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Stake Tests of Northeastern Species Treated with Copper-based Preservatives: Five-Year Results

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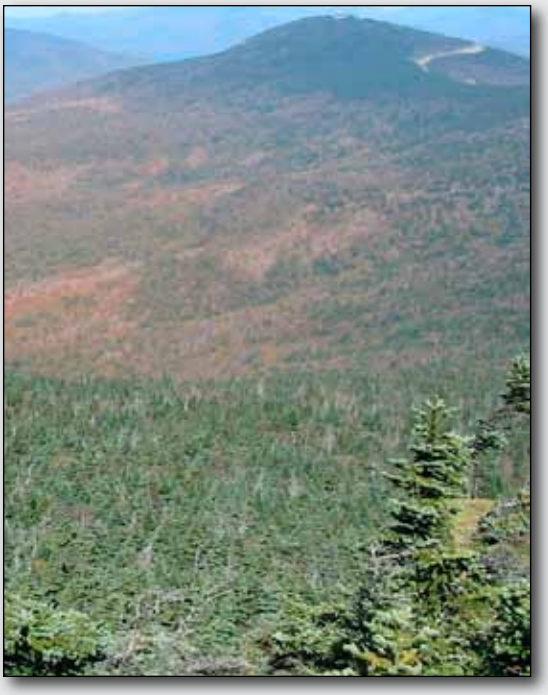

Abstract

The value of some northeastern tree species could be increased if they could be adequately treated with preservatives and shown to be durable in outdoor exposures. This paper reports on research to evaluate the ground-contact durability of northeastern species treated with copper-based preservatives. Stakes (19 by 19 by 457 mm) cut from balsam fir, eastern hemlock, eastern spruce, white pine, or red maple were treated with one of four concentrations of chromated copper arsenate, copper citrate, alkaline copper quat, or copper azole and placed into the ground at a test site in southern Mississippi. Similarly treated Southern Pine stakes were included for comparison. For 5 years, the stakes were rated annually for decay and termite attack. Untreated stakes of all wood species failed rapidly, indicating that none of the species evaluated have significant natural durability. Occasional failures have occurred in treated stakes, typically at the lower preservative retentions. Treated Southern Pine and eastern hemlock stakes have experienced the fewest failures, with treated white pine stakes performing nearly as well. Treated eastern spruce and red maple stakes had the most failures, and treated balsam fir stakes also had substantial failures. The failures in eastern spruce and balsam fir stakes appear to be attributable to poor preservative penetration and retention within individual stakes. Failures in the red maple stakes may be attributable to the differences in hardwood anatomy and the distribution of preservative within the wood structure. Of the northeastern species evaluated, eastern hemlock and white pine appear to perform most similarly to Southern Pine when treated with the copper-based preservatives. However, further exposure time is needed to allow more definitive conclusions.

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Keywords: Northeastern species, copper-based preservatives, stake tests, durability

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Stake Tests of Northeastern Species Treated with Copper-based Preservatives: Five-Year Results

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Introduction

Large areas of forest in the northeastern United States contain tree species that have relatively low commercial lumber value. The proportion of traditionally valuable species in these forests has declined because of selective harvesting. Adding value to alternative wood species would give forest managers more flexibility in economically managing the forest resource while preserving more traditional commercial species. It could also create business and employment opportunities in rural communities.

Before a wood species can gain acceptance for treatment with a particular preservative, research must demonstrate that adequate penetration and retention can be achieved with pressure treatment and that the treated wood is durable. Previous research has been conducted on the treatability of northeastern species with chromated copper arsenate (CCA) and ammoniacal copper arsenate (ACA). Smith (1986) reported on the treatability of eastern white pine, eastern hemlock, Norway spruce, and bigtooth aspen with CCA Type C (CCA-C). Preservative uptake was greatest in white pine, but also appeared promising in incised eastern hemlock. A separate treatability study of Canadian species concluded that eastern white spruce and balsam fir were among the most difficult to treat with CCA-C, although incising did improve treatment (Richards and Inwards 1989). A subsequent study evaluated the treatability of balsam fir, eastern spruce, eastern hemlock, and white pine with both CCA-C and ACA (Gjovik and Schumann 1992). The researchers found that penetration was generally greater with ACA than with CCA-C, and that the growth rate (fast or slow) of the material had no significant effect on penetration or retention. In agreement with previous researchers, Gjovik and Schumann found that incising significantly improved treatment. As a result of these studies and further unpublished efforts, eastern hemlock was added to the American Wood Preservers Association Book of Standards in 1997, and the incising requirement for eastern white pine was modified for CCA-C (AWPA 1997).

However, the types of preservatives used commercially have changed greatly since the research on treatability of northeastern species was conducted. ACA is no longer used in the United States, and the allowable uses of CCA-C have been greatly reduced. For most markets, these preservatives have been replaced with copper-based systems that do not contain arsenic or chromium. Arsenic-free alternatives that have been standardized by the AWPA include alkaline copper quat (ACQ) copper azole (CBA-A, CA-B, and CA-C) and copper citrate (CC). The chemistry of these newer wood preservatives is substantially different than that of CCA-C, and relatively little research has been published on their ability to penetrate and protect northeastern species. A study evaluating CCA-C and ammoniacal copper quat (ACQ-B) uptake in red maple reported that uptake was similar in sapwood, but that uptake of CCA-C was greater in heartwood (Smith and others 1996). Preservative penetration was not reported in that study. Since that time, ACQ-B has largely been replaced with the amine copper formulations of ACQ (ACQ Types C and D). In an earlier stage of the research reported in this paper, Lebow and others (2005) evaluated the treatability of northeastern species with either chromated copper arsenate Type C (CCA-C), ammoniacal copper citrate (CC), alkaline copper quat Type C (ACQ-C), or copper azole Type A (CBA-A). The results indicate that the arsenic and chromium-free alternatives to CCA-C can treat northeastern species at least as well as CCA-C and may offer treatability advantages over CCA-C in species such as eastern hemlock and balsam fir. Two species, red maple and eastern spruce, were not adequately treated with any of the preservatives, even after incising.

Because of unique interactions between wood and preservative chemistries, adequate treatment does not always ensure durability for a specific species/preservative combination. To determine preservative efficacy, the treated wood can be exposed in conditions that are at least as severe as those that would be encountered in service. This paper reports on research to evaluate the ground-contact durability of northeastern species treated with copper-based preservatives.

Materials and Methods

This research was conducted through the cooperative efforts of the Forest Products Laboratory (FPL); State and Private

Forestry; Northeastern Forest Alliance; Vermont Department of Forests, Parks and Recreation; preservative manufacturers; and cooperating lumber producers in the Northeast. Cooperating mills supplied eastern white pine, eastern spruce, balsam fir, eastern hemlock, and red maple lumber for the study. FPL supplied Southern Pine lumber for comparison. Cooperating preservative manufacturers provided chromated copper arsenate, copper citrate, alkaline copper quat, and copper azole wood preservative formulations for use in the study.

Specimen Preparation

Four hundred twenty stakes (19 by 19 by 457 mm) were cut from lumber of each wood species and conditioned to constant weight in a room maintained at 23 °C and 65% relative humidity. The stakes were weighed and then sorted into 16 groups of 25 and one group of 20 (four preservatives at four concentrations plus an additional 20 untreated stakes) so that each group had similar density profiles. An additional set of 400 incised specimens was also prepared for all species except Southern Pine. Because the finished stakes were too small to process in the incisor, 19-mm- (0.75-in.-) thick planks were incised and the specimens cut from the two edges. As a result, the specimens were only incised on three sides. The 25 stakes per treatment group were treated with one of the following solutions:

- Chromated copper arsenate Type C (CCA-C): Actives composition of 47.5% CrO_3, 18.5% copper (expressed as CuO), and 34.0% As_2O_5. CCA was evaluated at solution concentrations of 0.36%, 0.66%, 1.14%, and 1.71%.
- Alkaline copper quat Type C (ACQ-C): Actives composition of 66.7% copper (expressed as CuO) and 33.3% alkylbenzyldimethyl ammonium compound. The copper is solubilized in a solution of ethanolamine and water. ACQ was evaluated at solution concentrations of 0.29%, 0.71%, 1.14%, and 1.71%.
- Copper azole Type A (CBA-A): Actives composition of 49.0% Cu, 49.0% H_3BO_3 and 2.0% Tebuconazole. The copper is solubilized in a solution of ethanolamine and water. CBA-A was evaluated at solution concentrations of 0.21%, 0.52%, 0.84%, and 1.26%. Note that solution concentrations used for the CBA-A treatments were lower than intended because of an error in calculating the concentrations.
- Ammoniacal copper citrate (CC): Actives composition of 66.7% copper (expressed as CuO) and 33.3% citric acid. The copper is solubilized in a solution of ammonia and water. CC was evaluated at solution concentrations of 0.29%, 0.71%, 1.14%, and 1.71%.

