Pattern of Deterioration and Recovery of Wood from Dead Yellow-Cedar in Southeast Alaska

Paul E. Hennon, *USDA Forest Service, State and Private Forestry and Pacific Northwest Research Station, Juneau AK 99801;* **Dustin T. Wittwer**, *USDA Forest Service, State and Private Forestry, Juneau AK 99801;* **John Stevens**, *USDA Forest Service, Wrangell Ranger District, Wrangell, AK 99929; and* **Ken Kilborn**, USDA *Forest Service, Pacific Northwest Research Station, Wood Utilization Center, Sitka, AK.*

ABSTRACT: *Live yellow-cedar* (Charnaecyparis nootkatensis) *trees and five classes of snags dead up to 81 yr were contrasted based on the following: the retention of bark and sapwood,- the penetration of stain, decay, and weather checks; and the volume and grade of lumber recovered. Of 138 sample trees, most bark was retained on the boles of trees dead < 14 yr but thereafter sloughed away and was generally missing by 51 yr after death. Stain, decay, and weather checks were limited to the narrow sapwood on snags 26 yr after tree death* (n = *280 log end surfaces). Weather checking, the most serious deterioration defect in snags, did not encroach on heartwood until the sapwood was missing some 5lyr after death. Checking penetration averaged 1.3in. for the last two snag classes. Cubic volume recovery from 3O5mill-tength logs did not differ significantly by classes of live trees or snags dead up to 26 yr, and the significant reduction in recovery from snags dead 51 and 81 yr was less than 15%. Grades of lumber were generally similar among the classes of trees, but no clear lumber was recovered from the oldest snag class. These results indicate little to no measurable difference of recovered wood from live trees and the first three snag classes, dead up to 26 yr, and a modest reduction in volume and grade in snags dead up to 81 yr. West. J. Appl. For. 15(2):49-58.*

Yellow-cedar *(Chamaecyparis nootkatensis)* is an important and valuable tree species along the rainforest region of coastal Alaska and British Columbia. The species has a number of outstanding wood characteristics, most notably strength and extreme decay resistance. The bright yellow color and aroma of its heartwood come from compounds that produce great natural durability (Carlsson et al. 1952, Barton 1976). One such powerful heartwood constituent, nootkatin, reduces the growth of decay fungi at concentrations of only 0.00 1% (Rennerfelt and Nacht 1955). Yellow-cedar is con- sistently the most valuable wood grown in Alaska and is a highly desirable product in foreign markets.

An intensive decline and mortality problem affects yellow-cedar on more than 500,000 ac in southeast Alaska, however (Hennon and Shaw 1997). Yellow-cedar is the principal tree species dying; on average, 65% of its basal area is dead on these sites (Hennon et al. 1990a). Biotic agents (i.e., fungi, insects, and nematodes) are probably not responsible for tree mortality, and management activities will not spread the decline problem to unaffected forests (Hennon 1990, Hennon et al. 1990c). Most declining stands contain a mixture of long-dead trees, recently killed trees, dying trees, and some healthy trees. The natural decay resistance of yellow-cedar retards the rate of deterioration, allowing snags to remain standing for up to a century after death. A classification system has been developed for yellow-cedar snags in various stages of deterioration (Figure 1), and two methods were used to determine average time-since-death for each class (Hennon et al. 1990b).

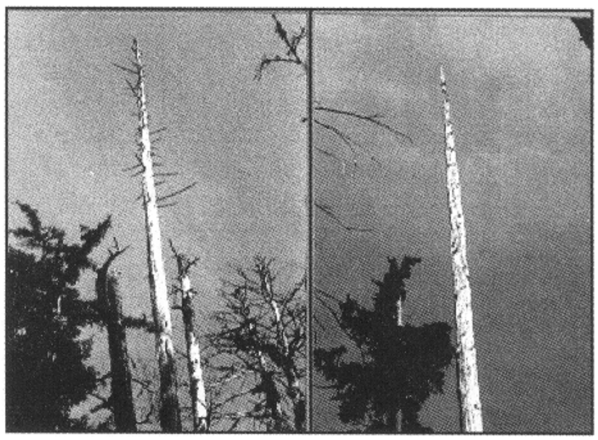
The extensive mortality and high commercial value of yellow-cedar suggest opportunities for salvage within the context of other management objectives. Information on deterioration, recovery, and properties of wood from dead yellow-cedar is needed to evaluate the value and utility of the dead yellow-cedar resource. Preliminary tests indicate no detectable loss in strength of wood from snags, even 8 decades after tree death (McDonald et al. 1997). Additional tests are being conducted now to confirm these results. Also,

NOTE: Paul Hennon is the corresponding author and can be reached at (907) 586-8769; Fax: (907) 586-7848; and E-mail: phennon@fs.fed.us. We extend our appreciation to Frank Age, tree falters, and mill employees at Pacific Rim Cedar, Inc. We thank personnel on the Wrangell Ranger District, particularly Tyler Gunn, who administered the yellow-cedar salvage sale. This work could not have been conducted without the successful cooperation among Pacific Rim Cedar, Wrangell Ranger District, and State and Private Forestry. We thank our certified grader, Les Funk, for grading the cedar lumber. Tim Max provided statistical review. We are also grateful for the helpful comments made by Tom Snellgrove and Eini Lowell on an early draft of this paper.

Class 1 Foliage, dead 4 yrs

Class 2 Twigs, dead 14 yrs

Class 3 Secondary branches, dead 26 yrs



Class 4 Primary branches, dead 51 yrs

Class 5 No branches, dead 81 yrs

Figure 1. Five snag classes of dead yellow-cedar based on the retention of foliage, twigs, secondary, and primary branches. Mean years since death are given for each class (from Hennon et al. 1990b)

we have initiated laboratory and field tests on durability (DeGroot, et al. 2000) and measurements on the concentration of heartwood constituents (Kelsey, unpublished data) in wood from dead yellow-cedars.

The objectives of this study are to describe the pattern of deterioration for dead yellow-cedar trees through time and to determine if there are differences in lumber volume recovery and lumber grade among live trees and the classes of dead trees.

