FIELD TESTING OF WOOD PRESERVATIVES IN CANADA: VIII STAKE TESTS OF WATER-BORNE WOOD PRESERVATIVES

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Abstract

Data are presented from field tests of preservative-treated stakes up to twenty years duration at Westham Island BC and up to thirty-eight years at Petawawa ON. Sapwood stakes were pressure-impregnated with a range of retentions of each preservative of interest. After drying, the stakes were installed to half their length in the field tests, and rated for decay annually. Mean ratings were computed and used in comparisons of preservative performance.

It was found that decay in stakes treated with arsenic-containing preservatives was accelerated at Westham Island compared to Petawawa, although this difference was not seen in other preservatives or in water-treated controls. Consequently, copper-based formulations with alternative co-biocides performed better than some arsenical formulations at Westham.

The most effective water-borne preservative was found to be the benchmark chromated copper arsenate (CCA). Of particular note was the excellent performance of CCA-type B over 38 years at Petawawa. Another water-borne preservative that performed well was acid copper chromate (ACC). Two preservatives outperformed ammoniacal copper arsenate (ACA) which is listed in preservation standards. These were a formulation of ammoniacal copper quaternary ammonium compound (ACQ), and copper-8-quinolinolate, which is approved for contact with foodstuffs. Contrary to expectations, wrapping ACA-treated stakes for 48 hours to retard loss of ammonia impaired subsequent performance in ground contact.

1. Introduction

In North America, stake testing, using AWPA Standard E7-93, is the standard test method for the assessment of wood preservative efficacy. It can confirm experimental laboratory results under natural biological and weathering conditions, and is required by international standards committees for approval of new preservatives or modification of existing standards. Field test results may also be used by the Canadian industry in the marketing of treated wood products.

Forintek is the only independent source of preservative performance data in Canada. Information from Forintek's field testing program helps Canadian species gain access to domestic and export markets for which standards compliance is important. Two field test sites have been maintained for over twenty years for this purpose, involving several thousand treated stakes. The sites are located at Westham Island, near Vancouver, British Columbia, and at the former Petawawa National Forestry Institute near Chalk River, Ontario. This report summarizes the performance of selected preservatives at Westham Island and Petawawa. These will be the final data from the Westham Island site, as Forintek decommissioned this site on December 31, 1997, after twenty years.

2. Materials and Methods

2.1 Stake Preparation

Ponderosa pine (*Pinus ponderosa* Laws.) sapwood stakes, prepared from kiln-dried timber and free of visible defects as specified in the IUFRO standard (Becker 1972) were used in the routine stake testing at the western site, with dimensions of 2.5 x 5.0 x 50 cm. Red pine (*Pinus resinosa* Ait.) was commonly used at the eastern site, with dimensions of 1.9 x 1.9 x 66 cm. Other species such as spruce (*Picea sp.*), eastern white pine (*Pinus strobus* L.) and aspen (*Populus sp.*) have also been used.

Stakes were individually weighed and sorted into density groups. Only stakes of similar density were used in each treatment. Prior to treatment the stakes were conditioned to a moisture content of 8-10%. The full cell process was used in treatment of the stakes: following an initial vacuum of 55 cm Hg for 30 minutes, the treating solution was introduced and pressure of not less than 700 kPa was applied for a minimum of two hours. Preservative retentions were calculated from the difference between initial and final weights of each individual stake. Following treatment, the stakes were air dried for a minimum period of one month.

At the western laboratory, the twenty-five stakes closest to the target retention for each preservative retention level were chosen for installation in the test plot. Fifteen stakes were designated as test stakes for long-term exposure and ten were intended as sacrificial stakes for removal to study leaching and fungal colonization. Five additional stakes were retained at the laboratory for future chemical analysis if required. At the eastern laboratory, generally ten stakes were selected as test stakes for each preservative retention level.

A range of preservative retentions was tested when evaluating a new formulation at the western laboratory. Two of these retentions were below (40 and 60 percent) the recommended retention (100 percent), which was usually based on laboratory results. Two retentions were above (130 and 160 percent) this level. When the toxic threshold was uncertain, an additional retention level (190 percent) was included in the test.

Control stakes treated only with the preservative solvent were also included for each preservative.

A list of preservatives tested at the two sites, including formulations of the water-borne preservatives, is presented in Table 1.

Table 1: Preservatives reported here

Preservative	Formulation	Site	Year Installed
CCA-C	48% CrO_3, 19% CuO, 33% As_2O_5	Westham	1977, 1987
CCA-C	not on record	Petawawa	1963, 1974
CCA-B	35% $Cr0_3$, 20% CuO, 45% As_2O_5	Westham	1977
CCA-B	Boliden K-33 (same as above)	Petawawa	1959, 1974
ACC	32% CuO 68% CrO_3	Westham	1979
ACA	50% CuO 50% As_2O_5	Westham	1977
ACA	66% CuO 34% As_2O_5	Westham	1977, 1986
ACA	66% CuO 34% As_2O_5	Petawawa	1974
ACB	50 % Cu 50 % H_3BO_3	Westham	1977
ACB	not on record	Petawawa	1974
Benzalkonium chloride	Alkyldimethylbenzylammonium chloride	Petawawa	1980
ACQ[1]	50% Alkyldimethylbenzylammonium chloride, 50% $CuSO_4$ (acid)	Petawawa	1980
ACQ[2]	50% Alkyldimethylbenzylammonium chloride, 50% CuO (ammoniacal)	Westham	1981
Copper-8-quinolinolate	PQ56 in water	Westham	1977

[1,2] *These are not commercial formulations of ACQ*

2.2 Stake Installation and Inspection

Stakes were installed during the spring or summer at the two test sites, with a random placement. Exceptions to this were the aspen stakes and stakes treated with creosote at Westham Island which were added to the main field in randomized blocks. At Westham Island the stakes were spaced on a one square metre grid, while at Petawawa they were installed in rows 60 cm apart with a spacing of 45 cm between stakes. The stakes at both sites were set to half their length in the ground, with the soil carefully tamped down around each sample.

All stakes were inspected annually between August and October. Each stake was removed from the ground and visually examined for evidence of decay, by carefully probing the below ground area to locate any soft pockets indicative of decay. A stake containing signs of decay was then flexed by hand to determine residual strength. If the stake broke under this bending test it was deemed to have failed due to decay. The stakes were assigned a numerical rating using the IUFRO scale (Becker 1972) and these stake ratings were stored in a computerized database. For reporting, the results were converted to the AWPA rating scale (AWPA 1997. See Table 2). The mean rating was calculated for each preservative treatment level for each year and multiplied by ten to give the logscore for that level. A logscore of below 70 was taken as the level at which a given retention of a particular preservative was no longer providing adequate protection.

2.3 Mathematical Modelling

The data have been illustrated here as depreciation plots of mean logscore with time for a range of retentions of each preservative with no attempt to fit curves. In other work (Morris 1998) an equation has been fitted to the complete data set for each preservative.

$$\text{Logscore} = 100 - e^{A}.(\text{retention})^{B}.\ (\text{time})^{C}$$

This equation simply states that the condition of the wood is a function of some constant e^{A}, probably related to the wood substrate and the test site, the preservative and the retention of that preservative and the time in test.

It may allow the service life provided by retentions proposed for standardization to be predicted from short-term performance of lower retentions. It may also allow the estimation of the effect on service life of adjustments to the preservative retention. Morris (1998) gives further details on progress towards these goals.

