Aboveground Decay Resistance of Selected Canadian Softwoods at Four Test Sites after 10 Years of Exposure

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Abstract

Aboveground field performance data are needed to help users select appropriate materials, assist in the development of evidence-based codes and standards, and support the development of new export markets. A review of the literature in the early 2000s revealed that there was very little hard data on the performance of North American naturally durable wood species, particularly for aboveground applications. Field tests of six Canadian wood species reputed to have moderate to high natural durability were therefore installed in test out-of-ground contact in the autumn of 2004 and spring of 2005 at two test sites in Canada and two in the United States. Decay results are reported after 10 years. The test site with the fastest aboveground decay rate was in Hawaii. Above ground, yellow cedar (*Callitropsis nootkatensis*) and western red cedar (*Thuja plicata*) were the most consistently durable at all four test sites. However, it would not have been possible to predict the relative performance of naturally durable species in one climate and location from their relative performance in another climate and location. The presence of sapwood was associated with more severe decay, although it was unclear whether the presence of sapwood increased the risk of decay in the adjacent heartwood. There was no substantial difference between decay in old-growth and second-growth samples above ground. The presence of a coating applied to decking had some protective effect against decay at the less aggressive test sites.

Field performance data are needed to help users select appropriate materials, assist in the development of evidence-based codes and standards, and support the development of new export markets. Although there is a long history of using naturally durable Canadian softwoods in exterior applications, there are very limited data available on their field performance, particularly above ground where they are primarily used. Durability classification in North America has largely been based on laboratory decay test data or ground contact field performance data on old-growth material (Scheffer and Morrell 1998, US Department of Agriculture Forest Products Laboratory [USDA FPL] 2010). Above ground, the moisture conditions are more variable, there is a greatly reduced influx of minerals that could act as micronutrients or help detoxify extractives, the typical inoculum is spores rather than mycelium or mycelial cords, and conditions may be less favorable for growth of organisms that might detoxify extractives. Because the conditions in ground contact differ so radically from the conditions above ground, it may be appropriate to define different ratings for ground-contact and aboveground exposures. This is the approach Australia has taken to classify naturally durable species (Standards Australia 2005).

The aboveground performance of North American western red cedar and Douglas-fir has been evaluated in an Australian L-joint test (Francis and Norton 2005, Brischke et al. 2013). Similarly, these species were included in Norwegian double-layer tests (Flæte et al. 2011). Western red cedar and yellow cedar have also been included in decking tests in Wisconsin and Mississippi (Kirker et al. 2012). However, in the early 2000s there was very little hard data on the performance of North American naturally durable wood species virtually, particularly for aboveground applications. The present study was therefore set up to

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evaluate matched material from six Canadian commercial softwoods at four field test sites. Although there was a need to rapidly generate data to address these issues, it was also important to calibrate the degree of acceleration for the data between tropical and temperate sites. As a result, two sites were selected in Canada and two in the United States covering a wide range of decay hazards as indicated by their Scheffer Indices (SI; Scheffer 1971, Setliff 1986).

Lumber produced from naturally durable species with narrow sapwood bands often has one sapwood corner. Because all sapwood is susceptible to decay, these corners may increase the risk of decay in adjacent heartwood. Alternatively, they may have little impact on adjacent heartwood decay for the reason that the most durable heartwood is generally closest to the heart–sap boundary. The present study compares the decay resistance of pure heartwood and mixed sapwood–heartwood decking in five species.

Lumber production from naturally durable species in Canada largely comes from a mix of old-growth and second-growth forests. With the proportion of second-growth material slowly increasing, questions have been raised about potential performance differences between old-growth and second-growth heartwood (Nault 1988). The present study compares the decay resistance of old-growth and second-growth material from four species.

Stains are often applied to naturally durable wood used in aboveground applications. The role of the stain is primarily aesthetic, to protect the surface of the wood from weathering; however, it may also potentially slow the rate of decay. The present study compares the decay resistance of stained and unstained decking.