Methods

Site and Tree Selection

Yellow-cedar sample trees were selected from an old-growth forest with a high concentration of dead trees typical of stands with yellow-cedar decline. This forest had no history of timber harvesting. The site had a westerly aspect and was located at an elevation of about 700 ft near Nemo Point (Latitude 56'1 7') on the west side of Wrangell Island in the central portion of Southeast Alaska. The ages of sample trees were not determined, but previous aging of yellow- cedar trees, live and dead, in this stand indicates most trees range from I 00 to 700 yr old (McDonald et al. 1997, McDonald et al., unpublished data).

The sample matrix was three diameter classes representing the range of tree sizes (12.0 to 15.9, 16.0 to 23.9, and 24.0 to 32.0 in. measured at breast height) by seven tree condition classes [healthy, dying (i.e., thinning and off-color foliage), and five recognizable classes of snags based on the retention of foliage, twigs, and branches (Figure 1)]. Our intent was to have 7 trees per sample cell, but we had difficulty finding enough dying trees and the sample consisted of 138 trees. Before harvest, the percentage of bark retained along the bole to a 6 in. top was visually estimated and recorded in increments of 10% for each of these sample trees.

Tree failing, yarding by helicopter, and transporting logs to the mill site were conducted in the fall of 1995. Unfortunately, a balanced design was not achieved be- cause trees in part of the study area were not felled, and some logs from felled trees were lost under an early snow or were left as cull. Information intended to be taken by falters about which sample trees yielded cull logs was not available. The sample logs available for study at the mill site are reported in Table 1.

Pattern of Deterioration

Measurements were made on 280 log end surfaces from 116 trees to describe the deterioration process. These sur- faces included the small end (top) and large end (bottom) of the same log, unless the adjacent surface (e.g., small end of the first log and large end of the second log) had already been measured. Tracking the length and identity of each log allowed us to determine the effects of height above ground on deterioration and recovery. The radial width of sapwood and the greatest radial penetration of stain, wood decay, and checks (cracks) were measured in each of four quadrants from the outer surface towards the pith for each log. The four values for each type of measurement were made to the nearest tenth inch and averaged. In addition, the percentage of wood in each quadrant affected by internal heart rot was determined by visually estimating the number of square inches with and without decay on these log end surfaces. Heart rot decay was assumed to be a pre-existing condition (occurring in the tree before death) if it was located internally on the log end surface and surrounded by sound wood. Thus heart rot was distinguished from decay of dead trees, which progressed from the periphery radially towards the center.

Volume Recovery

Logs transported to the mill site were in lengths ranging from 10 to 44 ft. These "woods-length logs" were cut into "mill-length logs," whose lengths were either 10 or 13 ft, the preferred lengths for export (i.e., 3 and 4 in). The diameters of the small end and large end of mill-length logs were each measured twice along perpendicular axes and averaged. Mill-length logs were then debarked before sawn into lumber.

The gross cubic volume for mill-length logs was calcu- lated from the small and large end diameters and log length using Smalian's formula (1) (Snellgrove and Cahill 1980). A different equation (2) (Bruce 1970) was used to estimate gross volume for the first log (i.e., butt log) of each tree.

$$V = L\,(A, + Ai)/2 \qquad (1)$$

$$V = L\,((0.75 * A,) + (0.25 * Al)) \qquad (2)$$

where

V = volume of log (ft3)

L = length of log (ft)

A, = surface area of small diameter end (ft2)

Al = surface area of large diameter end (ft2)

Results were based on cubic recovery from the 10 and 13 ft mill-length logs listed in Table 1. Mill-length logs were sawn to standard lumber sizes for grading with a conven- tional circular sawmill that had a three block carriage and 3/ 8 in. kerf. Sawing was conducted in a manner to maximize value, not volume recovery. All boards that qualified at the minimal grade by domestic and export rules (West Coast Lumber Inspection Bureau 1996) were considered recover- able for domestic and export markets, respectively. Measurements and grading were made on green logs and lumber; none of the sampled material was kiln-dried. Cubic volume recovery for each mill-length log was simply the sum of the volumes of boards that it yielded. Percent volume recovery was estimated by the following formula:

$$R = Vb \times loo/V, \qquad (3)$$

where

R = recovery (%)

Vb = sum of board volumes (ft3)

V, = gross log volume (ft3) [from Equations (1) or (2)]

With a number of logs missing from sample trees, it was not possible to build recovery equations on a tree basis. We did build volume recoveries for woods-length logs by sum-

Table 1. Number of sample trees, woods-length logs, mill-length logs, and pieces of gradable lumber in each tree/ snag class used in evaluating yellow-cedar deterioration and recovery.

	Trees		Woods-length logs		Mill-length logs		Boards
Tree/Snag class	*n*	Diam* (in.)	*nt*	Diaml (in.)	*n*	Diaml (in.)	*n§*
Healthy	20	21.3 ± 6.9	33 (20)	11.8 ± 5.7	54	15.2 ± 5.6	450
Dying	*5*	18.5 ± 1.9	6 (4)	10.7 ± 3.8	14	13.1 ± 3.0	81
Snag 1	23	20.4 ± 7.0	32 (21)	10.9 ± *5.1*	67	13.6 ± 4.7	441
Snag 2	2 1	21.5 ± 8.0	30 (21)	13.9 ± 6.8	*5 1*	13.7 ± 4.7	324
Snag 3	23	18.8 ± 4.6	33 (21)	12.1 ± 4.1	56	14.4 ± 4.0	373
Snag 4	24	19.7 ± 5.6	21 (16)	10.9 ± 4.3	4 1	13.1 ± 3.4	207
Snag 5	22	16.4 ± 2.9	14 (13)	8.7 ± 3.7	25	13.0 ± 2.5	121
Totals	138	19.6 ± 6.0	169(116)	11.7+5.2	308	13.9 ± 4.4	1,997

Values are mean ± standard deviation of tree diameters at breast height.

t Values are number of logs; values in parentheses are number of trees that yielded the logs. The logs reported here were used for measurements of deterioration on log ends; but 31 of these logs were not available to be cut into lumber for producing results on recovery.

Values are mean ± standard deviation of the small and diameter of logs.