Table 2: Stake ratings

Stake condition	IUFRO Rating	AWPA Rating
no attack	0	10
suspicion of, or superficial decay (< 1mm deep)	1	9
evident but moderate decay (1-3 mm deep)	2	7
severe decay but stake still sound (> 3 mm deep)	3	4
failure when flexed	4	0

2.4 Test Sites

The test site located at Westham Island BC in the Fraser River delta was established in 1977 and is owned by the Canadian Wildlife Service as part of the Alaksen National Wildlife area. It has been primarily in agricultural use since the early part of the 20th century. Temperatures annually average 9°C, with a December average of 2°C and a July average of 16°C. The site receives about 1900 hours of bright sunshine and approximately 1000 mm of precipitation per year. On average, 13 mm of rain falls in July and 150 mm in December. The climate index for wood exposed above ground at this site is 45 (Setliff 1986). This value, derived from rainfall and temperature data, puts Westham Island in the moderate decay hazard zone for North America. While this provides an indication of the combined effects of temperature and rainfall on wood decay above ground, the soil type has a major impact on the durability of wood in ground contact.

Beneath a ground cover of grass, the soil at the site is an orthic gleysol, a silty clay loam, with a pH of 5.7 to 6.0. Soil analysis revealed a high organic matter of 4.7 to 9.3 percent. A relatively high calcium (1700 to 2500 ppm) and magnesium (675 to 700 ppm) content suggests that crushed dolomite limestone may have been applied to the site in an effort to neutralize acidity. Nitrate-nitrogen content was low at around 45 ppm. Soil drainage is poor due to a high water table and fine soil texture. Standing water is common in winter months with a water table within 25 cm of the soil surface, falling to 125 cm during the summer. This site has been found to be unusually aggressive in its decay rate when compared to other test sites in temperate climates, particularly with respect to arsenical preservatives (Morris and Ingram 1988, Ruddick and Morris 1991).

The Canadian Wildlife Service decided several years ago that the testing of wood preservatives was not within their mandate, and asked Forintek to vacate this site. This removal of material was phased in over several years, with all material taken out by December 31, 1997.

The test site at Petawawa ON was established in 1960, and is located in a cleared natural forest area surrounded by a mixed coniferous/deciduous forest. Grass, wild strawberries and sweet fern cover the ground. 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. Below this lies coarse sand. The pH is 6.0 at the surface dropping to 5.4 at a depth of 9 cm, and the average moisture holding capacity of the soil is 25%. Results collected over the years have indicated that the level of soft rot activity at this site is low compared to other test sites. The climate index for wood exposed above ground at this site is 41 (Setliff 1986).

3. Results and Discussion

Data from the Petawawa site were not as comprehensive as from the Westham Island site, largely due to incomplete ranges of retentions. However in some instances the rates of decay could be compared between the two sites. Water-treated control stakes took from two to four years to approach failure at Westham Island (Figures 1 and 3) and approximately four years at Petawawa (Figures 4 and 5). This indicates that the aggressive nature of Westham Island (Morris and Ingram 1991) may not be relevant to untreated wood. Oilborne preservatives also showed similar performance at the two different sites (Ingram and Morris 1998). The difference between the sites showed up only with arsenical waterborne preservatives.

3.1 Chromated Copper Preservatives

Decay of stakes treated with CCA-C and CCA-B at the Westham Island site was much more rapid than at Petawawa. Nevertheless, CCA-C, at the retention of 6.4 kg/m^3 recommended in North American standards (CSA 1997) for ground contact, performed well compared to other preservatives, maintaining a logscore of over 70 for 17 years (Figure 1). Figure 1 indicates diminishing returns from increases in CCA-C retention above 6.4 kg/m^3. Stakes treated to retentions of 8.7 and 10.3 kg/m^3 both had logscores of around 80 after 20 years. The performance of CCA-B followed a similar trend (Figure 2), although its performance was marginally inferior to that of CCA-C at all retentions. Stakes treated with 6.3 kg/m^3 CCA-B reached a mean logscore of less than 70 in 13 years. CCA-B is no longer used in Canada.

A range of higher retentions of CCA-C was put in test at Westham Island in 1988 (Figure 3). Data from this test has provided useful information on the potential benefits of increasing the preservative retention to deal with aggressive soils. Logscores after 10 years ranged from 89 for stakes at 8.6 kg/m^3, to around 97 for stakes at 16.6 kg/m^3. For the original CCA-C installations, the logscores for 6.4, 8.7 and 10.3 kg/m^3 were 81, 89 and 85, respectively after 10 years. These results suggest that there may be some benefit in specifying a higher retention for wood products in conditions where detoxification of CCA by soil iron is anticipated.

At Petawawa, eastern white pine stakes treated to 5.9 kg/m^3 CCA-C had reached a logscore of 86 after 24 years of exposure (Figure 4). Red pine stakes treated with 4.4 kg/m^3 CCA-C had a logscore of 63 after 20 years of exposure at Petawawa (Figure 5), compared to a logscore of 18 after 20 years at Westham Island for ponderosa pine stakes treated to the same retention. CCA-B-treated ponderosa pine stakes treated to retentions of 5.4 kg/m^3 and 7.7 kg/m^3 had reached logscores of 85 and 77 after 23 years in test at Petawawa (Figure 6), compared to 43 after 20 years at Westham Island at 6.3 kg/m^3. Red pine treated with another formulation of CCA-B, designated Boliden K-33, was even less decayed, after 38 years of exposure (Figure 7). Retentions of 6.4 and 9.4 kg/m^3 gave similar performance.

At the Westham Island site, Acid copper chromate (ACC) at 8.4 kg/m^3 (Figure 8) gave a very similar performance to 6.4 kg/m^3 CCA-C. However, this may be due to the reduced effectiveness of arsenic as a biocide at this site (Morris and Ingram 1991, Morris 1993).

3.2 Ammoniacal Copper Preservatives

Two formulations of ammoniacal copper arsenate (ACA) are approved for the protection of wood in ground contact in Canada (CSA 1997). ACA is a 1:1 mixture of copper and arsenic oxides in ammonium hydroxide, while modified ACA has a 2:1 ratio. Modified ACA (Figure 9) performed better than conventional ACA at the Westham Island test site (Figure 10) however both decayed substantially more rapidly than the benchmark, CCA-C (Figure 1). At approximately the recommended retention of 6.4 kg/m^3, ACA-treated stakes reached a mean logscore of below 70 after eight years, and modified ACA reached 70 after 11 years. This severe decay has not been replicated at other test sites, including the Petawawa site where stakes treated to 5.4 kg/m^3 of modified ACA had a mean logscore of 75 after 25 years in test (Figure 11).

It was suggested that the poor performance of ACA at the Westham Island site may have been caused by the severe leaching of arsenic noted in a depletion study (Ruddick and Minchin 1986). There is a high leaching hazard at this site during the rainy winter months due to poor drainage. Greater than expected leaching could have been caused by poor fixation due to rapid evaporation of the ammonia solvent after treatment. This idea was supported by the enhanced leaching from oven dried ACA-treated wood found by Ruddick (1995) and the more rapid decay rate of such material in a soil bed found by Morris and Ingram (1996).

A field test was set up in 1986 to evaluate the effect of wrapping ACA-treated wood in plastic for 48 hours to slow the evaporation rate to one more representative of commodities dimensions. However, stakes treated with modified ACA in this manner (Figure 12) decayed at a faster rate than the original modified ACA treatment (Figure 9). Three additional factors must therefore have been involved in premature failure of ACA at Westham Island. First, detoxification of arsenic by soil iron mobilized under anaerobic conditions during the winter months (Ruddick and Morris 1991) has been shown to affect the performance of ACA (Morris 1993). Second, the brown rot fungus *Leucogyrophana pinastri* Ginns and Weresub, prevalent at this site is able to take advantage of this phenomenon (Morris and Ingram 1991, Morris 1993). Third, bacterial was found to be much more severe attack on ACA-treated than CCA-treated material at this site (Morris and Ingram 1991). The activity of tunneling bacteria may be enhanced by the alkaline conditions, or the added nitrogen (Ruddick 1995) in wood treated with ammoniacal preservatives.

