Field Tests of Naturally Durable Species

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Abstract

Six wood species generally accepted to represent a range of natural durability were exposed in American Wood Protection Association (AWPA) E7-09 (ground-contact) and AWPA E25-08 (aboveground) decay tests at field sites located near Maple Ridge, British Columbia, and Petawawa, Ontario, in Canada and Gainesville, Florida, and Hilo, Hawaii, in the United States. Variables examined included comparisons of sapwood to heartwood, old growth to second growth, and effect of a protective coating. The tests began between October 2004 and February 2005. Results are reported after 5 years of exposure. Ground-contact decay rates were fastest at sites in Florida and Hawaii. Yellow cedar (*Callitropsis nootkatensis* (D. Don) Örsted), western red cedar (*Thuja plicata* Donn ex D. Don), and eastern white cedar (*Thuja occidentalis* L.) had the highest condition ratings (least decay) for this measure after 5 years of exposure, followed by western larch (*Larix occidentalis* Nutt.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and then tamarack (*Larix laricina* (Du Roi) K. Koch). The aboveground decay rate was highest in Hawaii. For this measure, yellow cedar and western red cedar again had the highest average decay ratings (least decay) after 5 years of field exposure, followed by Douglas-fir, western larch, and tamarack. Eastern white cedar did not fit neatly into this pattern. It was durable at three of the four sites but failed rapidly in Hawaii. Sapwood appeared to have a larger impact on aboveground decay than on ground-contact decay. No substantial difference was found between old-growth and second-growth decay rates.

It may be surprising that a need exists to set up field tests of naturally durable species in the 2000s. However, there has been a lack of hard data on the performance of many of the naturally durable species in North America, particularly in aboveground exposure. Sale and use of these species has been largely based on long-term experience and anecdotal evidence of good performance.

A common assumption among wood product manufacturers and the general public is that current wood products made from the heartwood of species with a history of durability have the same durability as similar products formerly manufactured from old-growth trees. This is not necessarily correct. The fungal and insect resistance of wood primarily depends on the nature and content of secondary metabolites (commonly called extractives) in the wood. Research on many naturally durable species has shown that extractive content typically varies across the transverse plane of the log such that the extractive content is lowest at the pith and highest at the sapwood–heartwood interface. The early literature on this topic is summarized by Hillis (1962). The extractives content of heartwood lumber cut from a naturally durable species will be variable. Its durability will depend in part on the original location of the wood in the log. Lumber cut from the region around the pith will likely have lower extractive content and, hence, durability compared with lumber cut from near the heartwood–sapwood interface. Heartwood lumber cut from smaller, younger trees will normally have a lower level of extractives and subsequent durability than lumber cut from older, larger trees, though some very old trees may have lost durability in parts of the heartwood due to extractive detoxification.

These days, a reputation for durability may no longer be sufficient in existing markets, and hard data typically are required to support sales in new markets. As harvesting shifts toward more second-growth forests, hard questions

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are increasingly asked about the naturally durable heartwood species, including: ‘‘Is the lumber we are buying now as durable as the material we used to get?’’ ‘‘What is the effect on service life of sapwood faces on lumber?’’ ‘‘Can I substitute western larch or tamarack for western red cedar?’’ And in new markets: ‘‘Is white cedar or yellow cedar really as durable as western red cedar?’’ There are plenty of textbook references and anecdotal evidence but little or no hard data on which to base answers to such questions.

The textbook rating of naturally durable species is based mainly on laboratory pure-culture decay tests and ground-contact field tests, but the majority of this material is used in aboveground applications, where 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 will be 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 the ground, it may be appropriate to define different ratings for ground-contact and aboveground exposures.

At around the same time, Paul Morris of Forintek Canada Corp. (now FPInnovations) and Peter Laks of Michigan Technological University (MTU) both recognized the paucity of hard data with which to address these issues. Consequently, a collaborative field experiment using untreated, commercially produced lumber of species available in Canada and reputed to be naturally durable was established in 2004 (Morris et al. 2007). Early results were reported after 3 years (Laks et al. 2008). This article describes results of the 5-year inspections.

Materials and Methods

Wood species

Kiln-dried boards (2 by 6s and 2 by 4s) 8 feet in length were obtained from 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.). Boards were also obtained 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*), a perishable species, was used for comparison. The wood was procured from the following sources: western red cedar and yellow cedar boards from Delta Cedar Products in Delta, British Columbia; eastern white cedar from Scierie MSG in Bouchette, Quebec; western larch from Kalesnikoff Lumber Co. in Thrums, British Columbia; tamarack from Eloie Moisan in St. Gilbert, Quebec; Douglas-fir from West Wind Hardwood, Inc., in Sidney, British Columbia (Vancouver Island); and ponderosa pine from George Sherbinin Lumber Ltd. in Westbridge, British Columbia. With the exception of ponderosa pine and Douglas-fir, half of the boards were chosen to contain all heartwood and the other half to contain a mixture of heartwood and sapwood. Sapwood contents varied from 10 to 30 percent of cross section. Ponderosa pine boards were all sapwood, and Douglas-fir boards were initially all heartwood. Where possible, half of the boards were from old-growth trees, and the other half were from second-growth trees. It was not possible to obtain second-growth white cedar or old-growth tamarack. At a later date (2007), Douglas-fir and southern pine with a mixture of heartwood and sapwood were added. However, results from those sets are not included in this report, because the duration of exposure is too short. The seven species used in the initial testing are described in Table 1.