Number of boards graded by domestic rules. The number of boards graded by export rules is smaller because of more restrictive rules. Boards not qualifying at the minimum domestic grade are not included.

ming the volume of lumber from each of the mill-length logs that they yielded. We then estimated the percent recovery for domestic and export lumber for each woods-length log by using its gross cubic volume [i.e., Equation (3)].

Lumber Grade

Each board recovered was given two grades by a certified lumber grader: a domestic grade and an export grade. Standard grading rules were used (West Coast Lumber Inspection Service 1996). Domestic grades were (in descending order) clear, select structural, No. I structural, No. 2 structural, No. 3 structural, construction, standard, and utility; export grades were clear, select merchantable, No. I merchantable, and No. 2 merchantable. We then calculated and charted the percent- age of the recoverable lumber in each grade for all the volume recovered in each tree/snag class. Separate charts were produced for domestic and export grades for the tree/snag classes.

Data Analysis

Analysis of variance tests for unbalanced data in the general linear models procedure (GLM) of SAS Institute Inc. (1989) were used to test for differences among tree/snag classes for various factors. Variables tested were percent bark retention on trees; percent heart rot, percent volume recovery, and volume recovery per linear foot of log of woods- length and mill-length logs; and sapwood thickness and the penetration of stain, decay and checking on log end surfaces. Where analysis of variance indicated significant results, specific differences among means were tested with Bonferonni multiple comparison tests at the P value of 0.05. Lumber recovery was tested under minimum domestic and export rules (i.e., utility and better for domestic grades, No. 2 merchantable and better for export grades). For percent lumber recovery, means and least square means were calculated, the latter using analysis of covariance (SAS Institute Inc. 1989) to account for any imbalances in log diameter among classes. Differences among means were tested as described above; for least square means, differences were evaluated with t tests at the P value of 0.05.

Pearson's correlation coefficients (SAS Institute Inc. 1989) were calculated for sapwood width and height of log end surface above ground on live and recently killed trees (i.e., snag classes I and 2), and also for depth of weather checking and height of log end surface above ground on older, class 4 and 5 snags.

Regression equations were developed to estimate volume recovery of lumber that met domestic and export grades by diameter of mill-length logs. We initially used percent cubic volume recovered as the dependent variable in these equations, an approach found useful in similar studies (Snettgrove and Cahill 1980). We found that volume recovered per linear foot of log as a dependent variable produced better equations, however, and this allowed us to test the influence of tree/snag classes. Recovered volume per linear foot, instead of recovered volume per log, was used to standardize responses because both 10- and 13-ft woods-length logs were sawn into lumber. General models and the influence of log diameter and tree/snag classes were evaluated using the GLM procedure

Table 2. Retention of bark on the boles of 138 yellow-cedar trees and snags before harvest.

Tree/snag class	*n*	Bark retention Mean*	SD	Range
		.... (%)		
Healthy	20	100.Oa	0.0	100
Dying	*5*	100.Oa	0.0	100
Snag 1	23	97.Oa	6.3	80-100
Snag 2	2 1	61.9b	37.4	10-100
Snag 3	23	16.lc	18.5	0-70
Snag 4	24	3.3cd	7.0	0—20
Snag 5	22	0.0d	0.0	0

Means with different letters are significantly different at the 0.05 level.

(SAS Institute Inc. 1989). Heterogeneity of slopes among models developed for each tree/snag class and groups of tree/ snags was tested by analysis of covariance (Littell et al. 199 1). P values of 0.05 or less were used to indicate significant relationships for these various tests.

The same tests used in evaluating differences among tree/ snag classes in percent recovery for mill-length logs were used for woods-length logs. We did not, however, attempt to develop models of recovery for woods-length logs based on log diameter because these logs varied considerably in length.

Results

Pattern of Deterioration

Observations of bark retention on the boles of trees before harvest indicate a progression of bark loss after tree death (Table 2). Tree diameter class did not have an influence on bark retention, but differences by tree/snag class were highly significant ($P < 0.0001$). Nearly all bark was intact on class I snags (mean retention was 97%); bark sloughed away on class 2 and 3 snags (62 and 16% retained, respectively) and was nearly gone on class 4 snags (3% retained), and completely gone on class 5 snags.

Sapwood thickness, as measured on log end surfaces, also differed significantly (P < 0.00 1) by tree/snag class. It did not differ among classes of live trees and the first three snag classes (means ranged from 0.49 to 0.57 in.), indicating little loss of sapwood in these early snag classes (Table 3, Figure 2a). These classes had significantly thicker sapwood than class 4 and class 5 snags, which averaged just 0.09 in. for class 4 and was absent in class 5. On live trees and the first three snag classes, sapwood thickness was weakly correlated with log end surfaces lower in the tree (r = 0.74, P = 0.27) and significantly correlated with log diameter (r= *0. 15, P* = 0.03).

Stain was significantly different (P < 0.001) among some tree/snag classes (Table 3). A small amount of peripheral stain was present in the sapwood of some trees prior to death (i.e., in dying trees), then stain increased quickly after trees died. Penetration of stain was confined to sapwood of class I and 2 snags and, on class 3 snags, it was minimally greater than sapwood thickness. Thereafter, stain began to penetrate somewhat more deeply to discolor heartwood (Figure 2b). Decay showed the same trend through the snag classes, but had a slower, more delayed development than stain. Decay was confined to sapwood through class 3 snags. Even in classes 4 and 5

Table 3. Sapwood thickness and penetration of stain, decay, and checking measured on 280 log ends of yellow-cedar.

				Radial penetration					
		Sapwood thickness		Stain		Decay		Checking	
Tree/snag class (in.)	n	Mean*	SD	Mean*	SD	Mean*	SD	Mean*	SD
(in.)						(in.)			
Healthy	52	0.56a	0.16	0.0la	0.04	0.00a	0.03	0a	0
Dying	10	0.50a	0.07	0.13ab	0.11	0a	0	0a	0
Snag 1	53	0.56a	0.15	0.39bc	0.23	0.04a	0.10	0a	0
Snag 2	50	0.51a	0.13	0.49c	0.17	0. 18a	0.17	0.03a	0.16
Snag 3	53	0.49a	0.18	0.56c	0.21	0.38ab	0.17	0.24a	0.95
Snag 4	37	0.09b	0.09	0.51e	0.37	0.75b	1.74	1.26b	2.15
Snag 5	25	0b	0	0.80d	0.56	0.81b	0.63	1.28b	1.63

* Means with different letters are significantly different at the 0.05 level for the given characteristic.

snags, the average penetration of stain and decay in heart- wood was only 0.75 and 0.81 in., respectively (Table 3).