An alternative to ACA, where the arsenic was replaced by less toxic boron, ammoniacal copper borate (ACB), was tested at Westham Island (Figure 13). Its performance was inferior to that of ACA at retentions of 8.7 kg/m^3 and below. However, at 10.9 kg/m^3 decay rates were similar to those of ACA, with logscores of 43.3 for ACB (Figure 13) and 44 for ACA (Figure 10) after 17 years of exposure. At Petawawa, eastern white pine stakes treated to 3.3 and 6.0 kg/m^3 of ACB performed comparably to those at Westham Island, with failure of all stakes after 18 years (Figure 14). These results indicate that the extremely rapid decay of the arsenic-containing preservatives CCA and ACA observed at Westham Island compared to Petawawa, does not occur in treatments which do not contain arsenic. While ACB is unlikely to be used as a wood preservative, the results may be useful in understanding the relative roles of copper and unfixed co-biocides in formulations such as copper boron azole (Williams and Fox 1994).

Alkylammonium compounds, which performed well in laboratory experiments, did not achieve the same results in service at Westham Island (Ruddick 1986), or at Petawawa (Figure 15). Even a retention of 12.4 kg/m^3 of benzalkonium chloride failed in 11 years. One biocide combination which was moderately successful at Petawawa was acid copper Quat (ACQ^1) a mixture of benzalkonium chloride and copper sulphate, however logscores fell below 70 within 10 years at all retention levels (Figure 16). This may have been due to high solubility of copper in this sulphate formulation. Better performance was obtained from an ammoniacal copper quat, ACQ^2, a 1:1 combination of benzalkonium chloride and ammoniacal copper carbonate in ammonium hydroxide (Figure 17). ACQ^2 performed better than ACA and comparable to modified ACA probably due to the detoxification of arsenic in these two formulations. However, tunnelling bacteria have been found in ACQ^2-treated material at Westham Island (Figure 18).

3.3 Other Preservatives

Copper-8-quinolinolate is the sole preservative approved by CSA for wood expected to come into contact with foodstuffs. Although it is not approved for ground contact use, its performance at Westham Island has been quite good. Stakes treated to retentions of between 6.4 and 9.4 kg/m^3 in water performed comparably, reaching a mean logscore of below 70 in approximately 17 years (Figure 18). This exceeded the performance of ACA, which may have been hampered by the detoxification of arsenic.

4. Conclusions

- CCA-C at the standard recommended retention of 6.4 kg/m^3 performed well, despite aggressive conditions at Westham Island.

- Retentions of CCA-C above 8.0 kg/m^3 provided diminishing returns.

- CCA-C outperformed CCA-B at Westham Island.

- CCA-B at 6.4 kg/m^3 remained sound for 38 years at Petawawa.

- Wrapping ACA-treated stakes to retard loss of ammonia impaired subsequent performance.

- The aggressive nature of Westham Island against arsenical preservatives was due to detoxification of arsenic by available iron, combined with the presence of *Leucogyrophana pinastri* and tunnelling bacteria.

- In consequence, at this site, copper-based formulations with alternative co-biocides performed as well as some arsenical formulations.

5. Acknowledgements

All test material with over 12 years of data was installed under the supervision of Prof. J.N.R. Ruddick, formerly of Forintek Canada Corp. and its predecessor, the Western Forest Products Laboratory. The authors would like to acknowledge the technical assistance of D. Minchin, S. McFarling, K. Binnie K. Motani and E.E. Doyle in the inspection of test material. Forintek Canada Corp. would like to thank its industry members, Natural Resources Canada (Canadian Forest Service) and the Provinces of British Columbia, Alberta, Quebec, Nova Scotia, and New Brunswick for their guidance and financial support.

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Figure 1: Performance at Westham Island of stakes treated with a range of retentions of CCA-C

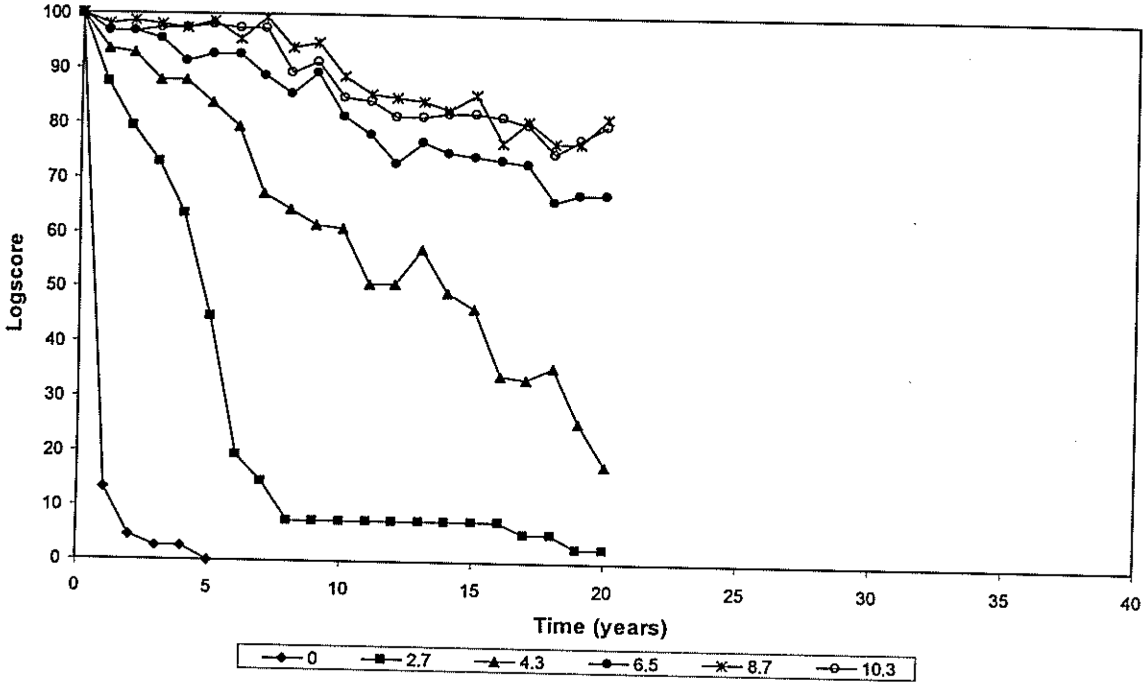


Figure 2: Performance at Westham Island of stakes treated with a range of retentions of CCA-B