Materials and Methods

Kiln-dried boards (2 by 6s) 8 feet in length were obtained of three species traditionally believed to be naturally durable, western red cedar (*Thuja plicata* Donn ex D. Don), yellow cedar (*Callitropsis nootkatensis* (D. Don) Örsted), and eastern white cedar (*Thuja occidentalis* L.); and from three species believed to be moderately durable, western larch (*Larix occidentalis* Nutt.), tamarack (*Larix laricina* (Du Roi) K. Koch), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Ponderosa pine (*Pinus ponderosa* Douglas ex C. Lawson), a perishable species, was used for comparison. The wood was procured from the following sources: old-growth and second-growth western red cedar and yellow cedar boards from Delta Cedar Products in Delta, British Columbia; old-growth eastern white cedar from Scierie MSG in Bouchette, Quebec; old-growth and second-growth western larch from Kalesnikoff Lumber Co. in Thrums, British Columbia; second-growth tamarack from Eloie Moisan in St Gilbert, Quebec; old-growth and second-growth Douglas-fir from West Wind Hardwood Inc. in Sidney, British Columbia; and ponderosa pine from George Sherbinin Lumber Ltd. in Westbridge, British Columbia. This material was believed to be representative of typical production of these species and was classified as old growth or second growth according to information obtained from the suppliers. With the exception of ponderosa pine and Douglas-fir, half of the boards were chosen to contain all heartwood, and the other half contained a mixture of heartwood and sapwood. Ponderosa pine boards were all sapwood, and Douglas-fir boards were all heartwood.

The exposure assemblies were constructed and installed using methods later standardized as AWPA standard E25-08 (American Wood Protection Association [AWPA] 2008). Two decks were prepared for each wood species and type for installation at each site. Each of 20 2 by 6-inch test boards was cut into four 500-mm boards, one for each site. In addition, a 50-mm reference sample was taken from each board for future analytical work if warranted. The decks were constructed using stainless steel screws, with the 20 experimental boards mounted in two rows of 10 boards. One row of deck boards was coated on all sides with a commercial deck water-repellent stain (Natural Deck Oil, Napier Inc.), while the other row was left unstained. The decks at the Maple Ridge, British Columbia, test site were refinished with the same stain after 3 years in service. All other decks were left without refinishing. The decks were mounted on leveled concrete blocks with the base of the frames 50 to 100 mm above the ground at four test sites (Table 1; Fig. 1). More detailed descriptions of the test sites are provided by Morris et al. (2011).

For three species—western red cedar, yellow cedar, and western larch—eight decks were constructed for exposure at each test site: two heartwood/old growth, two heartwood/second growth, two heartwood plus sapwood/old growth, and two heartwood plus sapwood/second growth. For Douglas-fir, the available combinations were two heartwood/old growth and two heartwood/second growth; for white cedar, two heartwood/old growth and two heartwood plus sapwood/old growth; and for tamarack, two heartwood/second growth and two heartwood plus sapwood/second growth. At each site there was one ponderosa pine sapwood deck. There were, therefore, a total of 37 decks at each location.

The decks in Florida and Hawaii were evaluated annually, while the sets of decks installed in Canada were formally rated after 5 and 10 years in test. Owing to advanced decay, the final deck evaluations were performed after 7 years in Hawaii and 8 years in Florida. The inspection method involved gentle probing of checks and end grain with a metal spatula for signs of softening or cavities. Particular attention was paid to areas of high moisture content, discoloration, or collapse visible on the surface and areas sounding hollow or dull when tapped with the blunt end of the spatula. Basidiomycete fruitbodies were noted, if present, on the ends and undersides of deck members, and these boards received a rating of 8 or lower. The rating scheme from AWPA E25-08 (AWPA 2008) is shown in Table 2.

The mean decay rating for the 20 boards per species and category were calculated for each annual inspection at the

Table 1.—Test sites.

Test site	Climate	Scheffer Climate Index[a]	Date of installation
Petawawa, ON	Continental	48	Oct 2004
Maple Ridge, BC	Temperate	63	Oct 2004
Gainesville, FL	Subtropical	110	Feb 2005
Mountain View, HI/ Kipuka, HI[b]	Tropical	400/350	Nov 2004

[a] Updated Scheffer Climate Index values from Morris and Wang (2008).
[b] Decks were moved from the Mountain View to the Kipuka test site after 1 year.

Figure 1.—Decking test units at the Kipuka test site in Hawaii after 7 years of exposure.

four test sites and were regressed against years of exposure using SigmaPlot. Regressions were based on fitting a simplified version of the equation developed by Cook and Morris (1995) for preservative-treated wood and further developed by Morris (1998), with the intercept for time zero constrained at 10.0. Overall, the equation below was able to fit curves highly correlated with the data.

$$\text{AWPA rating} = 10 + a(\text{exposure time})^b$$

where a and b are the derived constants for each curve.

The equations of these lines were used to calculate the years taken for the mean rating of each species and category to reach 7.0 (considered to have failed).

A preliminary statistical evaluation of the 10-year decay ratings data from Maple Ridge and Petawawa revealed a nonnormal distribution (skewedness = −1.869 (0.064), kurtosis = 5.277 (0.127)). As a result, and because decay ratings are ordinal data, nonparametric statistics were required to compare data between groups. Group medians were calculated and compared using Mann-Whitney U values and associated two-tailed asymptotic significance. For species comparisons, the Bonferroni correction was applied to account for the multiple comparisons.