These materials are believed to be representative of the typical production of these species. The lumber was classified as old growth or second growth according to information obtained from the suppliers.

Field sites

The FPInnovations test site at Maple Ridge, British Columbia, is located within the University of British Columbia Malcolm Knapp Research Forest. The soil at the site is a sandy silt loam to a depth of 0.3 m. It has a pH of approximately 5.1 and is relatively high in organic matter (approximately 18%). Below this is a layer of fine- to coarse-grained sand with some gravel and silt. In summer, groundwater is between 0.5 and 2.4 m below grade. This site has a rainfall of 2,150 mm per year and mean daily maximum and minimum temperatures of 6°C and 1°C, respectively, in January and of 23°C and 12°C, respectively, in July, with an average yearly temperature of 9.6°C. It falls within the moderate decay hazard zone for outdoor aboveground exposure using Scheffer’s climate index (Scheffer 1971, Setliff 1986), with an updated climate index of 55 using the methods of Morris and Wang (2008). This zone includes most of the major population centers of North America.

FPInnovations’ Petawawa test site is located on the grounds of the Petawawa Research Forest near Chalk River, Ontario. The site is located in a cleared natural forest area surrounded by a mixed coniferous/deciduous forest. Mean daily maximum and minimum temperatures are –7°C and –18°C, respectively, in January and 25°C and 13°C, respectively, in July. The site receives mean annual precipitation of 822 mm. It falls within the moderate decay hazard zone for outdoor aboveground exposure using Scheffer’s climate index (Scheffer 1971, Setliff 1986), with an updated climate index of 48 using the methods of Morris and Wang (2008). The soil is classified as a dark brown loam to a depth of 9 cm, changing to a light brown loam that extends to 18 cm, with coarse sand below. The pH is 6.0 at the surface and 5.4 at a depth of 9 cm. The average moisture-holding capacity of the soil is 25 percent, and ground cover is grass, wild strawberries, and sweet fern. Soil-inhabiting, strand-forming, wood-rotting basidiomycetes are very active at this site.

The MTU test site in Florida is located in the Austin Cary Forest near Gainesville. It is 7 m in elevation, with a sandy soil. The mean annual temperature is 20°C, and it receives annual precipitation of 1,280 mm, with a Scheffer climate index of approximately 110. This site is in an open-canopy southern pine plantation, typically with mixed shade and sun throughout the day. This is the only site with significant termite populations (*Reticulitermes flavipes* Kollar; the eastern subterranean termite).

MTU also maintains several test sites on the Big Island of Hawaii. For this study, the material was installed originally at a site near Mountain View, where the soil is a silty clay loam, at an elevation of 513 m. Precipitation there averages 4,660 mm annually, and the mean annual temperature is 20°C, resulting in a Scheffer index of 400. After 1 year, the

Table 1.—Wood species and material types initially put into test.

Species	Old-growth heartwood	Old-growth heartwood–sapwood	Second-growth heartwood	Second-growth heartwood–sapwood	Sapwood
Yellow cedar	✓	✓	✓	✓	
Western red cedar	✓	✓	✓	✓	
Eastern white cedar	✓	✓			
Douglas-fir	✓		✓		
Western larch	✓	✓	✓	✓	
Tamarack			✓	✓	
Ponderosa pine					✓

test material was transferred to the Kipuka test site near Keaau. This site is located at an elevation of 151 m; the soil is silty clay loam, and the Scheffer climate index is 350 due to an average annual temperature of 23°C and precipitation of 3,220 mm per year. The Kipuka site is an open, grassy field surrounded by tropical forest.

Exposure method

Stake tests were conducted in accordance with the procedures of the American Wood Protection Association (AWPA) Standard E7-09 (AWPA 2010a). For each species and wood type, 20 kiln-dried boards (2 by 4s) 8 feet in length were each cut into four 460-mm-long, end-matched stakes for installation at the four test sites. This resulted in 20 replicate stakes for each wood type and a total of 380 stakes for installation at each location. The stakes were installed with half of their length inserted into the ground. At the two Canadian sites, the stakes were spaced approximately 0.7 m apart in both columns and rows with as much randomization as possible in their placement. Stake holes were predrilled using a 6-inch-diameter powered auger. At the two American sites, stake spacing was according to the AWPA E7-09 Standard, with approximately 460 mm (18 in.) between stakes and 610 mm (24 in.) between rows. The holes for the randomized stakes were made with an appropriately sized dibble.

The stakes were installed at the test sites at Maple Ridge, British Columbia, and Petawawa, Ontario, in October 2004. To offset variations in soil conditions within the Maple Ridge test site, the stakes were split among the four quadrants of this test site. The Hawaii samples were installed in November 2004 at the Mountain View site and then moved to Kipuka in November 2005. The Florida samples were installed in February 2005.