Checks appeared as cracks in the periphery of wood that penetrated radially towards the center, or pith, of the log. Checking differed significantly by tree/snag class (P < 0.000 1) (Table 3). Checks were absent in live trees and class I snags, minimal in class 2 snags, and averaged about 0.3 in. deep and were still confined to sapwood in class 3 snags (Figure 2b). Checking penetrated more deeply into heartwood than either stain or decay in class 4 and class 5 snags, occurring a mean radial depth of approximately 1.3 in. for both classes (Figure 2b). Checking depth was weakly and negatively correlated with the vertical height of log end surfaces in the tree (i.e., slightly deeper checking lower in the tree) (r = -0.21, *P*= 0.09) for class 4 and 5 snags.

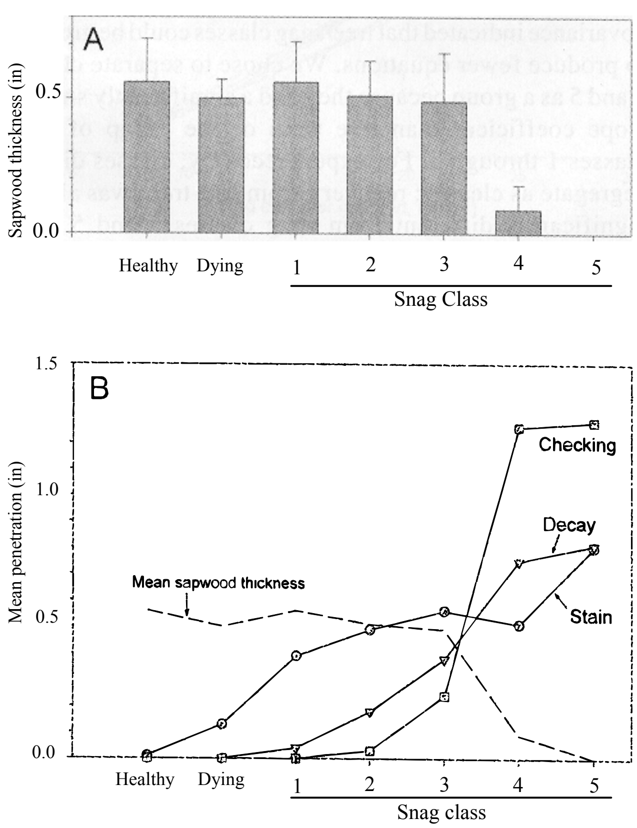


Figure 2. (A) Mean sapwood width for logs from the tree/snag classes. Error bars are ± one standard deviation. (B) Mean sapwood width (from Figure 2a) and mean radial penetration of stain, decay, and checking. See Table 3 for variation about these mean values and significant differences among tree/snag classes.

Heart rot was visible on approximately one-half of log end surfaces sampled. It was present on a low of 30% of log end surfaces from class I snags and a high of 61% of surfaces from healthy trees. The area colonized averaged 9% for all log surfaces and did not differ significantly by tree/snag class because of great within-class variation (ranges were from zero to over 67% in all but the "dying" class). Heart rot most frequently appeared as central brown-colored rot, ring shake (near the pith or in concentric arcs), white pocket rot, and decay associated with wounds. It was not difficult to distinguish heart rot from deterioration after tree death on most log end surfaces: the former often occurred near the center of the log or had peripheral sound wood, and the latter exhibited a pattern of initiating on the periphery and developing towards the center. Regardless of tree/snag class, heart rot was significantly correlated with log diameter (r = 0.37, P = 0.0001) and log end surfaces lower in the tree (r = 0.20, *P* = 0.0008).

Volume Recovery

Because of the small sample size of dying trees and minimal differences found between healthy and dying trees in deterioration, logs from healthy and dying trees were combined into a single class, "live," for analyses on volume recovery and charting lumber grade.

The most common lumber sizes produced for all tree/snag classes were 5 x 5 and 2 x 5 (dimensions given in inches) (Table4). Other common piece sizes included 2x4, 2x6, and 2x8 in. with an assortment of less common sizes. There was little variation among tree/snag classes in the proportion of lumber size sawn except the 5 x 5 size was more common in lumber graded as export from live trees.

Mean percent volume recovery was much higher (45%) for lumber that met domestic grading rules compared to lumber that met export grading rules (11%). Mean percent recovery was not significantly different among tree and snag classes for export recovery (P = 0.35), but was significantly influenced by tree class for domestic recovery (P = 0.02) where there was a general trend of lower recovery as snags aged (Figure 3). The only significant differences among individual tree classes for mean percent domestic recovery were between live trees and snags in classes 4 and 5. The actual reduction in domestic recovery was small, however. The 41 and 43% recoveries in the oldest class 4 and 5 snags, respectively, were less than a 15% reduction from the recovery of live trees. Using the least square means method of computing percent volume recovery resulted in less than a

Table 4. Percentage of lumber in each piece size (in inches) recovered and graded for each tree/snag class according to domestic and export grading rules. Data for lumber from healthy and dying trees have been combined in the class "live."

Tree/snag class	Domestic 5 x 5	Domestic 2 x 4	Domestic 2 x 5	Domestic 2 x 6	Domestic 2 x 8	Domestic Other	Export 5 x 5	Export 2 x 4	Export 2 x 5	Export 2 x 6	Export 2 x 8	Export Other
	(%)											
Live	28	9	35	6	7	15	60	3	31	1	2	3
Snag 1	27	13	29	6	6	19	46	7	32	3	1	11
Snag 2	28	11	29	9	5	18	55	12	22	1	3	7
Snag 3	27	10	31	7	8	17	41	12	34	5	0	8
Snag 4	28	7	31	9	6	19	45	3	38	3	3	8
Snag 5	23	2	35	14	10	16	71	0	29	0	0	0

I% difference from standard means for all tree/snag classes for both domestic and export recovery.