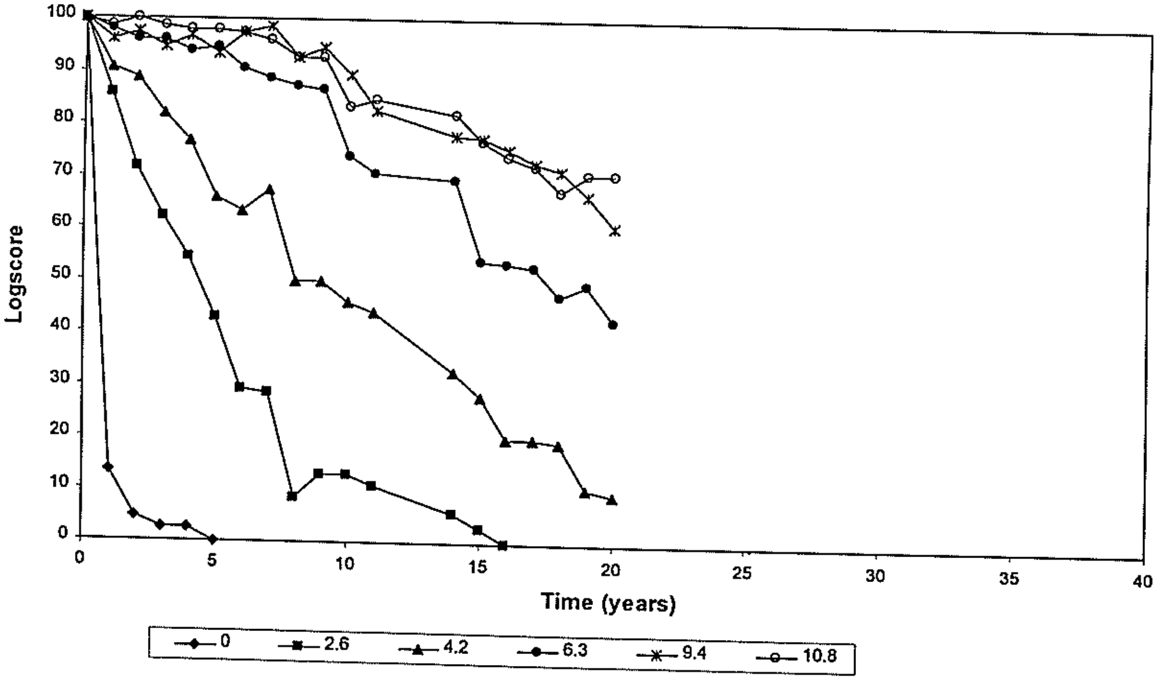


Figure 3: Performance at Westham Island of stakes treated with a range of high retentions of CCA-C

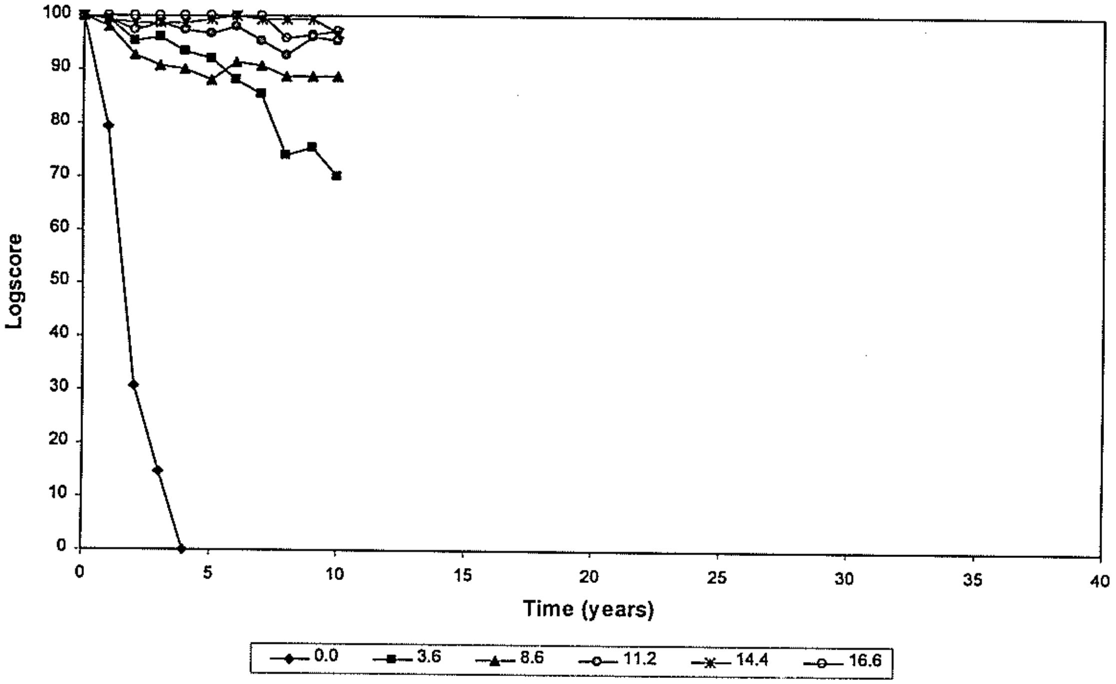


Figure 4: Performance at Petawawa of eastern white pine stakes treated with two retentions of CCA-C

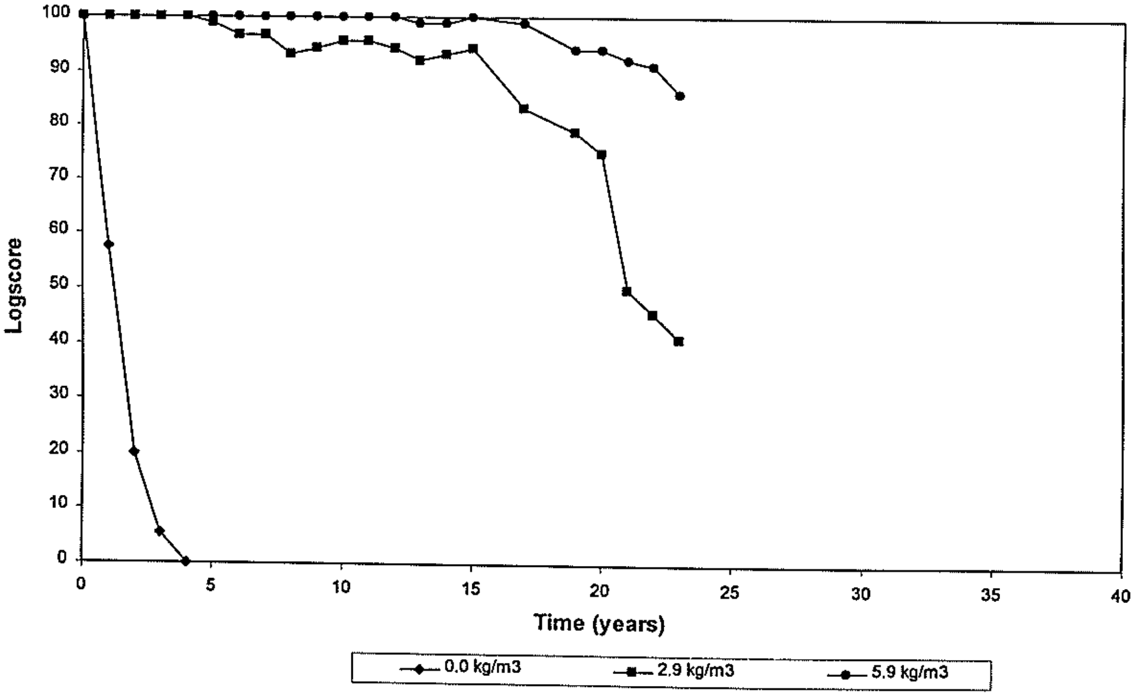


Figure 5: Performance at Petawawa of red pine stakes treated with two retentions of CCA-C