In September or October of each year in British Columbia and Ontario, November in Hawaii, and February in Florida, each stake was removed from the soil. Loose grass and dirt were brushed off, and the stake was examined visually for indications of decay, such as the presence of fungal mycelium or discoloration. If decay was suspected, the area of interest was gently probed with a metal spatula. Each specimen was then assigned a rating for decay based on the AWPA E7-09 rating system (Table 2).

Material at the British Columbia and Ontario test sites was evaluated by the same FPInnovations staff for all inspections. Material at the Florida and Hawaii test sites was evaluated by the MTU staff for all inspections. Consequently, some potential exists for interlaboratory variation in ratings, but the assignment of ratings by cross-sectional area of attack aids considerably in ensuring consistency. Commonly, a rating of 9.5 was given when mycelium with the appearance of wood-rotting basidiomycetes was seen on the wood surface but no softening was detected. The Florida and Hawaii stakes were also evaluated for insect damage using the AWPA E7-09 scheme. Insect damage in Florida was primarily from termites; any insect attack on the Hawaii stakes was from beetle larvae and/or adults.

The decking exposure assemblies were constructed and installed according to the new AWPA Standard E25-08 (AWPA 2010b). Two duplicate decks were prepared for each wood species and type for installation at each site, allowing destructive testing of one deck per site if needed. The method uses nominal 2 by 6s to construct a ‘‘mini-deck’’ that has two rows of 600-mm-long deck boards mounted on a support structure of the same species and lumber type constructed from 2 by 6s on-edge with a center joist to support one end of the deck boards. Each of twenty 2 by 6s was cut into four 500-mm-long boards, one for each site. The decks were constructed using stainless steel screws, with the 20 experimental boards mounted in two rows of 10 boards each. In addition, a 50-mm-long reference sample was taken from each board. One row of deck boards was coated with a commercial deck water-repellent stain (Natural Deck Oil; Napier, Inc.), while the other row was left unstained. The decks were mounted on levelled concrete blocks with the base of the frames 50 to 100 mm above the ground.

For 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. Therefore, each location had a total of 37 decks.

The Hawaii and Florida decks were evaluated annually, while the sets of decks installed in Canada were formally rated after 5 years in test. 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 to areas sounding hollow or dull when tapped with the blunt end of the spatula. Basidiomycete fruiting bodies were noted, if present, on the ends and undersides of deck members, and these boards received an automatic rating of 8 or lower. The rating scheme from AWPA E25-08 was used (Table 2).

Table 2.—Summary of American Wood Protection Association (AWPA) rating systems.

		Descriptors	
Rating	% of cross section affected	Stakes, decay/termites (AWPA E7-09)	Decking (AWPA E25-08)
10	0	Sound	Sound
9.5	0	Trace or suspicion[a]	Trace or suspicion
9	<3	Slight	Minor softening on end grain
8	3–10	Moderate	Small pockets on end grain
7	10–30	Moderate/severe	Moderate
6	30–50	Severe	Severe
4	50–70	Very severe	Very severe, likely to affect load bearing
0	>70	Failure	Failure when stepped on sharply

[a] Surface nibbles permitted.

Data analysis

The nonlinear, discontinuous nature of the numbers and cross sections in the AWPA rating system makes it difficult to statistically analyze the data, but the primary audience for this work is generally familiar with presentation of average decay ratings plotted over time. Linear fits rather than sigmoid curves were considered to be most appropriate for presentation of the ground-contact data, because the latter are considered to be artifacts of the AWPA rating system (Cook and Morris 1995, Morris 1998). Average deck decay ratings over 6 years in Hawaii were regressed against years of exposure using SigmaPlot. Regressions were based on 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 constrained at 10.0:

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

Overall, the equation was able to fit curves highly correlated with the data. r^2 values ranged from 0.91 to 1.00 with one outlier, second-growth Douglas-fir heartwood at 0.80. Values for the derived constants a and b for every curve are not shown here.

Results and Discussion

In ground contact, yellow cedar and western red cedar were generally the most durable, followed by western larch, Douglas-fir, and tamarack, with ponderosa pine the least durable (Table 3; Fig. 1). Eastern white cedar performed well in British Columbia, Ontario, and Florida but decayed rapidly in Hawaii. These results were generally in agreement with the relative durability classifications of these species in the *Wood Handbook* (US Department of Agriculture 2002).

The difference in decay rates in ground contact at the four test sites is illustrated by the rates of decay in yellow cedar, a durable species (Fig. 2), and in Douglas-fir, a moderately durable species (Fig. 3), at the four sites. Decay rates were most rapid at the Florida and Hawaii sites, intermediate in Ontario, and slowest in British Columbia. Aside from factors such as temperature, rainfall, and microorganisms, the fact that the Maple Ridge soil remains very wet for most of the year may account for the slow decay rates for ground contact.