We attempted to fit equations of percent cubic volume recovery as a function of log diameter but found poor correlation. The recommended equations using inverse polynomials for the independent variable log diameter (Snellgrove and Cahill 1980) produced poor relationships (i.e., R2 = *0.* 15 and 0. I I for percent domestic and export recovery, respectively) even when degree of heart rot and vertical position of log in the tree were added as independent variables. Recovered volume increased exponentially with log diameter, as did gross log volume, but the percent recovery appeared to increase only slightly and with high variability as log diameter increased.

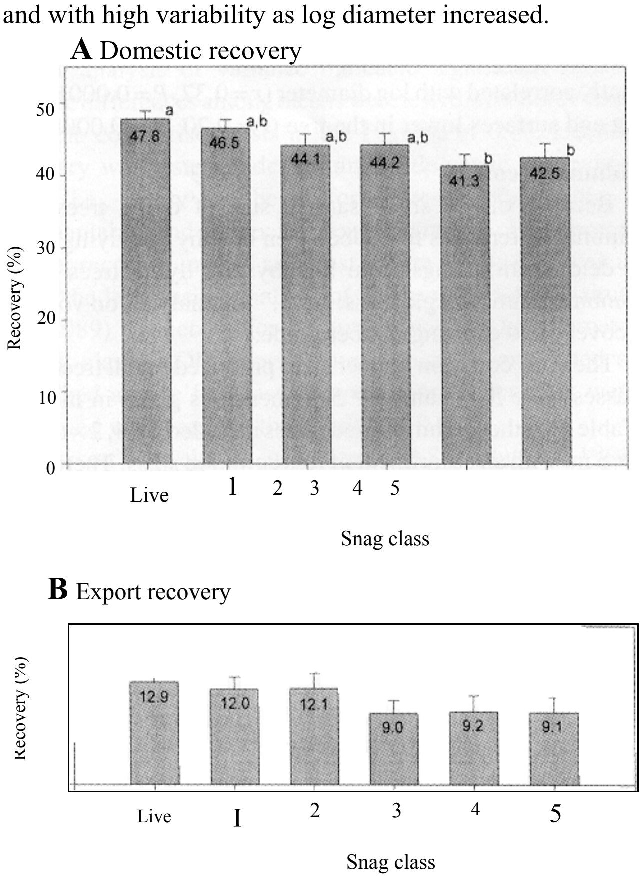


Figure 3. Percent cubic volume recovery for lumber meeting minimum domestic grades (A) and minimum export grades (B) for live yellow-cedars and five classes of snags. Values are mean percent cubic recovery + one standard error. Different letters for domestic recovery denote differences among classes as tested by ANOVA and Bonferroni at P = 0.05. Percent export recovery was not generally different among classes.

Equations using volume (ft3) recovery per linear foot of log as the dependent variable with independent variables of log diameter and tree/snag class produced much better relationships as measured by R2 and F values. This approach allowed us to more precisely evaluate the effect of snag/tree classes on recovery. Transforming the dependent variables of recovery by their logarithmic values improved the linear nature of the relationships for both domestic and export recovery (i.e., R2 = 0.88 and 0.48, respectively) and decreased the correlation of variance with log diameter.

In the general linear models procedure, log diameter explained more of the variation than did tree/snag class, but the latter class variable was significant in estimating both domestic and export volumes per linear foot of log (Table 5, Figure 4). For domestic recovery, analysis of covariance indicated that tree/snag classes could be grouped to produce fewer equations. We chose to separate classes 4 and 5 as a group because they had a significantly smaller slope coefficient than live trees or the group of snag classes I through 3. For export recovery, classes did not segregate as cleanly: recovery from live trees was almost significantly different from snag classes 4 and 5 *(P* = 0. IO), recovery from class I snags was greater than from classes 4 and *5 (P* = 0.02), but classes 2 through 3 did not differ significantly from live trees or from snag classes 4 and 5. We are providing the equation for live trees separately from snag classes I through 3 below, as some users may need recovery estimates for live trees. It is noted, however, that slope coefficients were not significantly different for live trees and this group of three early snag classes (P = 0.34, 0.45 for domestic and export equations, respectively).

From these results, the following regression equations have been developed to estimate cubic volume recovery for yellow-cedar from non-cull logs:

Domestic Recovery

Live trees:

$$\text{In}\ (I + yd,) = -0.228 + 0.0519x \quad (3)$$

Snag classes 1, 2, 3:

$$\text{In}\ (I + yd,) = -0.289 + 0.0544x \quad (4)$$

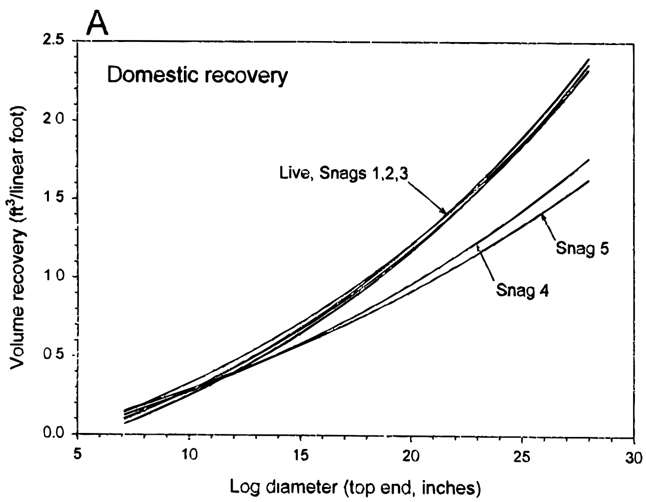
Snag classes 4, 5:

$$\text{In}\ (I + Yd,) = -0.\ 176 + 0.043\ lx \quad (5)$$

Table 5. Partial results from the analysis of variance tests used to estimate domestic and export volume recovery from mill-length logs of live and dead yellow-cedar trees.