Table 2.—Summary of AWPA rating systems.

Rating	% cross section affected	Descriptors
10	0	Sound[a]
9.5	0	Trace or suspicion
9	<3	Minor softening on end grain
8	3–10	Small pockets on end grain
7	10–30	Moderate
6	30–50	Severe
4	50–70	Very severe, likely to affect load bearing
0	>70	Failure when stepped on sharply

[a] Surface nibbles permitted.

Results and Discussion

Calculated times to a decay rating of 7.0 in Florida and Hawaii are shown in Table 3. In addition, the time to rating of 7.0 was calculated for ponderosa pine for British Columbia (7.7 yr) and Ontario (7.2 yr). Based on this one species, the aboveground acceleration factors with respect to the British Columbia site were 1.3 for Ontario, 1.4 for Florida, and 3.3 for Hawaii. Mean ratings of the decks in British Columbia and Ontario after 10 years of exposure are shown in Table 4. The shorter time to reach a rating of 7 in Hawaii compared with the other sites is predicted by its high SI. Direct comparisons among the sites can be made by reference to the 5-year data (Morris et al. 2011).

Yellow cedar and western red cedar were the most durable species above ground at all sites, and they stood out from the rest most strongly in Hawaii, with eastern white cedar, Douglas-fir, western larch, and tamarack all showing shorter, and similar, service lives. In Florida, yellow cedar, western red cedar, eastern white cedar, western larch, and tamarack all showed similar performance, whereas Douglas-fir decayed substantially faster. The relative durability of the species was different again at the two Canadian test sites. The relatively poor performance of eastern white cedar seen

Table 3.—Summary of years to a rating of 7.0 for decking in Hawaii and Florida.

Species	Type	Stain	Hawaii	Florida
Yellow cedar	Old-growth heartwood	Stained	7.1	7.8
		Unstained	7.3	7.5
	Second-growth heartwood	Stained	6.8	7.4
		Unstained	7.0	7.3
	Old-growth heart–sapwood	Stained	7.1	7.4
		Unstained	7.5	7.2
	Second-growth heart–sapwood	Stained	5.2	6.9
		Unstained	5.3	6.6
Western red cedar	Old-growth heartwood	Stained	7.0	7.2
		Unstained	6.3	7.1
	Second-growth heartwood	Stained	6.9	7.2
		Unstained	6.8	7.2
	Old-growth heart–sapwood	Stained	4.6	6.8
		Unstained	5.2	7.0
	Second-growth heart–sapwood	Stained	7.3	6.9
		Unstained	6.0	7.0
Eastern white cedar	Old-growth heartwood	Stained	4.6	7.0
		Unstained	4.0	6.9
	Old-growth heart–sapwood	Stained	4.5	6.8
		Unstained	4.0	6.3
Western larch	Old-growth heartwood	Stained	4.9	7.8
		Unstained	4.1	7.5
	Second-growth heartwood	Stained	5.6	7.5
		Unstained	5.3	7.3
	Old-growth heart–sapwood	Stained	4.7	6.8
		Unstained	3.1	6.7
	Second-growth heart–sapwood	Stained	4.8	6.7
		Unstained	3.5	6.5
Douglas-fir	Old-growth heartwood	Stained	4.9	6.3
		Unstained	4.6	6.0
	Second-growth heartwood	Stained	7.0	6.3
		Unstained	5.6	7.7
Tamarack	Second-growth heartwood	Stained	4.9	7.4
		Unstained	4.3	7.0
	Second-growth heart–sapwood	Stained	3.8	6.4
		Unstained	3.0	5.4
Ponderosa pine	Sapwood	Stained	NA[a]	NA
		Unstained	2.5	6.3

[a] NA = not applicable.

Table 4.—Summary of mean 10-year decay results for decking in British Columbia and Ontario.