All treatments were conducted using a full-cell pressure process. The initial vacuum was maintained at 75 kPa for 30 min; the pressure was maintained at 1.03 MPa for 1 h. Following treatment, the stakes were stacked in plastic bags for one week and then allowed to air-dry under room conditions. Twenty stakes treated with each solution were assigned to the exposure plot in Mississippi, while the remaining five were reserved for assay of preservative retention. 50-mm-long sections cut from the middle of the assay stakes were milled and digested for analysis of copper, chromium, and arsenic content (as appropriate) by inductively coupled plasma emission spectrometry (ICP-AES).

Stake Installation and Inspection

The Mississippi plot is located in a forested area within Harrison Experimental Forest (approximately 15 miles north of Gulfport–Biloxi). The location is within the American Wood Protection Association (AWPA) Deterioration Zone 5, which is considered a severe deterioration hazard (AWPA 2008). Although native subterranean termites are active at this site, the presence or activity of Formosan subterranean termites has not yet been reported. The stakes were placed in rows with 305-mm spacing between stakes within each row and 915 mm between rows. Because of the large number of stakes and large area of the plot, we had some concern that the severity of the exposure might vary spatially within the plot. To address this concern, the stakes were installed in repeating sets of treatment groups, with the order randomized within each set. A 25-mm diameter power auger was used to drill holes to a depth of 229 mm, allowing the stakes to be buried vertically to one-half their length. The stakes were installed in January 2003 and inspected at 1, 2, 3, 4, and 5 years after installation. At each inspection, the stakes were scraped lightly to remove soil and given a visual rating for decay and/or termite attack according to the 10, 9, 8, 7, 6, 4, 0 scale as described in AWPA Standard E7 (AWPA 2008). Test stakes were evaluated using a visual rating system corresponding to an estimated loss of cross section (Table 1). The ratings shown in Table 1 apply to all subsequent tables of ratings. For the purposes of this paper, we report the lower of the two ratings (decay or termite) for each stake at each inspection.

Typically, the lowest rating was associated with decay, although termites were the more destructive agent in approximately half of the failures in treated eastern hemlock and balsam fir stakes (Fig. 1).

Results and Discussion

As expected, untreated stakes of all wood species failed rapidly when placed in ground-contact in Mississippi (Table 2). The red maple and eastern hemlock stakes appeared to fail most rapidly, but it is evident that none of these wood species have significant natural durability when placed in the ground.

The combination of solution concentration, wood species, and incising produced a range of preservative retentions in the stakes (Table 3). In this paper, we have designated the groups of retentions produced by the four treatment solution concentrations as either “low,” medium-low,”

Table 1—Typical rating scheme for evaluation of stakes

Rating	Description of condition
10	No evidence of attack
9	Slight attack, up to 3% of cross-sectional area
8	Moderate attack, up to 10% of cross-sectional area
7	Moderate to severe attack, up to 30% of cross-sectional area
6	Severe attack, up to 50% of cross-sectional area
4	Very severe attack, up to 75% of cross-sectional area
0	Failure. Can be broken easily by hand or the evaluation probe can penetrate through the stake.

Table 2—Average annual biodegradation ratings and cumulative number of failures for 20 untreated stakes

	Year 1		Year 2		Year 3		Year 4		Year 5	
Wood species	Rating	Failure (no.)	Rating	Failure (no.)	Rating	Failure (no.)	Rating	Failure (no.)	Rating	Failure (no.)
Southern Pine	9.40	0	6.55	6	3.50	12	0.95	18	0.40	19
Balsam fir	9.55	0	6.75	5	2.85	13	1.10	17	0.35	19
Eastern hemlock	8.40	2	2.30	15	0.00	20	0.00	20	0.00	20
Eastern spruce	9.15	1	5.75	7	2.55	14	0.40	19	0.40	19
Red maple	8.55	2	2.90	13	0.80	18	0.75	18	0.00	20
White pine	9.65	0	6.95	4	3.00	13	0.45	19	0.00	20

"medium-high," or "high." However, it is important to note that each of these groups represents a range of preservative retentions and that retentions vary between species and between preservatives. Some of the retentions (for the CBA-A treatment, for example) are lower than anticipated, and this should be considered when reviewing the durability data. Incising did not consistently increase retention for any of the wood species or preservatives evaluated, perhaps because of the small dimensions (19 by 19 mm) of the test stakes.

Even stakes treated to the lowest preservative retentions were substantially more durable than the untreated stakes after 5 years (Tables 4–7, Figs. 2–9). Some degradation did occur, however, with occasional failures occurring in most wood species. Species from the Southern Pine group represent the vast majority of treated wood production in the United States and provide a useful comparison for the performance of the northeastern species. Only two of the treated Southern Pine stakes have failed (Fig. 1), and with the exception of one stake treated with CC (Fig. 6), the treated Southern Pine stakes have maintained ratings of "9" or "10" in the three highest retention groups. Because the CC preservative does not contain a co-biocide to complement the copper, it is possible that the failure of the CC-treated Southern Pine stakes is attributable to attack by copper-tolerant fungi. Treated eastern hemlock stakes are performing comparably to Southern Pine across the range of preservatives, and the treated white pine stakes are performing nearly as well. The treated balsam fir stakes have suffered one failure in the medium-high retention group with all the preservatives, and numerous failures at the lower retentions (Figs. 1, 3, 5, 7, 9). Failures in balsam fir are likely attributable to poor treatment quality in individual stakes. A previous study reported that average preservative retention and penetration in balsam fir was less than that in eastern hemlock and eastern white pine (Lebow and others 2005).

Red maple and eastern spruce appeared especially vulnerable to biodeterioration (Figs. 1, 3, 5, 7, 9), although this trend was not always consistent. Like balsam fir, eastern spruce may have suffered greater attack than the other softwoods because of resistance to treatment. It tended to have lower preservative retentions than other species, even when incised. Previous researchers have also reported that CCA-treated eastern and western white spruce stakes exposed in Florida suffered more failures than other softwood species, which Richards and McNamara (1997) attributed to poor preservative penetration. Crawford and others (1999) also noted poor performance of unincised ACA-treated eastern spruce stakes exposed in Mississippi, but with notably better performance of incised stakes. In the present study, the benefit of incising was less obvious for eastern spruce, although incising did improve average ratings for the low retentions of CCA, CC, and CBA-A. The performance of both unincised and incised eastern spruce did improve with higher retentions (Figs. 3, 5, 7, 9), suggesting that a combination of poor penetration and low retention contributed to the failures. Incising did appear to provide some general benefit when viewed across all species, as only 17 of the 43 treated stakes that failed were incised.