Source	DF	Sum of squares	Mean squar	*F* value	*Pr > F*
Domestic recovery					
Model	11	16.44	1.49	208.58	0.0001
Class *	5	0.17	0.03	4.68	0.0004
Diameter †	1	16.20	16.20	2,260.70	0.0001
Class x diameter	5	0.07	0.01	2.05	0.0715
Error	293	2.10	0.01		
Total	304	18.54			
Export recovery					
Model	11	4.89	0.44	24.47	0.0001
Class *	5	0.21	0.13	2.31	0.0445
Diameter †	1	4.48	0.04	246.25	0.0001
Class x diameter	5	0.21	0.04	2.28	0.0471
Error	293	5.33	0.02		
Total	304	10.22			

* Class is a descriptive variable representing tree condition: live, or snag classes 1 through **5**
† Diameter of the small end for mill-length logs.



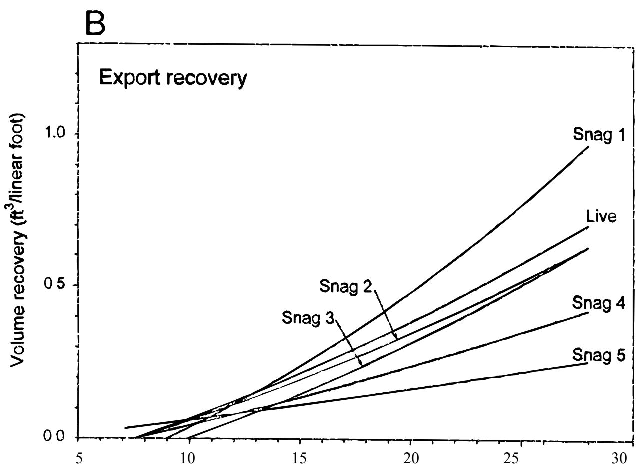


Figure 4. Effect of log diameter (small end) on domestic recovery (A) and export recovery (B) from live trees and snags in classes 1 through 5. Recovery values are expressed as volume per linear foot of log to standardize response because two different log lengths were used in sawing lumber. Equations used the log transformation of recovery volume, but results here are presented with untransformed recovery values. Note that coefficients of equations among classes are not necessarily significantly different.

Export Recovery

Live trees:

$$\text{In (I} + Ye,) = -0.198 + 0.0263x \quad (6)$$

Snag classes 1, 2, 3:

$$\text{In (I} + Ye,) = -0.260 + 0.0293x \quad (7)$$

Snag classes 4, 5:

$$\text{In (I} + Ye,) = -0.109 + 0.0156x \quad (8)$$

where

In is the natural logarithm (log e, c = 2.718)

Ydr = domestic recovery volume (ft3) per linear foot of log

Yer = export recovery volume (ft3) per linear foot of log

X = log diameter (small end) in inches

Each of the three models above estimating domestic recovery was significant [all *P* < 0.000 1; R2=0.92,0.88,0.7 1, respectively for Equations (3), (4), (5)]. The above models explained less of the variation for estimating export recovery but were still significant [all *P* < 0.00 1, R2 = 0.47,0.46, 0.16 for models (6), (7), (8), respectively].

Heart rot levels and vertical position of the log in the tree did not have significant influence on the model for most of these equations and are not included above. Heart rot was weakly associated with lower domestic recovery from live trees, early snags classes (1, 2, 3), and late snag classes (4, 5) *(P* = 0.07, 0.10, 0.28, respectively). Heart rot had a significantly negative effect on the export recovery of early snag classes (1, 2, 3) *(p* = 0.01) but not for live trees or late snag classes (P= 0.48, 0.22, respectively).

Vertical position of logs in trees had little influence (but always negative) on models for domestic recovery [P > 0.60 for live trees and the early (1, 2, 3) and late snag classes (4,5)]. Export recovery was significantly reduced for mill-length logs from increasing heights in trees for the early snag classes (1,2,3) *P* = 0.00 1); however, the effect was nonsignificant for live trees and late snag classes (4,5) *(P* = 0.31, 0.15, respectively).

Results on recovery from woods-length logs were developed by adding the recovered volume from the mill-length logs that they yielded. Few of these woods-length logs were cull (i.e., produced no recoverable lumber graded by domestic rules). Percent domestic recovery was 46.0 ± 2.5, 43.7 ± 3.0, 36.5 ± 3.3, 41.2 ± 2.4 38.7 ± 1.6, 37.7 ± 5.7, and percent export recovery was 12.1 ± 1.8,12.1 ± 1.9,10.6 ± 2.0, 7.5 ± 1.6, 9.2 ± 1.6, 8.5 ± 2.6 for live trees and snag classes I through 5, respectively (mean ± standard error). These recovery values were similar to recovery from niill-length logs (see Figure 3), except fewer classes were significantly different from one another. Results using least square means for recoveries, which adjusts means to a balanced design of log diameter (i.e., small-end diameter) for the tree/snag classes, were very similar (i.e., differed by less than 1%) to actual means per class.

Lumber Grade

The percentages of recovered lumber in domestic and export grades by tree and snag classes are illustrated in Figure 5. Differences appear minimal between live trees and snag class I for recovery by domestic grade. The most valuable grade, clear, showed a trend of being less commonly recovered in snag classes 2 through 4. Logs of class 5 snags differed from the other classes by having no recoverable clear grade and a higher percentage recovery of the lower grades.

In recovery by export grades, differences among live and snag classes I through 3 appeared minimal but somewhat variable. Less clear wood was recovered from class 4 snags and none was recovered from class 5 snags where the lower two grades were more common.

Discussion

Yellow-cedar trees progress through a series of recognizable stages of deterioration after they die. Bark on the holes of yellow-cedar persists for several years after death, then begins to loosen and sloughs away. After tree death, the sapwood of yellow-cedar is quickly colonized by fungi that initiate stain and decay. The low durability of sapwood from all tree species, including those thought to have durable wood, has been known for some time (USDA Forest Service 1935). In yellow-cedar, these defects are almost completely restricted to the narrow sapwood (i.e., approximately 0.6 in. thick) in the first three snag classes, some 26 yr after tree death. The presence of sapwood, whether stained, decayed, or unaffected, appears to protect the heartwood from its most serious defect-checking. Checks often reduce the quality and quantity of wood products that can be obtained from dead trees (Keepf 1978). The penetration of checks in yellow-cedar is variable in the older snags (i.e., classes 4 and 5), but averaged less than 1.5 in. from sample logs. All of the checking in class 5 snags and nearly all of it in class 4 snags occur in heartwood since the sapwood, or nearly all of it, has already decayed and sloughed away by the time snags have reached these classes. This information suggests that the minimum tree diameter of class 4 and 5 snags could be several inches larger than those for live trees or snag classes 1, 2, and 3 to account for checks when developing marking guides for salvage harvests.

