from Alaska yellow-cedar (combining all tree condition classes) had significantly less deterioration than southern yellow pine control sapwood for three of the four combinations of exposure location and exposure periods (**Table 3**). The 2-year interval in Alaska, where both species experienced about 5 to 6 percent deterioration was the exception. For Alaska yellow-cedar, median weight loss was just 5 and 10 percent in Alaska, but reached to 28 and 60 percent in Mississippi in 2 and 4 years, respectively. The southern yellow pine controls experienced median weight losses of 6, 18, 81 and 99 at each of the respective locations and exposure times.

Because of the large differences in ministake deterioration between Alaska and Mississippi, the influence of tree condition classes, tree sizes, and exposure period were evaluated separately for each location (**Table 4**). Also, median weight

Table 3. — Estimated mean log and median weight loss by tree condition classes (live, snag class 3, snag class 5) and tree diameter class for Alaska yellow-cedar; and also by separate combinations exposure location and exposure time for both wood species. Different letters indicate significantly different medians (p < 0.05) within tree condition class, tree diameter, and species differences within combinations of exposure location and exposure period.

Factor	Estimated mean log percent weight loss	Estimated median weight loss
	(SE)	(%)
Tree condition class × tree diameter[a]		
Live, small	2.76 (0.039)	15.73^{A}
Live, large	2.83 (0.039)	16.90^{A}
Snag class 3, small	2.83 (0.051)	16.97^{A}
Snag class 3, large	2.75 (0.053)	15.66^{A}
Snag class 5, small	2.91 (0.052)	18.36^{AB}
Snag class 5, large	3.08 (0.053)	21.68^{B}
Location × exposure × species		
Alaska, 2 year		
Cedar	1.70 (0.037)	5.46^{A}
Pine	1.79 (0.082)	5.99^{A}
Alaska, 4 year		
Cedar	2.30 (0.046)	9.94^{A}
Pine	2.87 (0.159)	17.62^{B}
Miss., 2 year		
Cedar	3.35 (0.050)	28.37^{A}
Pine	4.40 (0.183)	81.09^{B}
Miss., 4 year		
Cedar	4.09 (0.042)	60.03^{A}
Pine	4.60 (0.122)	99.05^{B}

[a] Alaska yellow-cedar only.

Table 4. — Estimated median and mean weight loss in ministakes by tree condition classes and tree size classes for each exposure location during two and 4 year exposure periods. Values in parentheses are natural log of standard error. SYP is the southern yellow pine control wood. See Figure 2 for explanation of snag classes. Small and large trees were 30 to 41 cm (12 to 16 in) and 43 to 53 cm (17 to 21 in) diameter, respectively.

	2 year exposure		4 year exposure	
Location\tree class	Estimated median weight loss	Estimated mean weight loss	Estimated median weight loss	Estimated mean weight loss
	---------------------- (%)	----------------------	----------------------	----------------------
Alaska				
Pine control	6.0 (0.08)	6.2 (0.08)	17.6 (0.16)	20.0 (0.17)
Cedar:				
Live, small	5.2 (0.05)	5.4 (0.05)	8.7 (0.07)[b]	9.8 (0.07)
Live, large	5.4 (0.05)	5.6 (0.05)	9.8 (0.07)[a]	11.1 (0.07)
Dead Cl 3, small	5.1 (0.06)	5.3 (0.06)	10.2 (0.09)[a]	11.5 (0.10)
Dead Cl 3, large	5.2 (0.06)	5.4 (0.06)	8.8 (0.09)[b]	9.9 (0.10)
Dead Cl 5, small	5.5 (0.06)	5.7 (0.06)	9.9 (0.09)[a]	11.2 (0.10)
Dead Cl 5, large	6.5 (0.06)	6.7 (0.06)	12.9 (0.09)	14.6 (0.10)
Mississippi				
SYP control	81.1 (0.18)	95.4 (0.20)	99.0 (0.12)	106.6 (0.13)
Cedar:				
Live, small	26.4 (0.08)[b]	31.0 (0.08)	51.6 (0.06)[b]	55.5 (0.06)
Live, large	25.9 (0.08)[b]	30.5 (0.08)	59.6 (0.06)[b]	64.1 (0.06)
Dead Cl 3, small	26.3 (0.10)[b]	30.9 (0.11)	60.8 (0.08)[a]	65.5 (0.08)
Dead Cl 3, large	25.8 (0.11)[b]	30.4 (0.11)	50.8 (0.08)[b]	54.7 (0.08)
Dead Cl 5, small	31.5 (0.10)[b]	37.0 (0.11)	66.3 (0.08)	71.4 (0.08)
Dead Cl 5, large	35.6 (0.10)[b]	41.9 (0.11)	74.2 (0.08)	79.8 (0.08)

[a] Significantly different ($p \leq 0.05$) from the respective southern yellow pine control wood, adjusted family-wise.