The extent of attack of red maple noted in this study does not appear to be solely attributable to poor treatment quality, as average red maple retentions were similar to other

Table 3—Average and standard deviation of the preservative for treatment group as determined by assay

	Retention (kg/m^3) (average and (standard deviation))															
	CCA group								CC[a] group							
	Low		Medium-low		Medium-high		High		Low		Medium-low		Medium-high		High	
Southern Pine	1.60	(0.14)	3.10	(0.72)	7.26	(1.68)	8.31	(1.74)	1.21	(0.22)	3.20	(0.15)	5.18	(0.53)	10.67	(3.95)
Balsam fir	1.22	(0.36)	2.59	(0.31)	3.63	(1.98)	4.76	(1.03)	0.78	(0.27)	2.26	(0.77)	5.53	(1.91)	7.81	(2.10)
Balsam, incised	1.54	(0.30)	2.50	(0.51)	4.44	(1.12)	7.29	(1.81)	1.01	(0.29)	3.38	(0.87)	5.54	(1.25)	7.36	(1.13)
Eastern hemlock	1.94	(0.34)	3.44	(0.97)	6.57	(1.19)	10.06	(3.60)	1.10	(0.38)	3.63	(1.08)	5.03	(1.39)	9.09	(2.06)
Eastern hemlock, incised	1.96	(0.33)	2.80	(0.68)	6.21	(1.33)	9.50	(1.99)	1.84	(1.24)	5.46	(2.78)	7.05	(0.43)	8.89	(4.17)
Eastern spruce	1.02	(0.65)	1.50	(1.00)	3.18	(1.28)	4.68	(1.42)	0.70	(0.32)	2.35	(0.88)	2.98	(1.70)	6.60	(4.75)
Eastern spruce, incised	1.14	(0.46)	1.84	(0.48)	2.99	(0.98)	4.12	(1.44)	0.63	(0.20)	1.51	(0.37)	2.66	(0.54)	5.06	(2.46)
Red maple	1.86	(0.33)	2.37	(1.05)	5.27	(1.52)	7.95	(1.96)	0.99	(0.50)	3.05	(1.09)	3.87	(2.73)	13.42	(4.96)
Red maple, incised	1.96	(0.23)	3.50	(0.37)	6.27	(0.69)	9.41	(0.60)	1.33	(0.10)	3.23	(0.34)	6.58	(0.42)	11.66	(1.81)
White pine	1.80	(0.36)	3.65	(0.70)	6.64	(0.77)	9.28	(0.82)	1.47	(0.27)	4.37	(0.45)	6.06	(0.88)	9.27	(1.44)
White pine, incised	2.13	(0.20)	4.01	(0.60)	7.39	(0.56)	10.92	(1.47)	1.21	(0.49)	4.01	(0.81)	6.93	(1.62)	10.18	(1.53)
	ACQ[a] group								CBA[a,b] group							
Southern Pine	2.15	(0.63)	4.78	(0.64)	7.46	(1.83)	9.38	(1.37)	1.20	(0.37)	2.69	(0.55)	4.04	(1.51)	3.18	(1.76)
Balsam fir	1.38	(0.34)	2.82	(0.30)	5.75	(2.19)	8.45	(2.01)	0.79	(0.30)	1.10	(0.58)	3.78	(0.88)	1.53	(1.16)
Balsam, incised	1.81	(0.26)	2.49	(0.27)	5.81	(1.56)	9.21	(2.75)	1.04	(0.26)	0.93	(0.28)	3.65	(0.73)	1.57	(0.31)
Eastern hemlock	1.78	(0.61)	3.84	(0.82)	6.67	(0.76)	8.77	(2.34)	1.18	(0.42)	1.20	(0.31)	2.64	(1.04)	3.95	(2.71)
Eastern hemlock, incised	2.07	(0.30)	4.12	(0.45)	6.49	(1.18)	10.77	(1.41)	1.17	(0.41)	1.44	(0.40)	4.84	(0.90)	2.27	(0.64)
Eastern spruce	0.92	(0.58)	2.28	(1.72)	5.33	(1.90)	5.62	(4.09)	0.38	(0.30)	0.60	(0.74)	1.45	(0.47)	1.39	(0.56)
Eastern spruce, incised	0.77	(0.27)	1.44	(0.50)	4.40	(1.80)	5.36	(1.91)	0.34(	(0.11)	0.99	(0.65)	2.49	(0.70)	0.72	(0.44)
Red maple	1.88	(0.15)	2.43	(0.96)	4.66	(1.50)	7.66	(3.56)	1.10	(0.13)	1.06	(0.75)	4.20	(1.72)	3.24	(2.54)
Red maple, incised	1.86	(0.26)	3.43	(0.39)	6.79	(1.04)	9.81	(0.75)	1.11	(0.05)	2.07	(0.07)	3.34	(1.37)	4.98	(1.33)
White pine	1.99	(0.19)	4.76	(1.01)	7.51	(3.04)	11.18	(1.89)	1.46	(0.27)	2.95	(1.17)	5.85	(1.44)	4.64	(1.97)
White pine, incised	2.08	(0.45)	4.77	(0.25)	7.66	(1.22)	10.71	(1.31)	1.62	(0.27)	3.42	(0.92)	5.30	(0.80)	6.01	(2.38)

[a]Based on assay of copper. Retentions of co-biocides calculated from their specified ratio to copper in the treatment solution.

[b]Note that although these stakes were targeted to treatment at the highest retention, for many species the retention is similar to or below that of the Medium-High retention group.

Table 4—Average and minimum annual biodegradation ratings for CCA-treated stakes[a]

Wood species	Retention kg/m³	Rating by year for low retention										Retention kg/m³	Rating by year for medium-low retention									
		1		2		3		4		5			1		2		3		4		5	
		Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min		Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min
Southern Pine	1.60	10	—	9.95	9	10.00	—	9.90	9	9.85	9	3.10	10	—	10.00	—	10.00	—	9.95	—	10.00	—
Balsam fir	1.22	10	—	10.00	—	10.00	—	9.85	8	9.75	8	2.59	10	—	10.00	—	10.00	—	9.95	—	10.00	—
Balsam, incised	1.54	10	—	10.00	—	9.95	9	10.00	—	9.75	9	2.50	10	—	9.95	9	10.00	—	9.90	—	9.90	9
Eastern hemlock	1.94	10	—	10.00	—	10.00	—	9.95	9	9.95	9	3.44	10	—	10.00	—	10.00	—	10.00	10	9.95	9
Eastern hemlock, incised	1.96	10	—	10.00	—	10.00	—	10.00	—	9.95	9	2.80	10	—	10.00	—	10.00	—	10.00	10	10.00	—
Eastern spruce	1.02	10	—	9.90	9	9.45	0	9.10	0	8.15	0	1.50	10	—	10.00	—	9.95	9	9.95	—	10.00	—
Eastern spruce, incised	1.14	10	—	10.00	—	9.95	9	9.95	9	9.75	9	1.84	10	—	10.00	—	10.00	—	9.90	—	9.90	9
Red maple	1.86	10	—	9.85	9	9.40	9	9.15	8	8.85	8	2.37	10	—	9.80	8	9.10	0	8.55	0	8.30	0
Red maple, incised	1.96	10	—	10.00	—	9.80	9	9.55	9	9.30	8	3.50	10	—	9.95	9	9.90	9	9.55	—	9.40	9
White pine	1.80	10	—	10.00	—	9.80	9	9.95	9	9.40	0	3.65	10	—	9.95	9	9.95	9	9.95	—	10.00	—
White pine, incised	2.13	10	—	9.95	9	9.90	9	9.85	9	9.70	8	4.01	10	—	10.00	—	10.00	—	10.00	10	9.90	9

	Retention kg/m³	Rating by year for medium-high retention										Retention kg/m³	Rating by year for high retention									
		1		2		3		4		5			1		2		3		4		5	
		Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min		Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min
Southern Pine	7.26	10	—	10	—	10.00	—	10.00	—	10.00	—	8.31	10	—	10	—	10.00	—	9.95	9	10.00	—
Balsam fir	3.63	10	—	10	—	9.50	0	9.50	0	9.45	0	4.76	10	—	10	—	10.00	—	10.00	—	10.00	—
Balsam, incised	4.44	10	—	10	—	10.00	—	10.00	—	10.00	—	7.29	10	—	10	—	10.00	—	10.00	—	10.00	—
Eastern hemlock	6.57	10	—	10	—	10.00	—	10.00	—	9.95	9	10.06	10	—	10	—	10.00	—	10.00	—	10.00	—
Eastern hemlock, incised	6.21	10	—	10	—	10.00	—	10.00	—	10.00	—	9.50	10	—	10	—	10.00	—	10.00	—	10.00	—
Eastern spruce	3.18	10	—	10	—	10.00	—	10.00	—	9.95	9	4.68	10	—	10	—	9.95	9	9.95	9	10.00	—
Eastern spruce, incised	2.99	10	—	10	—	10.00	—	10.00	—	9.50	0	4.12	10	—	10	—	10.00	—	10.00	—	9.85	9
Red maple	5.27	10	—	10	—	9.95	9	9.90	9	9.75	9	7.95	10	—	10	—	10.00	—	9.95	9	9.95	9
Red maple, incised	6.27	10	—	10	—	9.95	9	10.00	—	9.95	9	9.41	10	—	10	—	9.95	9	10.00	—	10.00	—
White pine	6.64	10	—	10	—	10.00	—	9.95	9	10.00	—	9.28	10	—	10	—	10.00	—	10.00	—	9.90	9
White pine, incised	7.39	10	—	10	—	10.00		10.00	—	10.00	—	10.92	10	—	10	—	9.95	9	9.95	9	10.00	—

[a] The minimum (lowest) rating is also shown for groups with an average less than "10."