Contrary to expectations based on some previous work, there did not generally appear to be a decay difference between old-growth and second-growth ground-contact stakes for yellow cedar and western red cedar (Figs. 4 and 5). As shown in Table 3 this was also seen for the other species and at the other three sites. Material with some sapwood did not generally decay faster than all-heartwood stakes. While the sapwood parts clearly decayed faster than the heartwood, the effect of small amounts of sapwood on the mean decay rating was negligible, possibly because the heartwood decayed relatively rapidly when in contact with the ground.

Among all ground-contact stakes, decay had become established in all species within 1 year in Ontario, British Columbia, and Florida. Extensive termite damage often occurred on the stakes in Florida; therefore, the stake decay ratings were influenced by the amount of termite damage. Surprisingly, deterioration in Hawaii was slower to appear, possibly due to high soil moisture content and the move to the Kipuka site at a critical time, although the mean ratings there had caught up to those of Ontario and British Columbia after 2 years. Piece-to-piece variability is often cited as an issue in the use of naturally durable wood. In this work, the first failures (rating 0) in old-growth and second-growth western red cedar heartwood in Florida occurred after 2 years, and 5 of 20 stakes were still in test at 6 years. The first failures in old-growth yellow cedar heartwood occurred after 3 years, and 8 of 20 stakes were still in test at 6 years. By comparison, in previous work pine sapwood stakes, though treated to an aboveground preservative retention, showed times to failure ranging from 3 to more than 15 years (Morris 1998). What may appear to be site-to-site differences in variability are due to the facts that decay is slower in some sites and that standard deviations are inherently low when ratings are approximately 8.0 or higher. Standard deviations are equally inherently low when ratings are approximately 4.0 or lower.

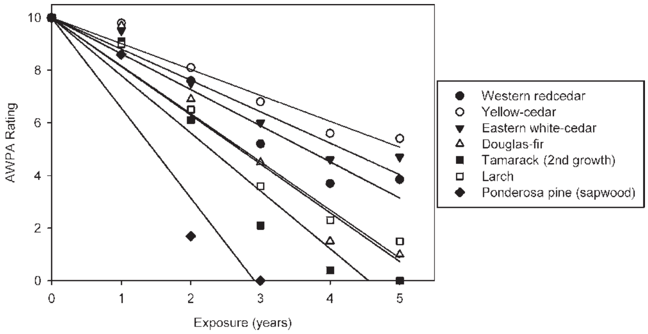

Figure 1.—Decay of old-growth heartwood in ground contact in Florida.

Table 3.—Mean 5-year decay (and Florida termite) results of stake tests.[a]

Species	Type	British Columbia	Ontario	Hawaii	Florida	
					Decay	Termite
Yellow cedar	Old-growth heartwood	8.0 (0.8)	6.3 (1.8)	5.2 (2.5)	5.4 (3.4)	8.1 (0.7)
	Second-growth heartwood	7.5 (2.0)	7.1 (2.3)	3.5 (2.8)	5.5 (2.9)	7.9 (0.6)
	Old-growth heartwood–sapwood	7.5 (0.8)	6.4 (1.6)	4.9 (1.6)	5.0 (3.5)	7.5 (2.2)
	Second-growth heartwood–sapwood	6.6 (1.0)	5.3 (2.3)	2.9 (2.3)	4.5 (3.4)	7.7 (0.8)
Western red cedar	Old-growth heartwood	7.8 (1.0)	6.6 (2.6)	2.3 (2.8)	3.9 (4.0)	7.9 (0.6)
	Second-growth heartwood	7.6 (0.7)	6.6 (2.5)	2.9 (2.9)	3.8 (3.9)	7.4 (0.8)
	Old-growth heartwood–sapwood	7.2 (1.0)	6.8 (1.4)	3.2 (2.9)	5.9 (3.2)	8.1 (0.6)
	Second-growth heartwood–sapwood	6.5 (1.8)	6.2 (2.0)	2.3 (2.7)	4.5 (3.8)	7.9 (0.8)
Eastern white cedar	Old-growth heartwood	7.6 (0.5)	6.9 (0.9)	0.2 (0.9)	4.7 (3.2)	8.1 (0.6)
	Old-growth heartwood–sapwood	7.5 (0.6)	7.1 (0.6)	1.2 (1.9)	4.3 (3.6)	7.8 (0.6)
Douglas-fir	Old-growth heartwood	7.8 (2.0)	3.8 (3.6)	1.3 (2.3)	1.0 (2.4)	8.3 (0.5)
	Second-growth heartwood	6.8 (3.0)	4.3 (3.8)	1.2 (2.4)	1.9 (3.3)	5.9 (3.7)
Western larch	Old-growth heartwood	7.8 (0.9)	6.0 (2.9)	2.4 (2.9)	1.5 (3.1)	5.8 (3.6)
	Second-growth heartwood	8.1 (0.8)	5.1 (2.9)	2.8 (2.8)	0.6 (2.0)	9.5 (0.7)
	Old-growth heartwood–sapwood	7.1 (1.0)	5.7 (2.6)	1.5 (2.4)	0.2 (0.9)	8.0 (0.0)
	Second-growth heartwood–sapwood	7.0 (1.2)	5.6 (2.4)	0.7 (1.8)	1.1 (2.4)	8.0 (0.0)
Tamarack	Second-growth heartwood	7.5 (0.7)	4.7 (3.0)	0.0 (0.0)	0.0 (0.0)	2.7 (4.6)
	Second-growth heartwood–sapwood	7.0 (0.9)	5.1 (2.9)	0.4 (1.2)	0.7 (2.2)	5.7 (5.1)
Ponderosa pine	Old-growth sapwood	6.2 (2.6)	1.4 (2.6)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

[a] Values in parentheses are standard deviations.