The presence of internal heart rot, which we considered to be a condition that exists before tree death in the snags,

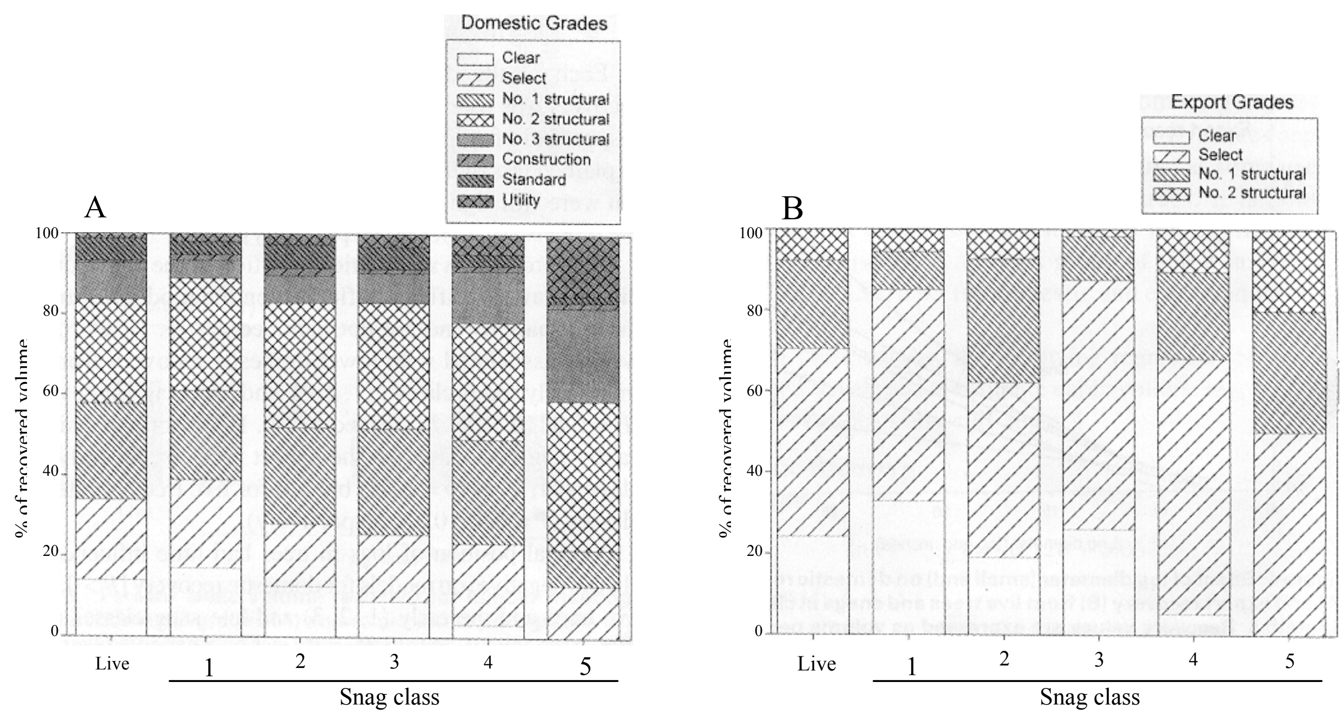


Figure 5. Percentage that each grade contributed to total domestic and export recovery volume for the tree/snag classes.

was quite variable from tree to tree but generally similar among all tree/snag classes. The extent to which heart rot continues after tree death is not known. Generally, heart rot may cause a greater loss to product recovery than whether the tree is live or dead, especially accounting for the heart rot-cull that is left in the woods at the time of harvesting. The outward appearance of many live and dead trees is not particularly useful in determining the presence or amount of heart rot.

The limited development of stain, decay, and checking suggests that recovery rates would not be greatly affected by time-since-death for snags. Indeed, volume recovery did not differ appreciably among live trees and snags in the early classes (classes I through 3). The sapwood becomes stained and decayed in some of these snags, but the thin sapwood is mainly discarded as slabs during the production of lumber whether it is defective or not. The modest reduction in recovery in the older snag classes was likely attributed to the deeper penetration of checks in those logs. This detailed information on the characteristics and condition of snags after tree death may be of use to wildlife biologists. Animal species might use loose hanging bark in the early snag classes (e.g., bats) or the open check cracks on the snag surface of class 4 and 5 snags as nesting habitat. The hard, undecomposed structure of the internal wood in snags, even in the oldest snag class, suggests that these dead trees are not desirable nesting habitat for cavity excavating animals. Primary excavators would more likely use other species, such as western hemlock, due to their high defect level as living trees and deterioration of heart- wood after tree death. Insects, which would serve as food prey for insectivorous birds, may be numerous on the early snag classes when cedar tissues are deteriorating, but occur in smaller numbers in the older snag classes on the nearly inert heartwood surfaces. To test these assumptions, the abundance of insects and birds on yellow-cedar snags is currently under study.

The limitations of this study should be recognized. All sample logs came from one general location on Wrangell Island in the middle portion of southeast Alaska. The sample size for trees and logs is small relative to some other recovery studies. Some of our marked sample trees were not felled, some logs from felled trees were lost under snow, and some logs containing large amounts of defect were not removed. This latter group is a concern, particularly because many of the missing logs were from the older snag classes. However, we cannot predict how many of these logs could have yielded recoverable lumber. Some of the logs left in the woods probably had high levels of defect, but we hesitate to assume that most or all would have produced only cull logs. Thus, results on recovery from the older snag classes, especially classes 4 and 5 where more logs are missing, should be interpreted cautiously. Recovery reported in this study should be viewed as what is potentially recoverable, especially from noncull logs, and should not be used to estimate average recovery volumes from a sample of standing trees.