[b] Highly significant difference ($p \leq 0.01$) from the respective southern yellow pine control wood, adjusted family-wise.

loss for each tree condition–exposure period combination is presented graphically (**Fig. 3**). The generally rapid deterioration in Mississippi yielded significant differences between each tree condition class and control wood in the first 2 years (**Table 4**, **Fig. 3**). Median weight loss was 26 percent for live trees and class 3 snags, and 32 and 36 percent for small and large class 5 snags, respectively. After exposure of 4 years in Mississippi, the control wood was almost completely deteriorated (99% weight loss), often with only the metal tags remaining. Weight loss was 51 to 61 percent for live trees and class 3 snags, 66 percent for small class 5 snags, and 74 percent for large class 5 snags. Only slight deterioration occurred in Alaska after 2 years, where wood from none of the tree condition classes differed from the southern yellow pine control wood. After exposure of 4 years in Alaska, however, each of the Alaska yellow-cedar tree condition classes had significantly less deterioration than that of the control pine wood (**Table 4**, **Fig. 3**), except the wood from large class 5 Alaska yellow-cedar (13%). The decay of wood from live and class 3 snags (9 to10%) classes was approximately one half that of pine (18%).

Discussion

We detected vastly different rates of deterioration between Alaska and Mississippi, and also significant differences between the wood from Alaska yellow-cedar and the southern yellow pine sapwood controls. For Alaska yellow-cedar, tree condition class had an influence on wood deterioration, but not between live trees and the more recently-killed class 3 snags; wood from class 3 snags, dead approximately 26 years, showed no difference in deterioration compared to wood from live cedar trees. Wood from the larger, old dead class 5 snags, dead 81 years, experienced a greater rate of decay than wood from live trees and class 3 snags, but less than the southern yellow pine controls.

Interestingly, DeGroot et al. (2000) found a similar pattern of wood decay when challenging small pieces of Alaska yellow-cedar wood from different tree condition classes and tree size classes with the fungus *Gloeophyllum trabeum* in vitro. Class 3 cedar wood did not differ in the amount of decay from wood from live trees, but the wood from large class 5 snags had significantly greater decay. These results are similar to our field tests reported in this paper. DeGroot et al. (2000) also challenged Alaska yellow-cedar wood with several soil-inhabiting fungi and reported rapid decay of wood that did not vary by tree condition class. This suggests that Alaska yellow-cedar wood, even from live trees, does not perform particularly well in service when in contact with the soil and in the presence of particular soil-inhabiting fungi.