For the aboveground tests, after 5 years of exposure of decking in Ontario and British Columbia, very little decay was noted, except in ponderosa pine (Table 4). Hawaii had the highest aboveground decay hazard, with complete failure of the ponderosa pine decks after 3 years of exposure. Results were intermediate in Florida. Therefore, discussion will be confined to the results in Hawaii.

The higher aboveground decay rate for Hawaii compared with the other sites can be predicted by its high Scheffer climate index (350 compared with 110 for Florida, 63 for Maple Ridge, and 48 for Petawawa; Morris and Wang 2008). Figure 6 shows the decay in old-growth heartwood decks of each species at Hawaii, with the exception of tamarack and ponderosa pine, where no old-growth heartwood was installed. Yellow cedar and western red cedar were the most durable, followed by Douglas-fir and then tamarack, eastern white cedar, and western larch, with ponderosa pine the least durable. The relatively poor performance of eastern white cedar seen in the Hawaii decks and stakes was not seen at any of the other three sites above ground or in ground contact. However, fungal growth found on samples of eastern white cedar decking kept in storage since installation of these tests may indicate that this poor performance may have been due to preinfection with decay fungi in the standing tree. This material was not kiln dried.

Similar to ground-contact results, little difference was found in the performance of old-growth and second-growth wood in the Hawaii decks (Table 4; Figs. 7 through 10). In all species except eastern white cedar, however, noticeably less decay was found in heartwood boards compared with those containing some sapwood (Figs. 7 through 10). This was confirmed by *t* tests at the 95% confidence level and was the case whether or not a coating had been applied. With the singular exception of second-growth western larch boards containing a mixture of heartwood and sapwood, no

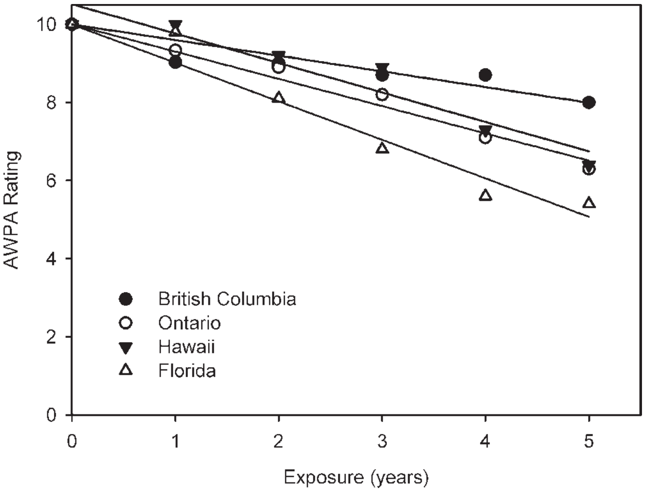

Figure 2.—Decay of old-growth yellow cedar heartwood in ground contact.

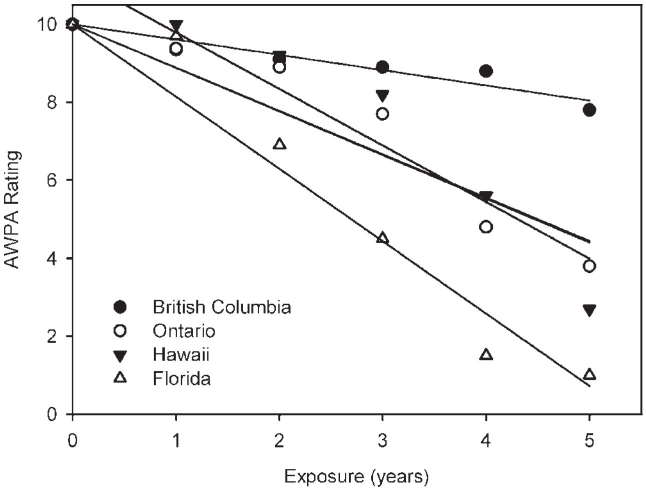

Figure 3.—Decay of old-growth Douglas-fir heartwood in ground contact.