Tree falters may sometimes assume that logs will not yield recoverable wood based on the outward appearance of snags or because decay was observed in the stump. Those interested in determining the value of the dead yellow-cedar resource need to learn to look past the sloughing bark and outer decaying wood that may be seen on snags. Observations made on the condition of internal wood as old snags are felled would allow tree falters to make better judgements about recovery. We would advise falters to make another bucking cut several feet above the stump height before snags are declared to be cull because we have observed a number of class 5 snags with deep penetrating decay limited to near the ground line. This decay appears to develop in class 5 snags until they finally lose enough structural support and break at the root collar.

The slow decay of yellow-cedar trees allows for lumber recovery long after tree death. We are not aware of information on wood recovery from trees dead up to 80 yr, as in our study. The defensive compounds in yellow-cedar's heartwood and the coot climate of southeast Alaska are likely responsible for such slow deterioration. The cool, year-round rainy climate may also limit the development of checking as the sapwood sloughs away and exposes the heartwood to drying in the class 4 and 5 snags.

Lowery (1982) discusses several examples of deteriorating conifer snags in western North America where very little usable wood can be recovered 5 yr after tree death. Boyce (1929) reports less substantial deterioration from large trees in the Olympic Peninsula up to 15 yr after a large-scale blowdown event. Western redcedar had the lowest volume loss of the tree species (note that yellow-cedar was not present) because only its sapwood was deteriorated.

Percent recovery of lumber using domestic rules for yellow-cedar (41 to 48%) was comparable to recovery in many other studies. Sawing to maximize value rather than volume may have produced the high variability that we found in all tree/snag classes. The low percentage of wood recoverable as export for all tree/snag classes was due to the excessively restrictive rules used for export and, again, the approach of sawing to maximize value. Much of the lumber that did not meet the minimal export grade, and therefore that we classified as unrecovered, appeared to be heading to the export market anyway. A separate grader at the mill was giving these boards export grades using the mill's internal grading system.

Results from this study should be linked with preliminary (McDonald et al. 1997) and more comprehensive, forthcoming results on properties and durability of wood from snags. Combining this information will provide a broader view of the economic value of the dead yellow- cedar resource in southeast Alaska. Thus far, results on recovering commercially valuable wood from yellow- cedar snags are encouraging. Strength properties do not appear to degrade with time after tree death. Recovery volume and grades reported here from the first three snag classes are similar to those from live trees, and those from older snags have only modest reductions.

Literature Cited

BARTON, G.M. 1976. A review of yellow cedar *(Chamaecyparis nootkatensis* [D. Don] Spach) extractives and their importance to utilization. Wood Fiber 8:172-176.

BOYCE, J.S. 1929. Deterioration of wind-thrown timber on the Olympic Peninsula, Washington. USDA For. Serv. Tech. Bull. 104. Washington, DC. 28 **p.**

BRUCE, D. 1970. Estimating volume of Douglas-fir **butt** logs. USDA For. **Serv.,** Res. Note PNW- 1 17. 5 **p.**

CARLSSON, B., H. **ERDTMAN,** A. **FRANK, ANDW.E. HARVEY.** 1952. The chemistry of the natural order Cupressates. VIII. Heartwood constituents of *Chamaecyparis* nootkatensis-carvacrol, nootkatin and chamic acid. Acta Chernica Scandinavica 6:690-696.

DEGROOT, R.C., B. **WOODWARD, AND** P.E. **HFNNON.** 2000. Natural decay resistance of heartwood from dead, standing yellow-cedar trees: Labora- tory evaluations. For. Prod. **J.** 50(l):53-59.

HENNON, PE. 1990. Fungi on *Chamaecyparis nootkatensis. Mycologia* 82:59-66.

HENNON, P.E., E.M. **HANSEN, AND** C.G. **SHAW 111.** 1990a. Dynamics bfdecline and mortality of *Chamaecyparis nootkatensis* in southeast Alaska. Can. **J.** Bot. 68:651-662.

HENNON, P.E., **AND** C.G. **SHAW 111.** 1997. The enigma of yellow-cedar decline: What is killing these long-lived, defensive trees? **J.** For. 95(12):4-10.

HENNON, P.E., C.G. **SHAW 111, AND** E.M. **HANSEN.** 1990b. Dating decline and mortality of *Chamaecyparis nootkatensis* in southeast Alaska. For. **Sci.** 36:502-515.

HENNON, P.E., C.G. SHAW III, AND E.M. HANSEN. 1990c. Symptoms and fungal associations of declining *Chamaecyparis nootkatensis* in southeast Alaska. Plant Dis. 74: 267-273.

KEEPF, C.J. 1978. Industry product recovery experience in operating a sawmill on dead timber. P. 11-18 in Proc. Symp.: The dead softwood timber resource. Washington State Univ., Pullman.

LITTELL, R.C., R.J. FREUND, AND P.C. SPECTOR. 1991. SAS system for linear models. Edition 3. SAS Institute Inc., Cary, NC. 329 p.

LOWERY, D.P. 1982. The dead softwood timber resource and its utilization in the West. USDA For. Serv. Gen. Tech. Rep. INT-125. 18 p.

McDONALD, K.A., P.E. HENNON, J.H. STEVENS, AND D.W. GREEN. 1997.MechanicalpropertiesofsalvageddeadyelIow-cedarinsoutheastA]aska, Phase 1. USDA For. Serv., Forest Products Laboratory, Madison, WI. Res. Pap. FPL-RP-565. 9 p.

RENNERFELT, E., AND G. NACtiT. 1955. The fungicidal activity of some constituents from heartwood of conifers. Svensk Botanisk Tidskrift 49:419-432.

SAS INSTITUTE INC. 1989. SASISTAT user's guide, Ver. 6, Ed. 4, Vol. 2. SAS Institute Inc., Cary, NC. 846 p.

SNELLCIROVE, T.A., AND J.M. CAHILL. 1980. Dead western white pine: Charac- teristics, product recovery, and problems with associated utilization. USDA For. Serv. Res. Pap. PNW-270.63 p.

USDA FOREST SERVICE, FOREST PRODUCTS LABORATORY. 1935. Wood hand-book. U.S. Dep. Agric., Washington, DC. Agric. Handb. 72. 528 p.

WEST COAST LUMBER INSPECTION SERVICE. 1996. Grading rules for west coastlumber. Standard No. 17. West Coast Lumber Inspection Service, Port- land, OR. 275 p.