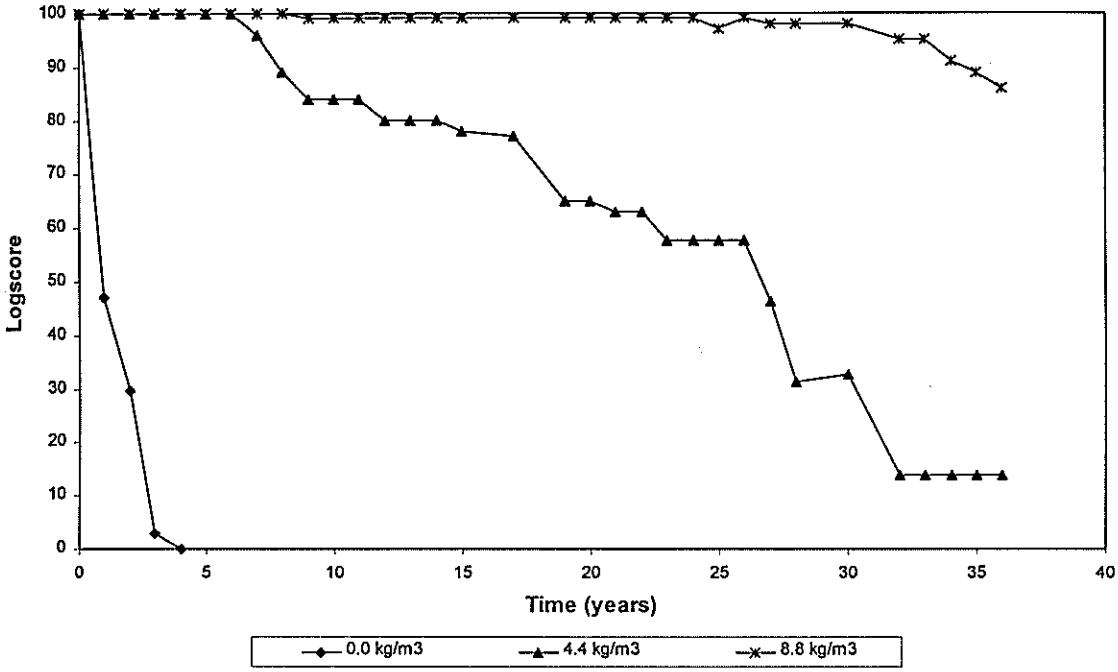


Figure 6: Performance at Petawawa of ponderosa pine stakes treated with two retentions of CCA-B

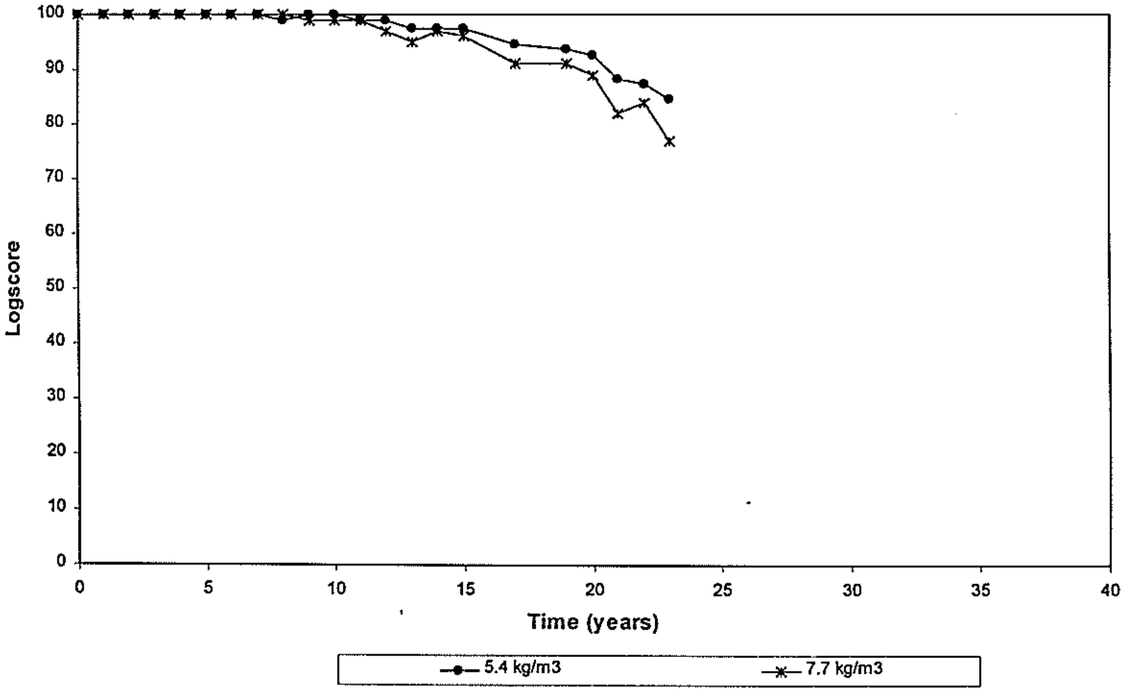


Figure 7: **Performance at Petawawa of red pine stakes treated with two retentions of CCA-B (Boliden K-33)**

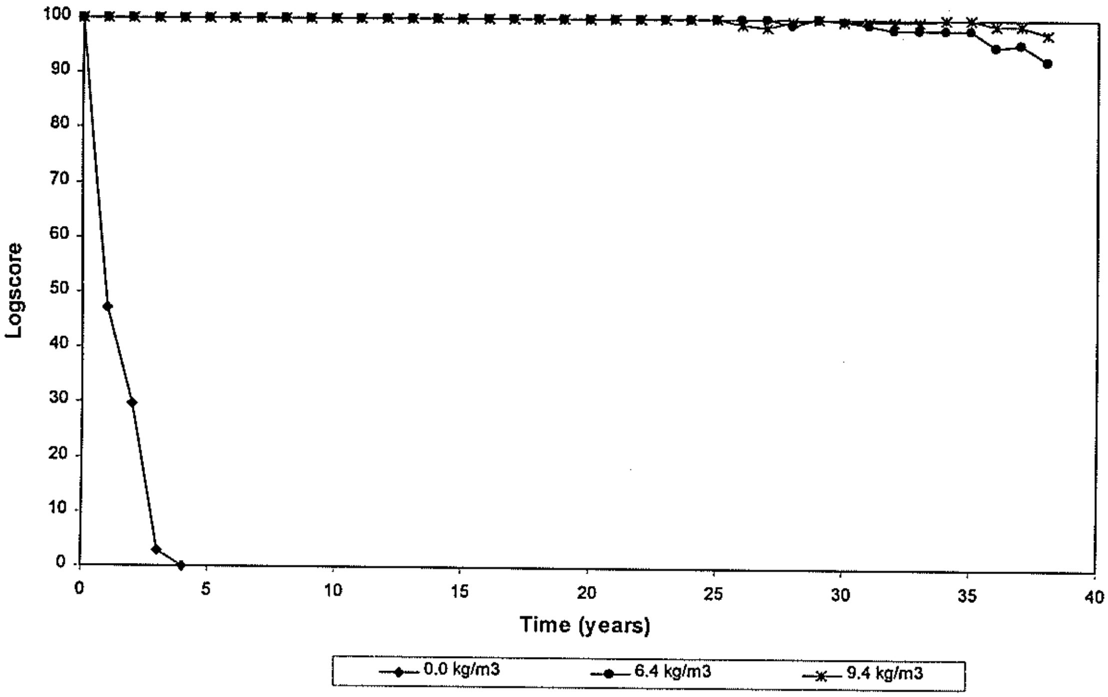


Figure 8: **Performance at Westham Island of stakes treated with a range of retentions of ACC**