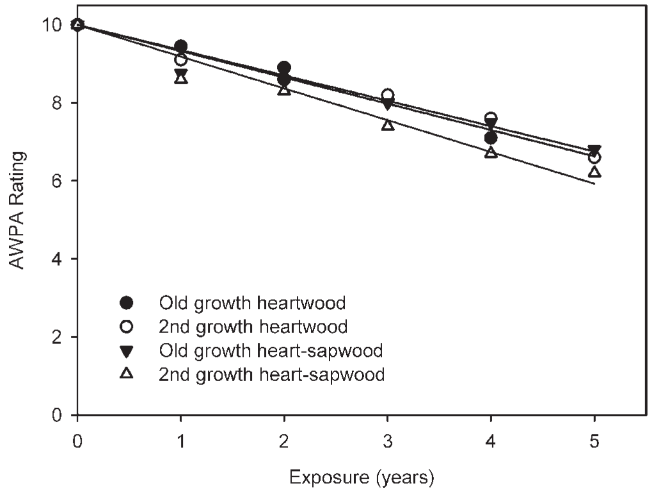

Figure 4.—Decay of western red cedar in ground contact in Ontario.

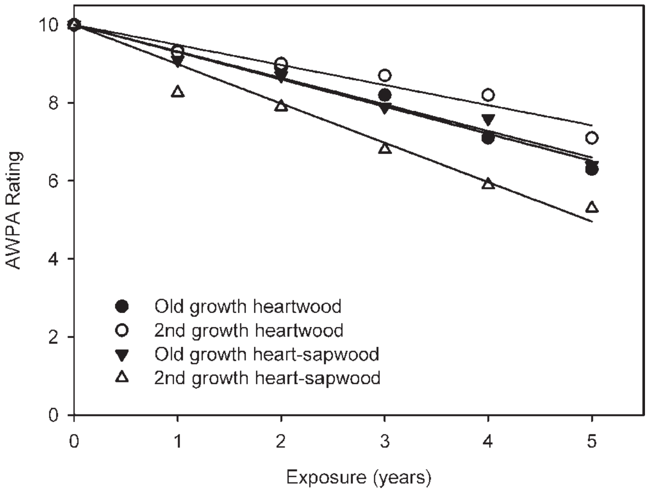

Figure 5.—Decay of yellow cedar in ground contact in Ontario.

statistically significant protective effect of applied stain against decay was found. Consequently, data from stained boards are not reported here.

The curves fitted to the aboveground data ranged from first to fifth order, with the samples containing sapwood showing more linear deterioration and the samples with durable heartwood showing higher exponents for time. This may be due to the rapid onset of decay in the sapwood and the time required for depletion of extractives in the pure heartwood. Another possibility for the heartwood was a lag phase, followed by a linear decay phase, but the high r^2 for the equation suggests this was not the case. The linear decay rates in ground contact suggest that extractive depletion was either not required for decay to begin or was extremely rapid.

Correlation of decay condition with extractives content for the western red cedar heartwood stakes in this experiment has also shed new light on the relative importance of the different types of extractives in this species (Morris and Stirling, in press).

Conclusions

The test sites with the fastest ground-contact decay rates were Florida and Hawaii, while the fastest aboveground decay rate was in Hawaii. The best fits for all the ground-contact data were linear, based on 5 years of exposure.

After 5 years of exposure in ground contact at the four sites, yellow cedar and western red cedar were the most durable, followed by western larch and Douglas-fir and then tamarack, with ponderosa pine the least durable. Eastern white cedar was durable at three of the four sites but failed rapidly in Hawaii. After 5 years of aboveground exposure at Hawaii, yellow cedar and western red cedar were the most durable, followed by Douglas-fir, western larch, tamarack, and eastern white cedar in a close grouping, with ponderosa pine the least durable.

Table 4.—Mean 5-year (and 6-year in Hawaii) decay results of decking tests.[a]