Table 5—Average and minimum annual biodegradation ratings for ACQ-treated stakes[a]

Wood species	Retention kg/m³	Rating by year for low retention										Retention kg/m³	Rating by year for medium-low									
		1		2		3		4		5			1		2		3		4		5	
		Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min		Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min
Southern Pine	2.15	10.00	—	9.95	9	9.95	9	9.75	9	9.65	9	4.78	10.00	—	10.00	—	10.00	—	10.00	—	9.95	9
Balsam fir	1.38	10.00	—	10.00	—	10.00	—	9.35	0	8.50	0	2.82	10.00	—	10.00	—	10.00	—	9.95	9	9.95	9
Balsam, incised	1.81	10.00	—	10.00	—	10.00	—	9.95	9	9.85	9	2.49	10.00	—	10.00	—	10.00	—	9.95	9	10.00	—
Eastern hemlock	1.78	10.00	—	9.95	9	10.00	—	10.00	—	9.85	9	3.84	10.00	—	10.00	—	10.00	—	10.00	—	9.95	9
Eastern hemlock, incised	2.07	10.00	—	10.00	—	10.00	—	9.95	9	9.95	9	4.12	10.00	—	10.00	—	10.00	—	10.00	—	9.95	9
Eastern spruce	0.92	9.95	9	9.45	0	9.20	0	8.95	0	8.35	0	2.28	10.00	—	9.80	7	9.45	0	9.20	0	9.00	0
Eastern spruce, incised	0.77	10.00	—	9.85	7	9.85	7	8.60	0	8.35	0	1.44	9.95	9	9.90	9	9.90	9	9.80	9	9.75	9
Red maple	1.88	10.00	—	9.75	9	9.50	9	8.75	0	7.60	0	2.43	10.00	—	9.80	9	9.60	9	9.40	8	9.10	8
Red maple, incised	1.86	10.00	—	9.80	9	9.55	9	9.45	9	8.90	7	3.43	10.00	—	9.90	9	9.75	9	9.15	0	9.00	0
White pine	1.99	10.00	—	10.00	—	10.00	—	10.00	—	9.90	9	4.76	10.00	—	10.00	—	9.95	9	9.90	9	9.90	9
White pine, incised	2.08	10.00	—	10.00	—	10.00	—	9.95	9	9.80	9	4.77	10.00	—	10.00	—	10.00	—	10.00	—	10.00	—

	Retention kg/m³	Rating by year for medium-high retention										Retention kg/m³	Rating by year for high retention									
		1		2		3		4		5			1		2		3		4		5	
		Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min		Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min
Southern Pine	7.46	10	—	—	—	10.00	—	10.00	—	10.00	—	9.38	10	—	10.00	—	10.00	—	10.00	—	10.00	—
Balsam fir	5.75	10	—	—	—	10.00	—	9.95	9	9.95	9	8.45	10	—	10.00	—	10.00	—	10.00	—	9.95	9
Balsam, incised	5.81	10	—	9.50	0	10.00	—	9.50	0	9.50	0	9.21	10	—	10.00	—	10.00	—	10.00	—	9.95	9
Eastern hemlock	6.67	10	—	9.95	9	10.00	—	10.00	—	10.00	—	8.77	10	—	10.00	—	10.00	—	10.00	—	10.00	—
Eastern hemlock, incised	6.49	10	—	—	—	10.00	—	9.95	9	10.00	—	10.77	10	—	10.00	—	9.95	9	10.00	—	10.00	—
Eastern spruce	5.33	10	—	—	—	9.95	9	9.90	9	9.80	9	5.62	10	—	9.95	9	10.00	—	9.90	9	10.00	—
Eastern spruce, incised	4.40	10	—	9.95	9	9.95	9	9.85	9	9.75	8	5.36	10	—	10.00	—	9.95	9	9.95	9	9.85	9
Red maple	4.66	10	—	—	—	9.90	9	9.60	8	8.95	0	7.66	10	—	9.95	9	9.95	9	9.95	9	9.30	0
Red maple, incised	6.79	10	—	9.85	9	9.90	9	9.80	9	9.70	7	9.81	10	—	10.00	—	10.00	—	9.90	9	9.75	9
White pine	7.51	10	—	—	—	10.00	—	10.00	—	9.95	9	11.18	10	—	10.00	—	10.00	—	10.00	—	10.00	—
White pine, incised	7.66	10	—	—	—	10.00	—	10.00	—	10.00	—	10.71	10	—	10.00	—	10.00	—	10.00	—	10.00	—

[a]The minimum (lowest) rating is also shown for groups with an average less than "10."

Table 6—Average and minimum annual biodegradation ratings for CC-treated stakes[a]

Wood species	Retention kg/m³	Rating by year for low retention										Retention kg/m³	Rating by year for medium-low retention									
		1		2		3		4		5			1		2		3		4		5	
		Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min		Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min
Southern Pine	1.21	10.00	—	10.00	—	9.85	9	9.25	0	9.10	0	3.20	10.00	—	9.95	9	10.00	—	9.90	9	9.90	9
Balsam fir	0.78	10.00	—	9.70	8	8.75	0	8.85	0	7.40	0	2.26	10.00	—	10.00	—	9.95	9	9.35	0	8.55	0
Balsam, incised	1.01	10.00	—	9.50	0	9.25	0	9.00	0	8.90	0	3.38	10.00	—	10.00	—	10.00	—	9.95	9	10.00	—
Eastern hemlock	1.10	10.00	—	9.80	8	9.95	9	9.15	0	8.55	0	3.63	10.00	—	9.90	9	10.00	—	10.00	—	9.90	9
Eastern hemlock, incised	1.84	10.00	—	9.95	9	10.00	—	9.80	9	9.35	7	5.46	10.00	—	10.00	—	10.00	—	10.00	—	9.90	9
Eastern spruce	0.70	9.95	9	9.60	7	7.65	0	6.25	0	5.60	0	2.35	10.00	—	9.95	9	10.00	—	9.70	8	9.60	8
Eastern spruce, incised	0.63	9.95	9	9.85	8	9.15	0	8.75	0	7.55	0	1.51	10.00	—	10.00	—	10.00	—	9.65	9	9.50	7
Red maple	0.99	9.95	9	9.65	9	9.05	7	7.40	0	5.75	0	3.05	9.95	9	9.85	9	9.55	8	9.30	8	8.10	0
Red maple, incised	1.33	10.00	—	9.75	9	9.30	8	9.00	6	8.30	0	3.23	10.00	—	9.85	9	9.65	9	8.95	0	8.05	0
White pine	1.47	10.00	—	9.95	9	9.75	8	8.65	0	8.45	0	4.37	10.00	—	10.00	—	10.00	—	9.90	9	9.95	9
White pine, incised	1.21	9.95	9	9.95	9	10.00	10	9.60	7	8.40	0	4.01	10.00	—	10.00	—	10.00	—	9.50	0	9.40	0