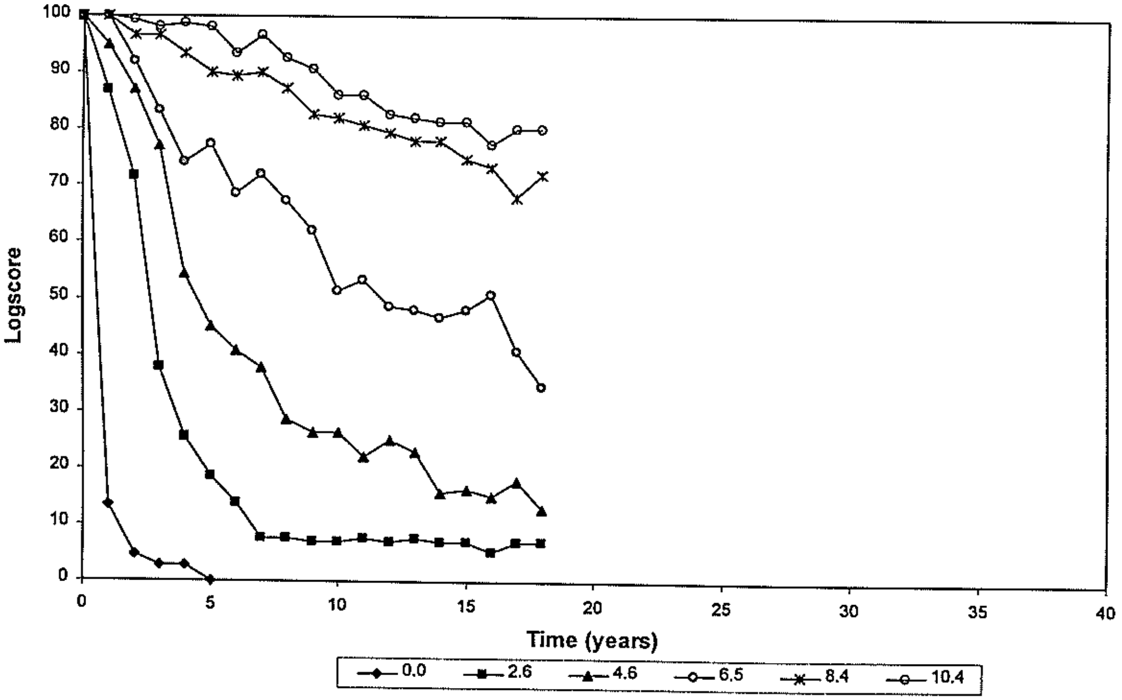


Figure 9: Performance at Westham Island of stakes treated with a range of retentions of modified ACA (2:1 Copper : Arsenic, oxides basis)

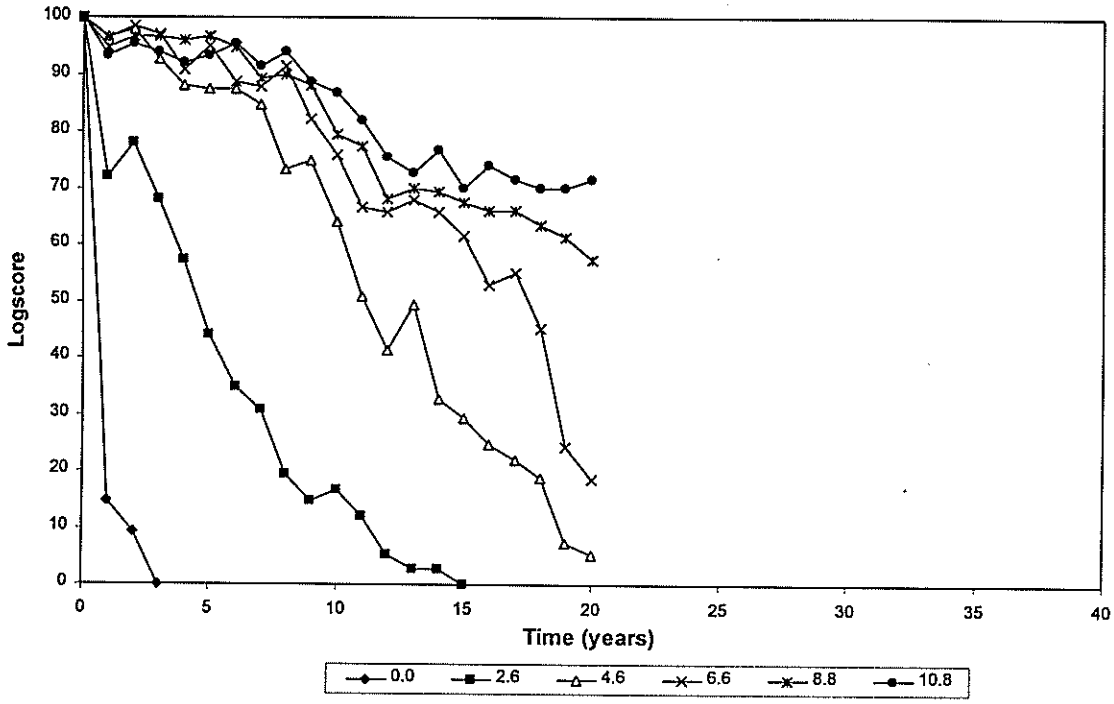


Figure 10: Performance at Westham Island of stakes treated with a range of retentions of ACA (1:1 Copper: Arsenic, oxides basis)

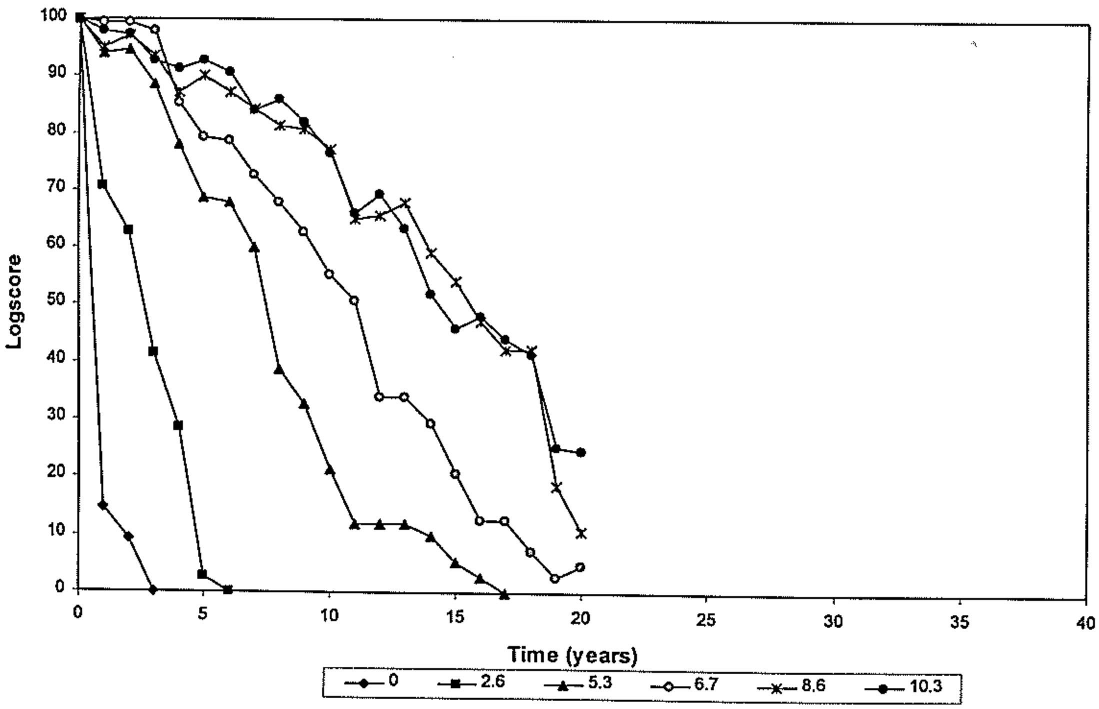


Figure 11: Performance at Petawawa of stakes treated with modified ACA and modified ACA/decanoic acid