Species	Type	British Columbia, 5 y	Ontario, 5 y	Hawaii		Florida, 5 y
				5 y	6 y	
Yellow cedar	Old-growth heartwood	10.0 (0.0)	10.0 (0.0)	9.1 (0.9)	7.8 (1.2)	9.9 (0.4)
	Second-growth heartwood	10.0 (0.0)	10.0 (0.0)	8.7 (1.1)	7.3 (2.3)	9.6 (0.5)
	Old-growth heartwood–sapwood	10.0 (0.0)	9.9 (0.3)	7.9 (1.1)	7.6 (0.8)	9.4 (0.8)
	Second-growth heartwood–sapwood	10.0 (0.2)	9.1 (2.2)	7.0 (1.2)	6.4 (1.7)	8.7 (1.0)
Western red cedar	Old-growth heartwood	10.0 (0.0)	10.0 (0.0)	8.7 (0.9)	6.6 (2.2)	8.6 (0.5)
	Second-growth heartwood	10.0 (0.0)	10.0 (0.0)	8.8 (0.9)	8.1 (2.0)	9.0 (0.7)
	Old-growth heartwood–sapwood	10.0 (0.0)	10.0 (0.2)	7.2 (1.2)	6.4 (2.9)	8.5 (0.5)
	Second-growth heartwood–sapwood	10.0 (0.0)	9.8 (0.4)	8.1 (1.2)	6.3 (2.5)	9.1 (0.8)
Eastern white cedar	Old-growth heartwood	10.0 (0.0)	9.9 (0.3)	4.2 (4.3)	2.4 (2.3)	8.7 (0.6)
	Old-growth heartwood–sapwood	9.9 (0.4)	9.8 (0.3)	4.6 (4.4)	3.6 (3.7)	8.1 (0.7)
Douglas-fir	Old-growth heartwood	10.0 (0.0)	10.0 (0.0)	6.8 (2.7)	3.7 (3.3)	9.1 (0.8)
	Second-growth heartwood	10.0 (0.0)	10.0 (0.0)	8.0 (1.0)	5.1 (3.1)	9.4 (0.3)
Western larch	Old-growth heartwood	10.0 (0.0)	10.0 (0.0)	5.4 (2.7)	1.7 (2.5)	9.7 (0.6)
	Second-growth heartwood	10.0 (0.2)	9.9 (0.2)	7.9 (0.7)	4.9 (2.5)	9.8 (0.4)
	Old-growth heartwood–sapwood	10.0 (0.0)	9.7 (0.7)	2.2 (2.6)	0.0 (0.0)	9.1 (0.8)
	Second-growth heartwood–sapwood	10.0 (0.0)	9.5 (0.7)	3.7 (3.0)	1.2 (2.4)	8.5 (1.2)
Tamarack	Second-growth heartwood	10.0 (0.2)	10.0 (0.2)	5.8 (2.4)	1.5 (2.1)	9.0 (0.4)
	Second-growth heartwood–sapwood	9.9 (0.4)	9.5 (0.8)	2.3 (3.4)	1.6 (2.8)	7.2 (3.2)
Ponderosa pine	Old-growth sapwood	9.2 (1.0)	8.4 (0.8)	0.0 (0.0)	0.0 (0.0)	9.2 (0.9)

[a] Values in parentheses are standard deviations.

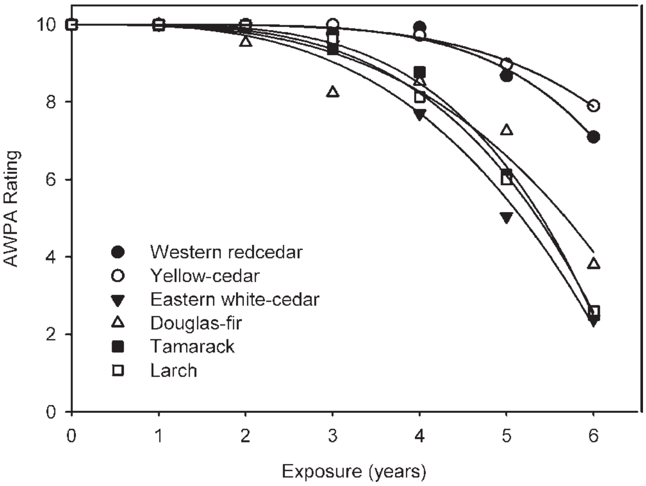

Figure 6.—Decay of old-growth heartwood above ground in Hawaii.

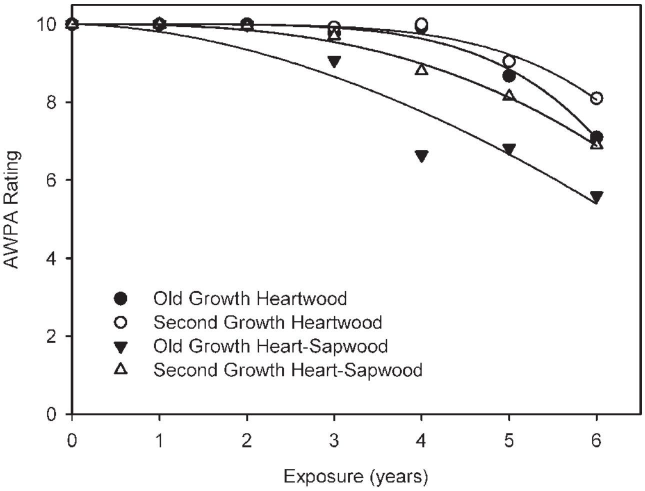

Figure 7.—Decay of western red cedar above ground in Hawaii.

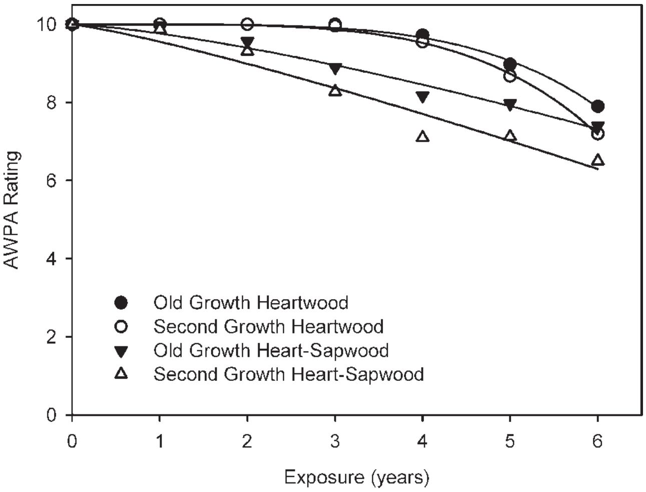

Figure 8.—Decay of yellow cedar above ground in Hawaii.