	Retention kg/m³	Rating by year for medium-high retention										Retention kg/m³	Rating by year for high retention									
		1		2		3		4		5			1		2		3		4		5	
		Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min		Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min
Southern Pine	5.18	10.00	—	10.00	—	10.00	—	10.00	—	9.50	0	10.67	10	—	10.00	—	10.00	—	10.00	—	9.95	9
Balsam fir	5.53	10.00	—	10.00	—	10.00	—	9.85	9	9.45	0	7.81	10	—	10.00	—	10.00	—	10.00	—	10.00	—
Balsam, incised	5.54	10.00	—	10.00	—	10.00	—	9.90	9	9.90	9	7.36	10	—	9.95	9	10.00	—	9.90	9	10.00	—
Eastern hemlock	5.03	10.00	—	9.95	9	9.95	9	9.95	9	10.00	—	9.09	10	—	10.00	—	10.00	—	10.00	—	10.00	—
Eastern hemlock, incised	7.05	9.95	9	9.95	9	9.95	9	9.95	9	9.95	9	8.89	10	—	10.00	—	10.00	—	10.00	—	10.00	—
Eastern spruce	2.98	10.00	—	9.95	9	9.95	9	9.65	8	9.55	8	6.60	10	—	10.00	—	10.00	—	9.95	9	9.95	9
Eastern spruce, incised	2.66	10.00	—	9.95	9	9.95	9	9.85	9	9.80	9	5.06	10	—	10.00	—	10.00	—	9.80	9	9.70	7
Red maple	3.87	10.00	—	10.00	—	9.85	9	9.55	8	9.10	0	13.42	10	—	10.00	—	10.00	—	9.70	8	9.20	0
Red maple, incised	6.58	10.00	—	9.90	9	9.70	9	9.60	8	9.50	8	11.66	10	—	10.00	—	9.95	9	9.85	9	9.35	0
White pine	6.06	10.00	—	10.00	—	10.00	—	10.00	—	9.95	9	9.27	10	—	10.00	—	10.00	—	10.00	—	10.00	—
White pine, incised	6.93	10.00	—	10.00	—	10.00	—	10.00	—	9.50	8	10.18	10	—	10.00	—	10.00	—	10.00	—	10.00	—

Table 7—Average and minimum annual biodegradation ratings for CBA-treated stakes[a]

Wood species	Retention kg/m^3	Rating by year for low retention										Retention kg/m^3	Rating by year for medium-low retention									
		1		2		3		4		5			1		2		3		4		5	
		Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min		Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min
Southern Pine	1.20	10.00	—	10.00	—	9.90	9	9.70	8	9.60	7	2.69	10.00	—	10.00	10	10.00	—	10.00	—	9.80	7
Balsam fir	0.79	9.75	8	8.65	0	7.05	0	6.35	0	5.45	0	1.10	10.00	—	9.95	9	9.90	9	9.90	9	9.50	8
Balsam, incised	1.04	10.00	—	9.85	9	9.80	9	9.45	8	8.50	0	0.93	10.00	—	10.00	—	9.90	8	9.75	8	9.70	8
Eastern hemlock	1.18	10.00	—	10.00	—	9.70	9	9.70	9	9.40	8	1.20	10.00	—	10.00	—	9.95	9	9.90	9	9.85	9
Eastern hemlock, incised	1.17	10.00	—	9.80	9	9.95	9	9.85	9	9.45	8	1.44	10.00	—	9.95	9	10.00	—	9.95	9	9.85	9
Eastern spruce	0.38	9.95	9	9.60	7	7.70	0	6.50	0	4.90	0	0.60	10.00	—	9.90	9	9.15	0	8.00	0	7.40	0
Eastern spruce, incised	0.34	10.00	—	9.85	8	9.35	6	8.55	0	6.95	0	0.99	10.00	—	9.95	9	9.90	9	9.75	9	9.45	8
Red maple	1.10	10.00	—	9.60	9	8.95	7	7.85	0	6.10	0	1.06	9.95	9	9.30	0	8.95	0	8.50	0	7.85	0
Red maple, incised	1.11	10.00	—	9.85	9	9.20	8	8.45	0	7.35	0	2.07	10.00	—	9.85	9	9.75	9	9.20	8	8.90	8
White pine	1.46	10.00	—	9.95	9	9.90	9	9.55	8	9.05	7	2.95	10.00	—	10.00	—	10.00	—	9.45	0	9.35	0
White pine, incised	1.62	10.00	—	9.95	9	9.75	8	9.50	7	9.20	7	3.42	9.95	9	9.95	9	9.85	9	9.75	9	9.85	9

	Retention kg/m^3	Rating by year for medium-high retention										Retention kg/m^3	Rating by year for high retention [b]									
		1		2		3		4		5			1		2		3		4		5	
		Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min		Avg	Min	Avg	Min	Avg	Min	Avg	Min	Avg	Min
Southern Pine	4.04	9.95	9	10.00	—	9.95	9	10.00	—	9.95	9	3.18	10	—	10.00	—	10.00	—	10.00	—	9.95	9
Balsam fir	3.78	10.00	—	9.95	9	9.35	0	9.25	0	9.30	0	1.53	10	—	10.00	—	10.00	—	9.90	9	9.90	9
Balsam, incised	3.65	10.00	—	10.00	—	10.00	—	10.00	—	10.00	—	1.57	10	—	10.00	—	9.95	9	9.90	9	9.90	9
Eastern hemlock	2.64	9.95	9	9.95	9	9.95	9	9.95	9	9.95	9	3.95	10	—	10.00	—	10.00	—	10.00	—	10.00	—
Eastern hemlock, incised	4.84	10.00	—	9.95	9	10.00	—	9.90	9	9.85	9	2.27	10	—	10.00	—	10.00	—	10.00	—	9.95	9
Eastern spruce	1.45	10.00	—	9.95	9	9.35	0	8.50	0	7.85	0	1.39	10	—	10.00	—	10.00	—	9.75	9	9.45	8
Eastern spruce, incised	2.49	10.00	—	10.00	—	9.95	9	9.75	9	9.45	8	0.72	10	—	10.00	—	9.95	9	9.80	9	9.75	9
Red maple	4.20	10.00	—	9.90	8	9.65	8	9.30	8	9.05	8	3.24	10	—	9.95	9	9.80	9	9.60	9	9.15	7
Red maple, incised	3.34	10.00	—	10.00	—	9.95	9	9.60	9	9.40	8	4.98	10	—	9.95	9	9.90	9	9.55	8	9.55	9
White pine	5.85	10.00	—	10.00	—	10.00	—	10.00	0	9.95	9	4.64	10	—	9.95	9	10.00	—	10.00	—	9.90	9
White pine, incised	5.30	10.00	—	10.00	—	9.85	8	9.90	9	9.85	9	6.01	10	—	10.00	—	10.00	—	10.00	—	9.95	9

[a]The minimum (lowest) rating is also shown for groups with an average less than "10."

[b]Note that although these stakes were targeted to treatment at the highest retention, for many species the retention is similar to or below that of the Medium-high retention group.

species (Table 2). Previous studies have noted that CCA can be less effective in protecting hardwoods than softwoods, possibly because of differences in the microdistribution of CCA within the wood structure (Butcher 1979; Daniel and Nilsson 1987; Smith and others 1996). The results of our study indicate that CCA is as effective as the newer copper-based preservatives in protecting red maple. At the lower retentions, it appears that the CCA provides less protection to red maple than to softwoods treated to equivalent retentions. However, protection of red maple may be possible if higher retentions are used (Fig. 3).

In many cases, the retentions evaluated in our study are well below those specified for protection of Southern Pine lumber placed in contact with the ground. AWPA standards specify minimum ground-contact retention of 6.4 kg/m^3 for ACQ-C and CCA-C, and 6.5 kg/m^3 for CBA-A (AWPA 2008). Before its removal from AWPA standards, CC was standardized for ground-contact use at a retention of 6.4 kg/m^3 (AWPA 2005). Thus, it is not surprising to observe failures or low ratings, especially in the Low-retention group where average retentions were generally below 2 kg/m^3 and as low as 0.34 kg/m^3 (CBA-A treatment of eastern spruce). With the exception of eastern spruce, the various wood species met the ground-contact specification at the Medium-high and/or High retentions of ACQ, CCA and CC, but retentions in the CBA-A treated stakes did not reach this threshold. Because of the Low CBA-A retentions, interpretation of the durability results should be limited to a comparison between wood species and should not be used as a predictor of the durability of commercially produced material.

The formulations of ACQ and copper azole in this study used copper dissolved in ethanolamine. In the last few years, formulations of ACQ and copper azole that use finely ground copper particles dispersed or suspended in the treatment solution have been developed. The findings in this study may not be directly applicable to these particulate copper formulations.