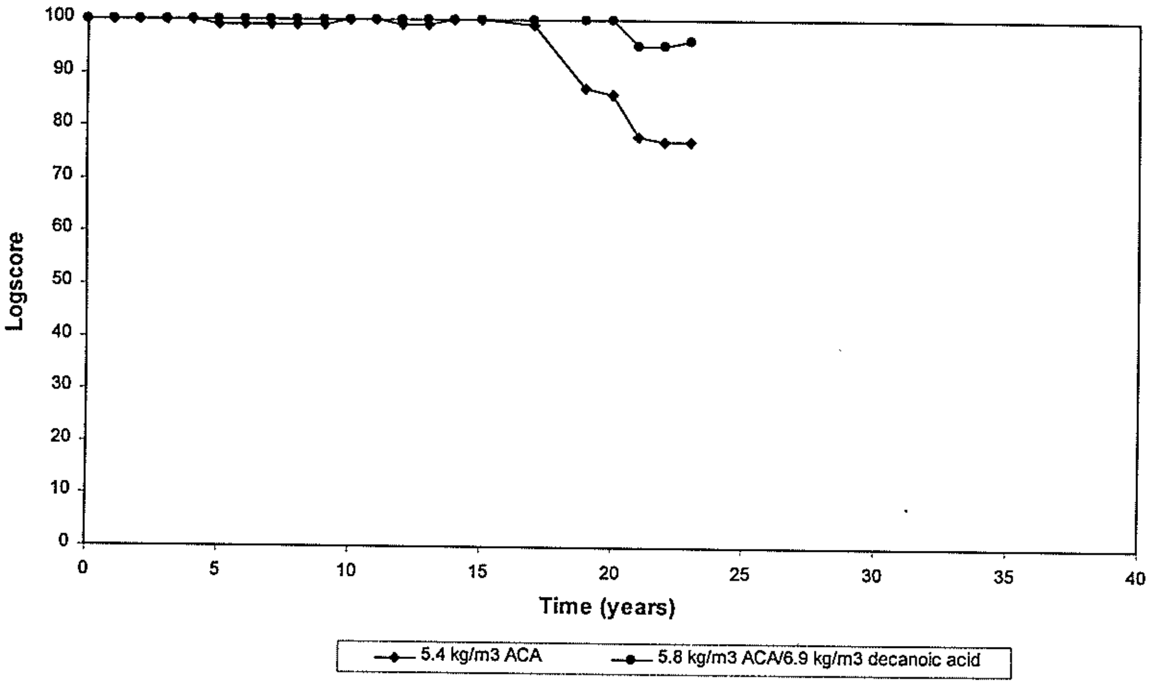


Figure 12: Performance at Westham Island of stakes treated with a range of retentions of wrapped modified ACA (2:1 Copper: Arsenic, oxides basis)

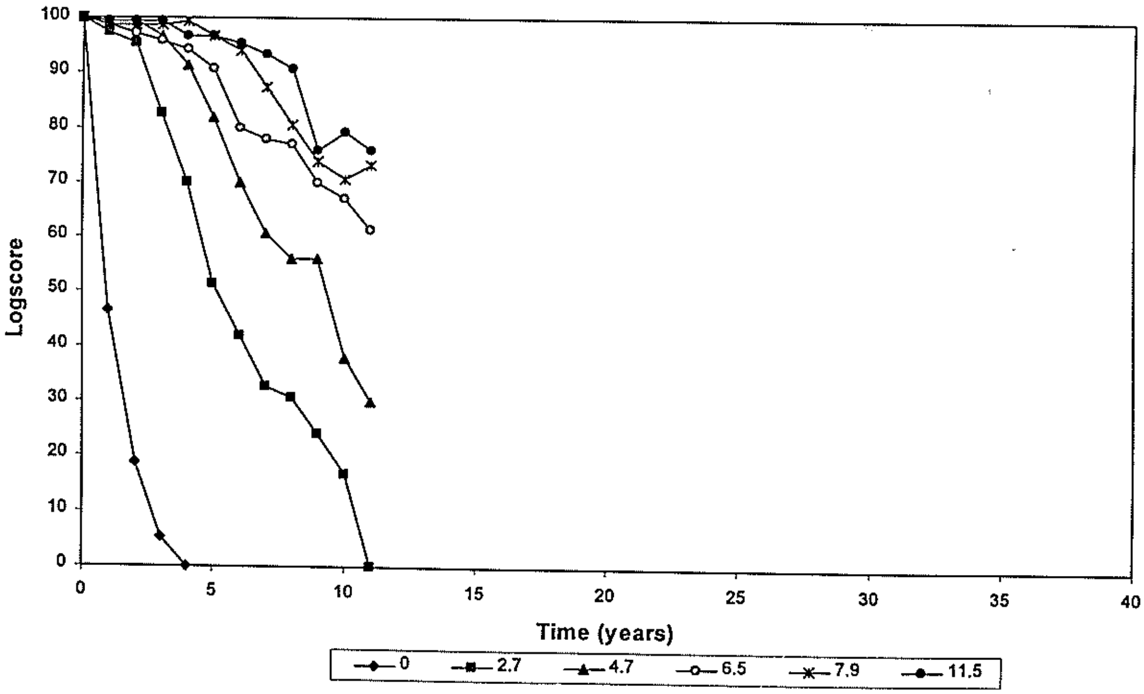


Figure 13: Performance at Westham Island of stakes treated with a range of retentions of ACB

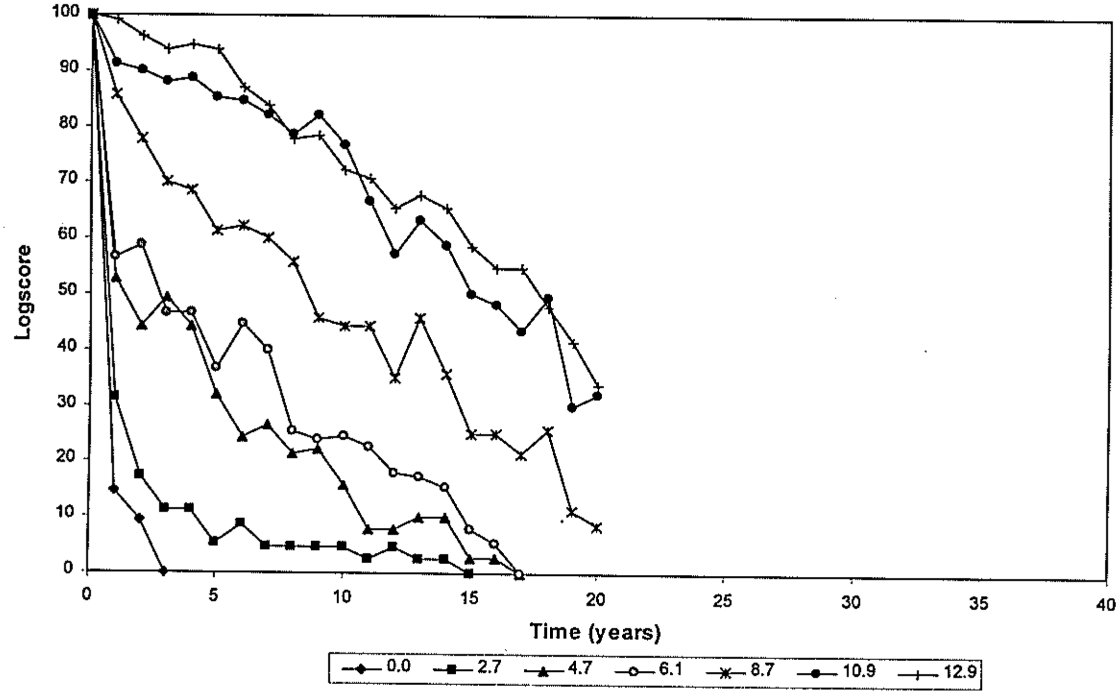


Figure 14: Performance at Petawawa of red pine stakes treated with two retentions of ACB