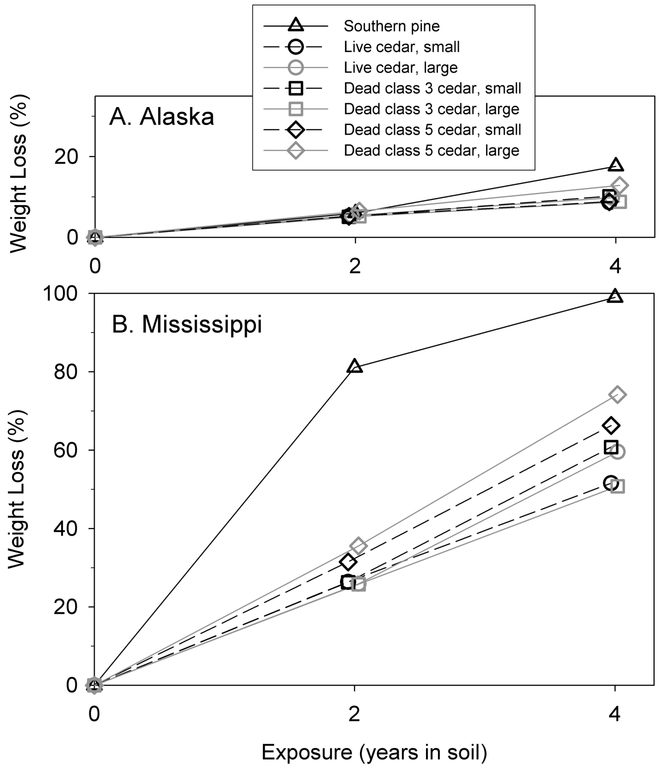

Figure 3. — Estimated median weight loss for ministake wood from large and small Alaska yellow-cedar trees that were live, class 3 (dead 26 yr), or class 5 (dead 81 yr) at A) Wrangell Island, Alaska, and B) Harrison Experimental Forest, Saucier, Mississippi. The wood of southern yellow pine served as a control. See Table 4 for error values and statistical tests on median values.

Englerth and Scheffer (1955) exposed small heartwood stakes of western redcedar, western larch, Douglas-fir, and lodgepole pine in field tests in Missoula, Montana; Madison, Wisconsin; and Gulfport, Mississippi. Approximately 20 percent of the Douglas-fir wood was decayed in 4 years, giving an average life of 3 years. Redcedar stakes at the Gulfport site experienced 19 to 30 percent weight loss after 4 years, which was more decay than the other species. Decay of redcedar was more prevalent in the outer zones of the stakes, whereas test stakes for the other species were more uniformly decayed. The authors suggested that the decay susceptibility of the redcedar was due to the leaching of the extractives responsible for redcedar's decay resistance by the prevalently wet soil at the Gulfport site. Decay resistance of wood coming from different locations of the tree varied according to a fairly well-defined pattern with the outer heartwood being more resistant than the inner heartwood. Apparently, small wood stakes from most tree species, even resistant species such as western redcedar and Alaska yellow-cedar, will not perform for long in these soils. In a separate study, larger Alaska yellow-cedar stakes (2.5 cm (1 in) by 5 cm (2 in)) have been exposed at the Gulfport site for 7 years (Woodward and S. Lebow, unpublished data). Thus far, only the outer heartwood from small class 5 snags and all heartwood from large class 5 snags have completely failed, with an average life of 7 and 5 years, respectively. Wood from live trees and class 3 snags would be expected to have a longer life in soil.

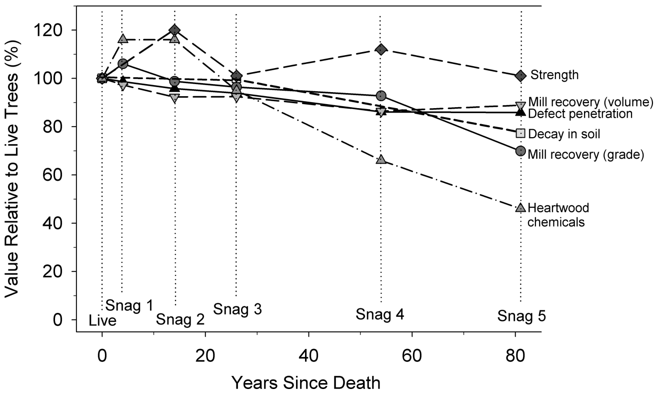

Figure 4. — Graphical summary from this and previous studies on changes in wood properties after tree death as compared to wood from live Alaska yellow-cedar trees. Time-since-death estimates of each snag class are from Hennon et al. 1990a. Volume and wood grade recovery was similar for live trees and the first three snag classes, then had a modest reduction for class 4 and 5 snags, with a greater reduction for grade (Hennon et al. 2000). Defect penetration (deepest occurrence of stain, wood decay, or checking into heartwood on a typical 18-in-diameter snag) only occurred on class 4 and 5 snags (Hennon et al. 2000). There was no difference for any strength property (SG, hardness, modulus of rupture, and modulus of elasticity, mean of the latter two shown above) among live trees and any of the snag classes (McDonald et al. 1997, Green et al. 2002). Decay resistance was similar between wood from live trees and class 3 snags, but experienced a reduction for class 5 snags (DeGroot et al. 2000 and this paper). Heartwood chemistry (mean concentration of the five important compounds shown above) began to change at snag class 3 and continued to decline to snag class 5, in which compounds persisted, but in lower concentrations (Kelsey et al. 2005).