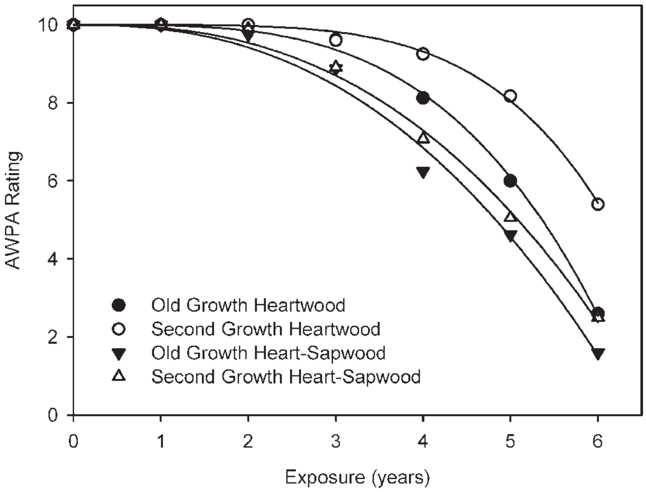

Figure 9.—Decay of western larch above ground in Hawaii.

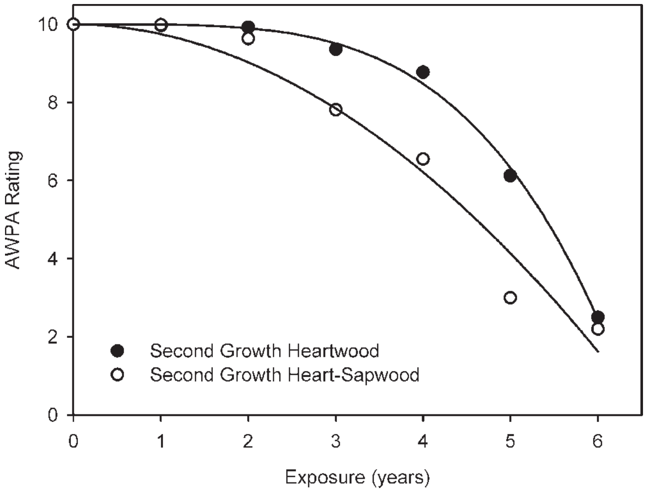

Figure 10.—Decay of tamarack above ground in Hawaii.

In addition, the equation presented above was able to fit curves highly correlated with the aboveground decay data from Hawaii. The presence of sapwood appeared to have more impact on the rate of decay in the aboveground test than in ground contact. No obvious difference was found between decay in old-growth and second-growth samples either in ground contact or above ground, and the presence of stain applied to decking appeared to have a protective effect against decay only in second-growth western larch boards containing sapwood.

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Literature Cited

American Wood Protection Association (AWPA). 2010a. Standard method of evaluating wood preservatives by field tests with stakes. Standard E7-09. AWPA, Birmingham, Alabama. 8 pp.

American Wood Protection Association (AWPA). 2010b. Standard field test for evaluation of wood preservatives to be used above ground (UC3B): Decking method. Standard E25-08. AWPA, Birmingham, Alabama. 7 pp.

Cook, J. A. and P. I. Morris. 1995. Modelling data from stake tests of waterborne wood preservatives. *Forest Prod. J*. 45(11/12):61–65.

Hillis, W. E. 1962. The distribution and formation of polyphenols within the tree. *In:* Wood Extractives and Their Significance to the Pulp and Paper Industries. Academic Press, New York. pp. 59–131.

Laks, P. E., P. I. Morris, G. M. Larkin, and J. K. Ingram. 2008. Field tests of naturally durable North American wood species. International Research Group on Wood Protection IRG/WP 08-10675. IRG Secretariat, Stockholm. 11 pp.

Morris, P. I. 1998. Beyond the log probability model. *Proc. Am. Wood Preserv. Assoc*. 94:267–273.

Morris, P. I., P. Laks, and J. K. Ingram. 2007. Field testing of wood products in Canada XVI: Initiating tests of naturally durable species. *Proc. Can. Wood Preserv. Assoc*. 28:89–94.

Morris, P. I. and R. Stirling. Western red cedar extractives associated with durability in ground contact. *Wood Sci. Technol*. (in press).

Morris, P. I. and J. Wang. 2008. A new decay hazard map for North America using the Scheffer index. International Research Group on Wood Protection IRG/WP 08-10672. IRG Secretariat, Stockholm. 13 pp.

Scheffer, T. C. 1971. A climate index for estimating potential decay in wood structure above ground. *Forest Prod. J*. 21(10):29–31.

Setliff, E. C. 1986. Wood decay hazard in Canada based on Scheffer's climate index formula. *Forestry Chron*. 62(5):456–459.

US Department of Agriculture. 2002. Wood handbook: Wood as an engineering material. General Technical Report 113. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. 463 pp.