Species	Type	Stain	British Columbia	Ontario
Yellow cedar	Old-growth heartwood	Stained	10.0	9.5
		Unstained	10.0	9.3
	Second-growth heartwood	Stained	10.0	9.6
		Unstained	9.9	8.8
	Old-growth heart–sapwood	Stained	9.3	8.1
		Unstained	8.2	8.3
	Second-growth heart–sapwood	Stained	7.9	7.7
		Unstained	8.3	7.2
Western red cedar	Old-growth heartwood	Stained	10.0	9.0
		Unstained	9.4	8.1
	Second-growth heartwood	Stained	9.9	9.5
		Unstained	9.7	8.6
	Old-growth heart–sapwood	Stained	9.3	8.5
		Unstained	8.5	7.7
	Second-growth heart–sapwood	Stained	8.2	7.4
		Unstained	7.2	6.6
Eastern white cedar	Old-growth heartwood	Stained	9.8	7.7
		Unstained	9.4	8.2
	Old-growth heart–sapwood	Stained	9.3	8.4
		Unstained	7.7	7.8
Western larch	Old-growth heartwood	Stained	9.3	7.2
		Unstained	8.8	7.1
	Second-growth heartwood	Stained	9.8	7.5
		Unstained	9.2	7.8
	Old-growth heart–sapwood	Stained	8.2	7.1
		Unstained	8.5	7.2
	Second-growth heart–sapwood	Stained	9.5	7.7
		Unstained	9.0	7.4
Douglas-fir	Old-growth heartwood	Stained	9.9	9.9
		Unstained	10.0	9.7
	Second-growth heartwood	Stained	10.0	9.0
		Unstained	9.8	8.4
Tamarack	Second-growth heartwood	Stained	9.9	7.1
		Unstained	9.5	6.0
	Second-growth heart–sapwood	Stained	8.0	5.8
		Unstained	6.7	6.6
Ponderosa pine	Sapwood	Stained	6.2	5.3
		Unstained	3.4	4.7

in Hawaii may be related to fungal growth found on samples kept in storage for 5 years after installation of these tests, which may indicate preinfection with decay fungi in the standing tree.

It would not have been possible to predict the relative performance at one site based on results at another. This contrasts with the findings of Francis and Norton (2005), where relative decay rates for species with useable data were identical at all sites, but a comprehensive review of tests of shorter duration (Brischke et al. 2013) concluded that the relative durability of different species is not necessarily the same at climatically different places. This agrees with earlier multisite aboveground field performance comparisons, which concluded that the relative performance of different preservative systems also varied among sites (Zahora et al. 2012). These findings support Health Canada's Pest Management Regulatory Agency policy to require wood preservative field testing in Canada and to not rely on data from subtropical or tropical sites.

There was insufficient decay in most of the decks exposed in the Canadian test sites to fit an accurate model to predict time to a rating of 7. Instead, statistical comparisons of the 10-year decay data were made between various groups. There was a significant difference between 10-year decay ratings from British Columbia and Ontario (Table 5) with less severe decay in British Columbia. The SI calculated over the duration of the test (SI_t) was 56 in Maple Ridge and 58 in Petawawa. The higher than normal SI_t in Petawawa and lower than normal SI_t in Maple Ridge explains in part why decay was more rapid in Petawawa than in Maple Ridge.

Species comparisons were made using data from old-growth and second-growth heartwood decks from both sites

Table 5.—Statistical comparison of 10-year decking decay results in British Columbia and Ontario.

Test site	Median	Mean	SD	Mann-Whitney *U*
Maple Ridge	10	9.0	1.5	164,489.5*[a]
Petawawa	8	7.9	1.9	

[a] * Significantly different at $P < 0.05$.

(data from heartwood–sapwood decks were excluded from this analysis). All of the test species were significantly more resistant than ponderosa pine to decay above ground (Table 6). Yellow cedar, Douglas-fir, and western red cedar were the most durable, followed by eastern white cedar, western larch, and tamarack. Western red cedar and eastern white cedar decay resistance was not significantly different. Douglas-fir was more decay resistant in Canada than was observed on matched material in Florida and Hawaii. Parallel work evaluating the ground contact performance of these species found similar trends in relative performance (Laks et al. 2008, Morris et al. 2011).

The effect of old-growth versus second-growth wood was evaluated within each species, excluding mixed heartwood–sapwood samples. There was a statistically significant difference between old-growth and second-growth Douglas-fir; however, median ratings were 10 for both groups (Table 7). There was no significant difference between old-growth and second-growth larch, western red cedar, or yellow cedar. Overall the second-growth material evaluated in this study exhibited similar decay resistance to the old-growth material. These results are consistent with the conclusions of Scheffer and Englerth (1952) for Douglas-fir in laboratory and stake tests and of Freitag and Morrell (2001) for western red cedar in laboratory tests. However, in the latter case, as with many other studies, second growth was not compared directly with old growth at the same time in the same test. In contrast, Clark and Scheffer (1983) found second-growth redwood to be considerably less durable than old growth.

The effect of sapwood was evaluated within each species (Table 8). There was no significant difference between larch heartwood samples and mixed heartwood–sapwood samples, but there was a significant difference between pure heartwood and mixed heartwood–sapwood samples of western red cedar, tamarack, eastern white cedar, and yellow cedar. Because mean ratings were above 7 in most of these groups, it is not clear whether the decay is limited to the sapwood, or whether the presence of decayed sapwood hastens colonization of the adjacent heartwood. This may become apparent in future inspections when the decayed cross-sectional area exceeds the cross-sectional area of the sapwood.