The great differences in deterioration rates between our two field sites could be attributed to considerable warmer temperatures, longer growing seasons, or perhaps to the presence of termites in Mississippi. Termites do not exist in Alaska, and their presence in Mississippi could in part explain the rapid deterioration there. Termites feed on sapwood but not heartwood of Alaska yellow-cedar (Morales-Ramos et al. 2003); however, testing with wood from dead cedar trees has not been conducted. The cold soils and short growing seasons in Alaska surely limit microbial activity and may be primarily responsible for our large site differences.

Using the same snag classification system in our various studies on wood properties (e.g., mill recovery, strength properties, heartwood chemistry, and decay resistance) from dead Alaska yellow-cedar trees allows us to summarize and integrate results here (**Fig. 4**). None of the properties tested in our various studies indicate any differences in the heartwood from live trees and from snag classes 1 or 2. The first indication of a change occurs in heartwood chemistry of class 3 snags, about 26 years after tree death (Kelsey et al. 2005). This change corresponds with the class of snags where decaying sapwood begins to slough off and expose heartwood (Hennon et al. 2000) to external environmental factors that can expedite physical and chemical change. Even with the sapwood decaying in these class 3 snags, however, the mill recovery by wood volume and grade is unchanged relative to wood from live trees. Class 3 snags still had high overall levels of defensive compounds (not significantly different from live trees or snag classes 1 and 2), but two important chemicals thought to convey much of the decay resistance, nootkatin and carvacol, had diminished concentrations at this stage (Kelsey et al. 2005). This gradual reduction in chemical defense continues as the snags remain standing and subsequently leads to a decline in heartwood decay resistance. Nootkatin and carvacol were reduced even further in class 4 and 5 snags, but some other heartwood constituents were still present (Kelsey et al. 2005). The greater deterioration rates in the old class 5 snags, but not class 3 snags, reported both by DeGroot et al. (2000) and in this study suggest that changes in chemistry precede changes in decay resistance. Full exposure of heartwood in class 4 and 5 snags and the resulting checks (cracks) are probably responsible for the slightly reduced volume and grade recovery once the protective sapwood is lost (Hennon et al. 2000). Interestingly, strength properties (those measured were SG, modulus of rupture, modulus of elasticity, and hardness) are the properties slowest to change as there was no measurable decline in any strength property among the snag classes, even those dead some 80 years (McDonald et al. 1997, Green et al. 2002). Apparently, the remaining natural chemistry in old snags is adequate to limit wood decay aboveground, and strength properties are preserved. Some 100 years after tree death, enough wood decay occurs in the major roots and root collar of snags that dead standing trees eventually break at the ground level and fall to the ground, where soil-inhabiting fungi decompose the wood (Hennon et al. 2002).

The unique heartwood chemistry of Alaska yellow-cedar, and the slow way in which it is altered after tree death, have profound ecological and economic implications. Dead Alaska yellow-cedar trees across 200,000 ha (500,000 ac) of southeast Alaska remain standing as snags for up to a century, and because the heartwood remains strong, hard, and undecayed while standing, they probably offer little in the way of habitat for cavity nesting animals (Hennon et al. 2002). This limited deterioration and surprising persistence of wood properties also offer considerable opportunities at recovering valuable wood products.

Conclusions

Our study of field exposure indicates that the deterioration of wood of Alaska yellow-cedar from the early snag classes, with trees dead up to 26 years or so, is comparable to wood from live Alaska yellow-cedars. Wood from Alaska yellow-cedar in the older snag classes (we tested the class 5 snag wood in this study) appears to have a lower resistance to decay, probably the result of altered heartwood chemistry. Thus, wood from these older snags would probably have a more limited service longevity in exposed locations compared to wood from live trees or the early snag classes, but would still be superior to many species of wood. In addition, the persistence of strength properties from these old snags, even in the oldest snag class, demonstrates that this wood could be used indoors where the trait of decay resistance is less important than strength or appearance. The rapid rates of deterioration of Alaska yellow-cedar wood in ground contact at the Mississippi field site suggest that wood from this species, whether from live or dead trees, does not perform particularly well in the soil environment.

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