Conclusions

All but three of the 120 untreated stakes have failed after 5 years of ground-contact exposure in southern Mississippi. A few failures have also occurred in treated stakes of each wood species. These treated-stake failures generally occurred in stakes treated to retentions well below that specified for protection of Southern Pine placed in ground contact. Treated Southern Pine and eastern hemlock stakes have experienced the fewest failures, with treated white pine stakes performing nearly as well. Treated eastern spruce and red maple stakes had the most failures, and balsam fir stakes also had substantial failures. The failures in eastern spruce and balsam fir stakes appear to be attributable to poor preservative penetration and retention within individual stakes. Failures in the red maple stakes are concentrated in the lower retentions and may be attributable to the differences in hardwood anatomy and the distribution of preservative within the wood structure. Of the northeastern species evaluated, eastern hemlock and white pine appear to be the strongest candidates for treatment with the newer copper-based preservatives. However, it is difficult to draw strong conclusions after 5 years, and the stakes will continue to be evaluated with a final report expected after 10 years of exposure.

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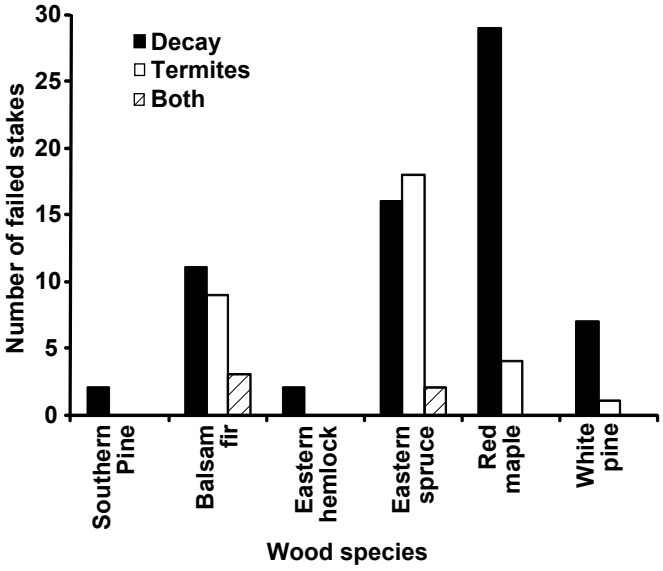

Figure 1. Number of failures and primary cause of failure in treated stakes (combined preservatives and retentions) by wood species.

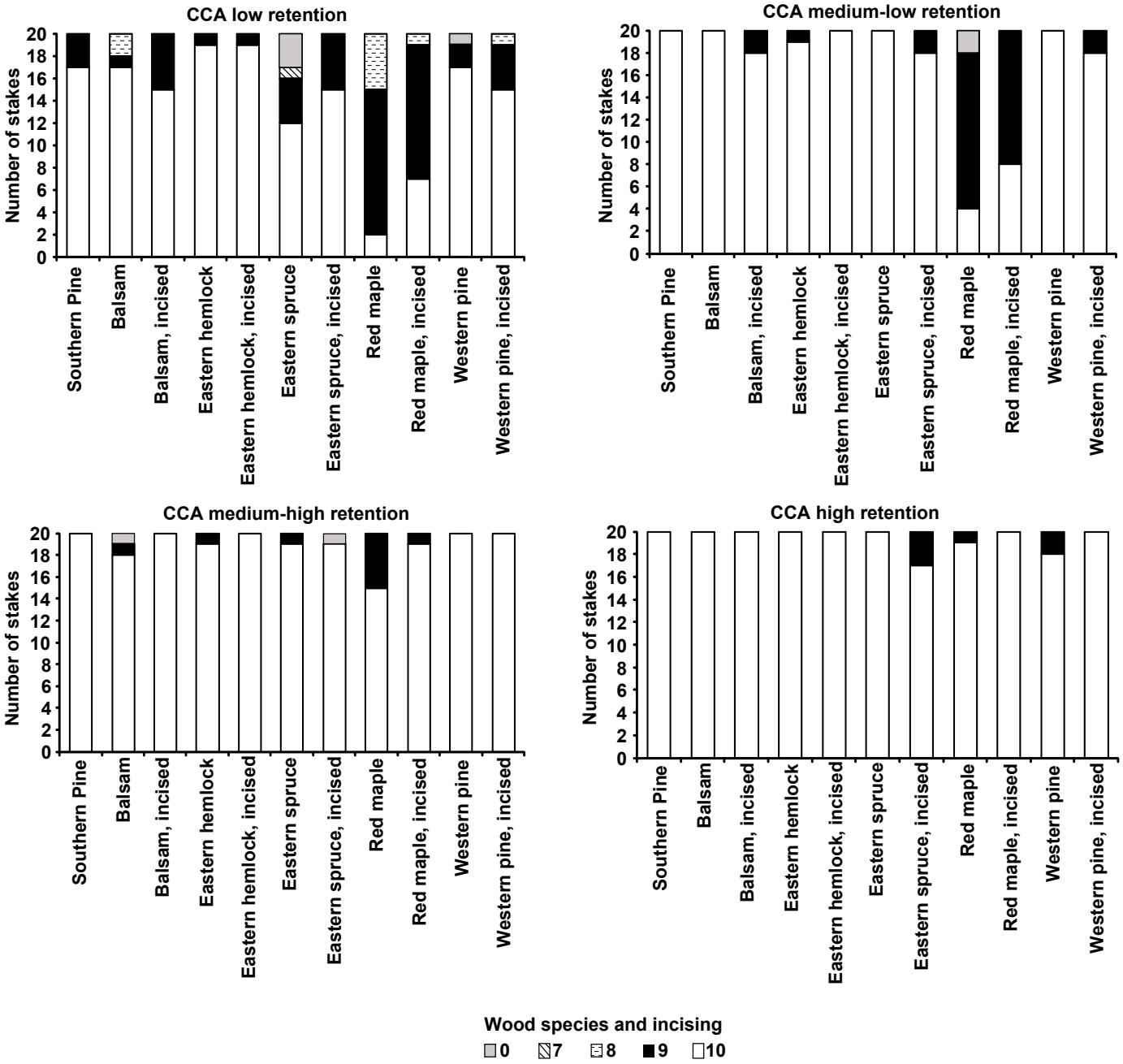

Figure 2. Distribution of Year 5 biodegradation ratings for stakes treated with four concentrations of CCA. None of the stakes treated with CCA had a rating of "4" or "6" after 5 years.

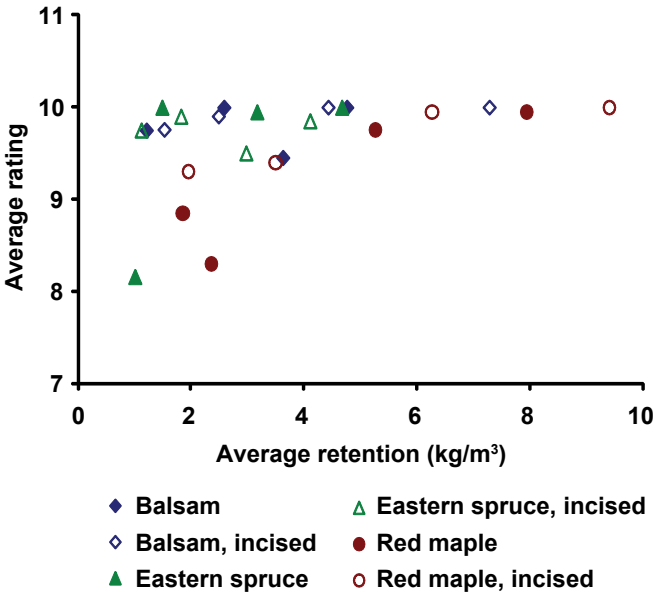

Figure 3. CCA treatment: relation between group retention and ratings for wood species most prone to biodeterioration.