The effect of staining was evaluated in Petawawa where the decks were only stained prior to installation and in Maple Ridge where they were refinished after 3 years (Table 9). There was a significant reduction in decay associated with staining at both sites. After 10 years, the stain on the top surface was almost completely degraded; however, the stain on the underside was still in good shape. It was not clear whether the benefit of staining arose from protection of the top surface for the first few years, thus delaying decay initiation, and/or from long-term protection against humidity from the stain on the bottom surface. Although deck stains generally do not significantly affect decay risk (Thelandersson et al. 2011), these data suggest some potential improvements associated with a high-quality stain at sites with low or moderate decay hazards.

Table 6.—Statistical comparison of decay ratings for each species (heartwood only) after 10 years in British Columbia and Ontario.

Species	Median decay rating	Mean decay rating	SD	Statistically distinct groups[a]
Ponderosa pine	6	4.9	3.0	A
Tamarack	8	8.1	2.2	B
Western larch	9	8.3	1.6	B
Eastern white cedar	9	8.7	1.2	BC
Western red cedar	9.5	9.3	0.9	CD
Douglas-fir	10	9.6	1.1	D
Yellow cedar	10	9.6	0.6	D

[a] Two-tailed asymptotic significance associated with Mann-Whitney with Bonferroni correction to account for multiple comparisons ($P < 0.05$).

Table 7.—Statistical comparison of decay ratings for old-growth and second-growth decking after 10 years in British Columbia and Ontario.

Species	Old or second growth	Median decay rating	Mean decay rating	SD	Mann-Whitney *U*
Douglas-fir	OG	10	9.8	0.5	2,658.5*[a]
	SG	10	9.3	1.5	
Western larch	OG	8	8.1	1.8	2,748
	SG	9	8.6	1.5	
Western red cedar	OG	9.5	9.1	1.1	2,790
	SG	10	9.4	0.8	
Yellow cedar	OG	10	9.7	0.5	2,976
	SG	10	9.6	0.7	

[a] * Significantly different at $P < 0.05$.

Table 8.—Statistical comparison of decay ratings for heartwood and mixed heartwood–sapwood decking after 10 years in British Columbia and Ontario.

Species	Wood type	Median decay rating	Mean decay rating	SD	Mann-Whitney *U*
Western larch	Heartwood	9	8.3	1.6	12,008.5
	Heart–sapwood	8.5	8.1	2.0	
Western red cedar	Heartwood	9.5	9.3	0.9	5,806.5*[a]
	Heart–sapwood	8	7.9	1.5	
Tamarack	Heartwood	8	8.1	2.2	2,052*
	Heart–sapwood	7	6.7	2.4	
Eastern white cedar	Heartwood	9	8.7	1.2	2,456.5*
	Heart–sapwood	8	8.3	1.0	
Yellow cedar	Heartwood	10	9.6	0.6	4,268*
	Heart–sapwood	8	8.1	1.4	

[a] * Significantly different at $P < 0.05$.

Table 9.—Statistical comparison of decay ratings for stained and unstained decking after 10 years in British Columbia and Ontario.

Test site	Stain	Median	Mean	SD	Mann-Whitney *U*
Maple Ridge	Unstained	9	8.7	1.7	55,154.5*[a]
	Stained	10	9.3	1.3	
Petawawa	Unstained	8	7.7	1.9	58,955.5*
	Stained	8	8.0	2.0	

[a] * Significantly different at $P < 0.05$.

Conclusions

Yellow cedar and western red cedar were the only two species that performed consistently well above ground at all four test sites.

There was no consistent difference between decay in old-growth and second-growth samples above ground.

The presence of sapwood was associated with more severe decay, although it was unclear whether the presence of sapwood increased the risk of decay in the adjacent heartwood.

It would not have been possible to predict the relative performance of naturally durable species in one climate and location from their relative performance in another climate and location. This could make service life prediction more problematic than has hitherto been envisaged.

Based on one species, the aboveground acceleration factors with respect to the British Columbia site were 1.3 for Ontario, 1.4 for Florida, and 3.3 for Hawaii.

The equation, AWPA rating $= 10 + a(\text{exposure time})^b$, was able to fit curves highly correlated with the above-ground decay data.

Stain applied to decking had a protective effect against decay in British Columbia and Ontario. It was too rapidly degraded in Hawaii and Florida to have any beneficial effect.

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