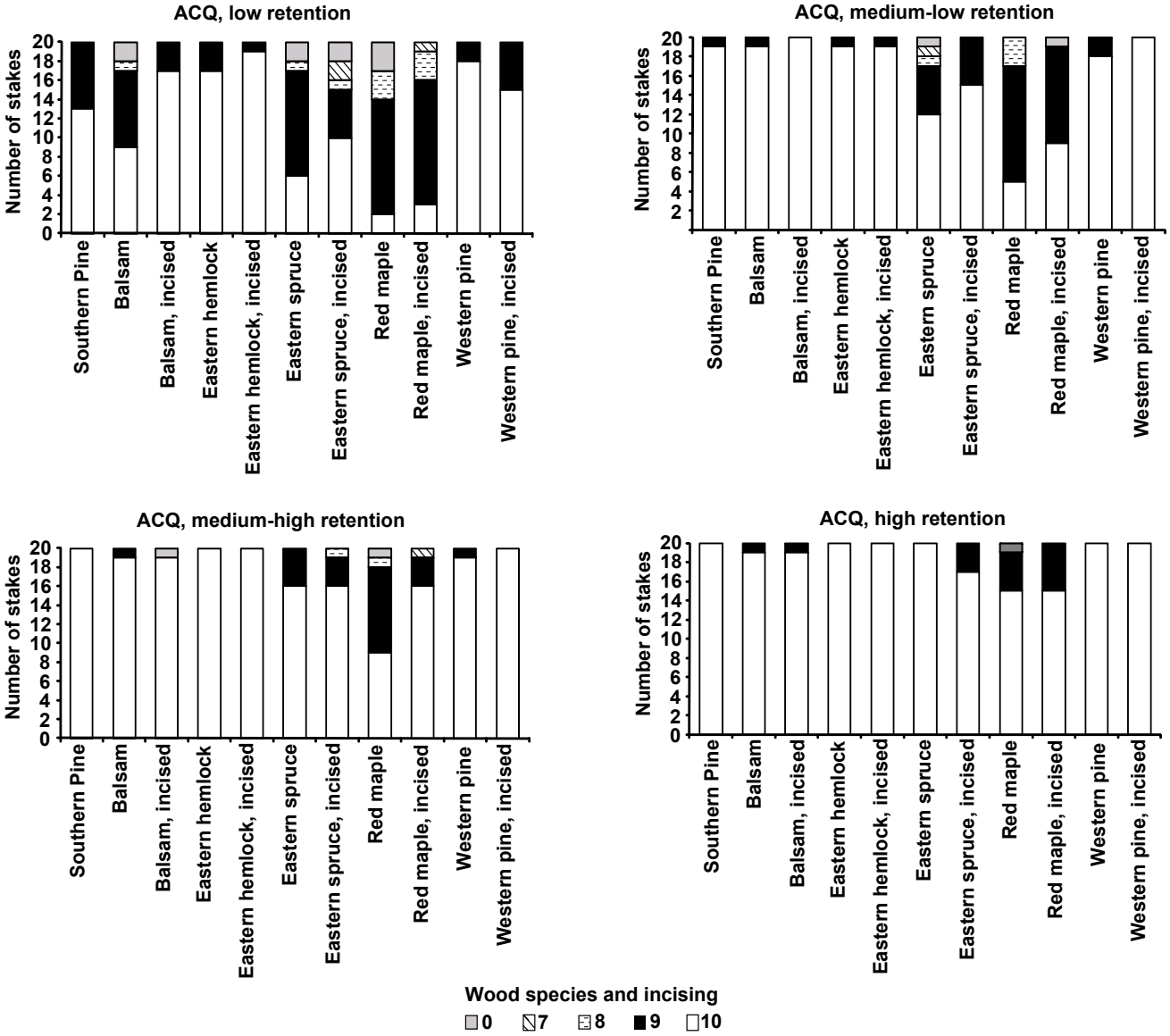

Figure 4. Distribution of Year 5 biodegradation ratings for stakes treated with four concentrations of ACQ. None of the stakes treated with ACQ had a rating of "4" or "6" after 5 years.

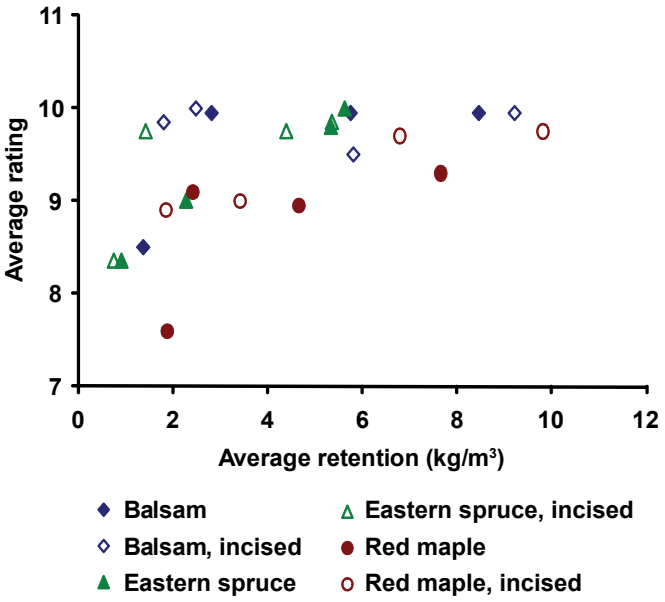

Figure 5. ACQ treatment: relation between group retention and ratings for wood species most prone to biodeterioration.

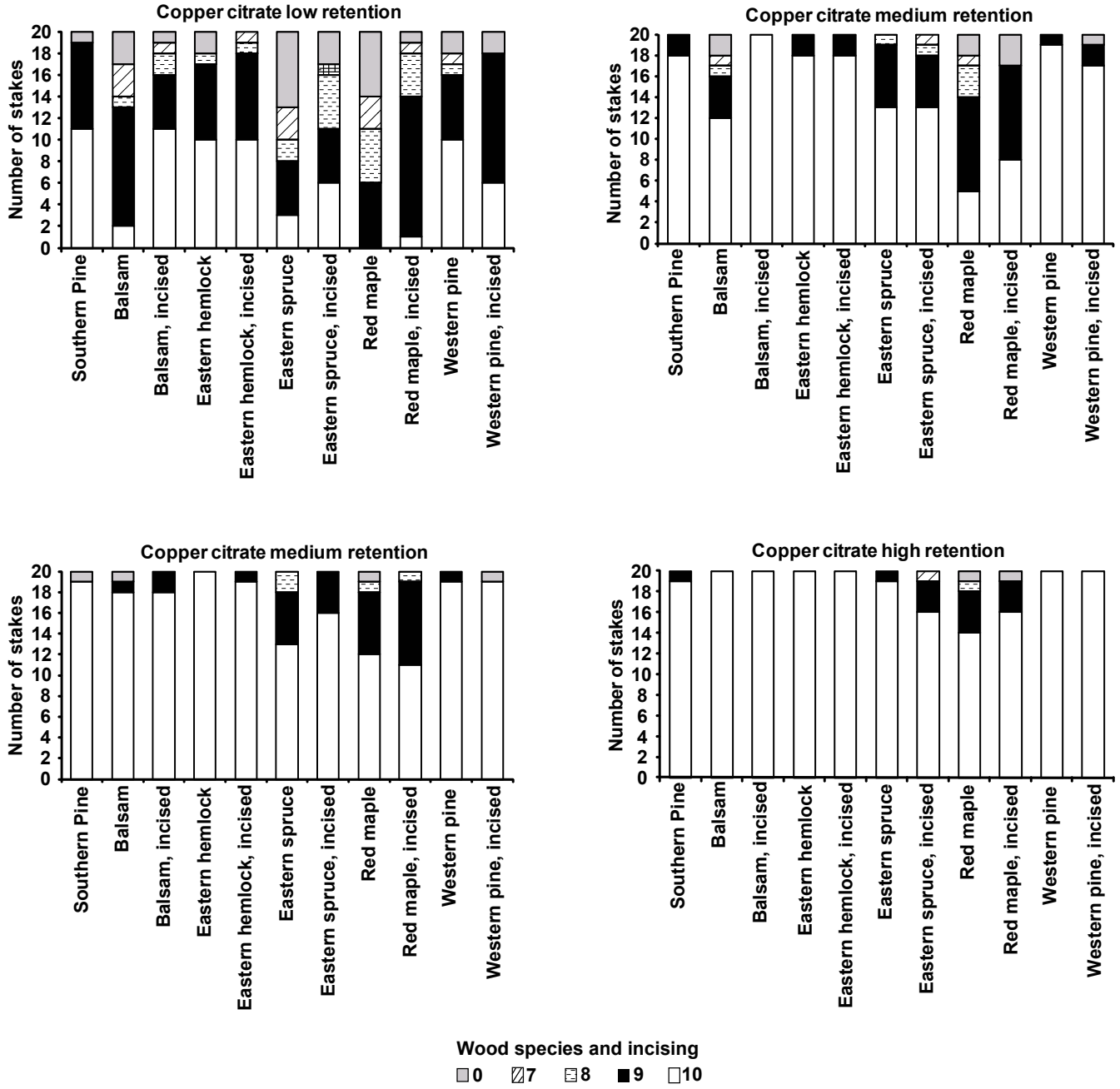

Figure 6. Distribution of Year 5 biodegradation ratings for stakes treated with four concentrations of copper citrate. None of the stakes treated with the three highest copper citrate retentions had a rating of "4" or "6" after 5 years.

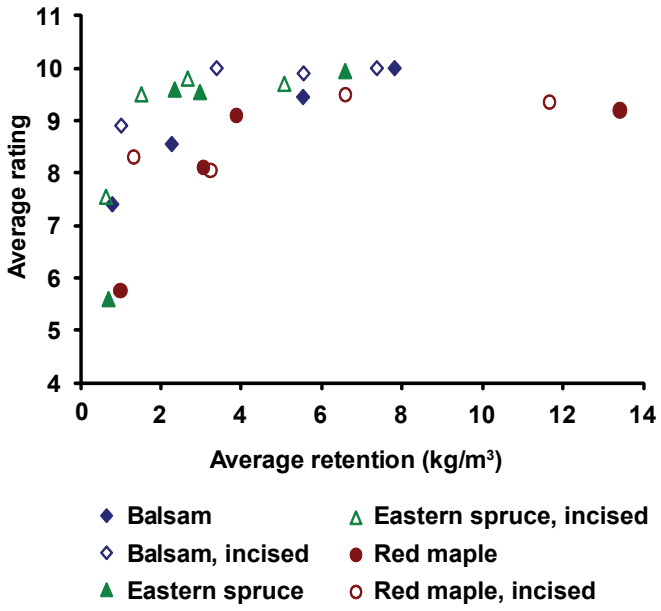

Figure 7. CC treatment: relation between group retention and ratings for wood species most prone to biodeterioration.

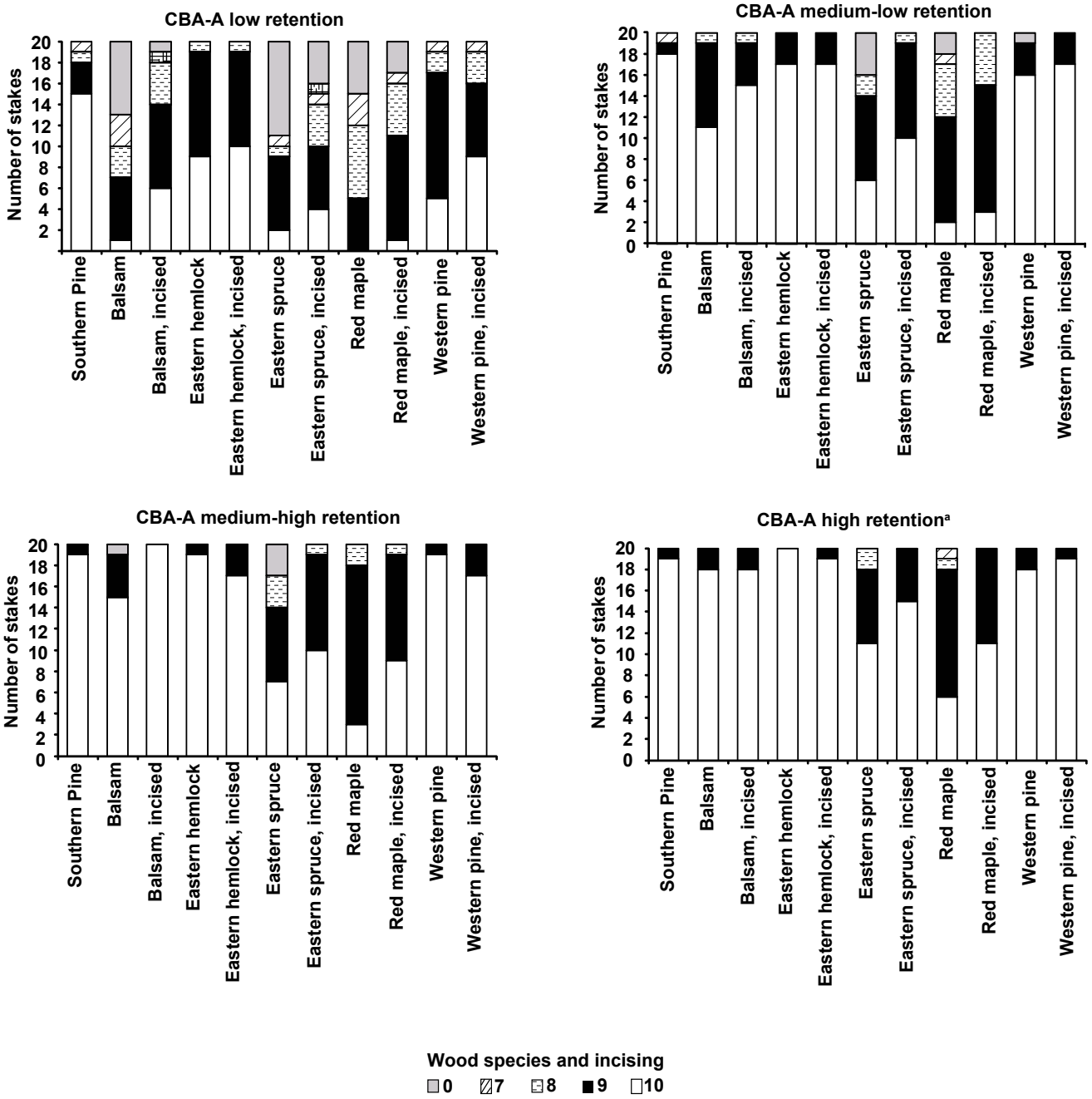

Figure 8. Distribution of Year 5 biodegradation ratings for stakes treated with four concentrations of CBA-A. None of the stakes treated with the three highest CBA-A had a rating of "4" or "6" after 5 years.

[a]Note that although these stakes were targeted to treatment at the highest retention, for many species the retention is similar to or below that of the Medium-high retention group (see Table 2).

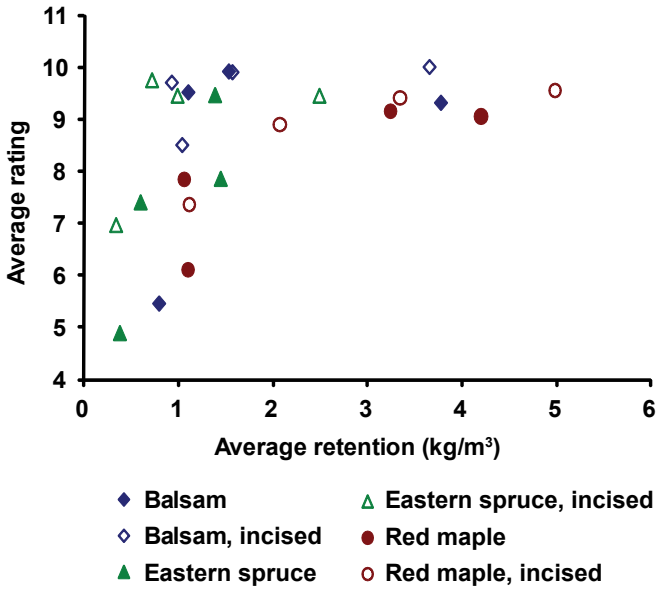

Figure 9. CBA-A treatment: relation between group retention and ratings for wood species most prone to biodeterioration.