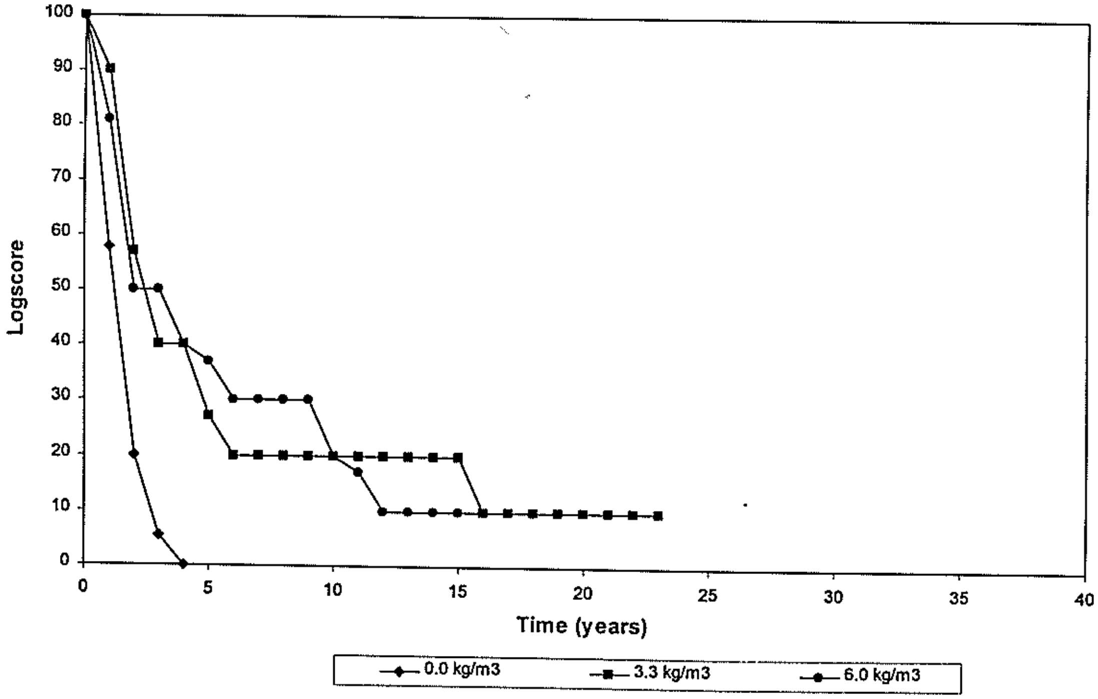


Figure 15: Performance at Petawawa of red pine stakes treated with a range of retentions of benzalkonium chloride

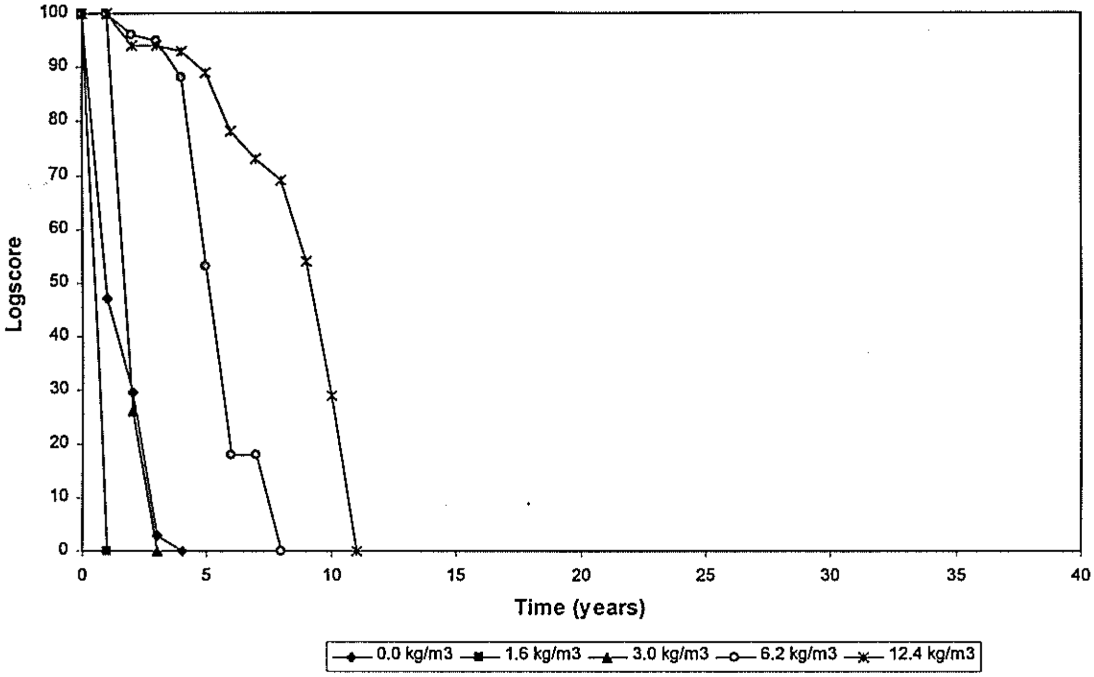
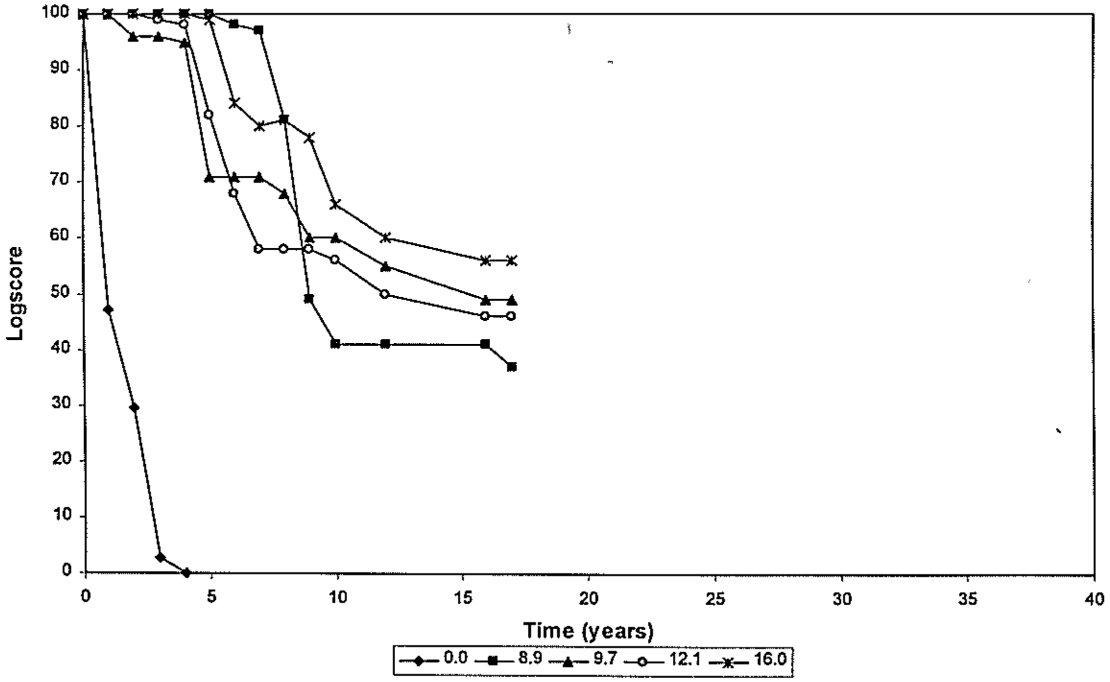


Figure 16: Performance at Petawawa of red pine stakes treated with a range of retentions of ACQ[1]



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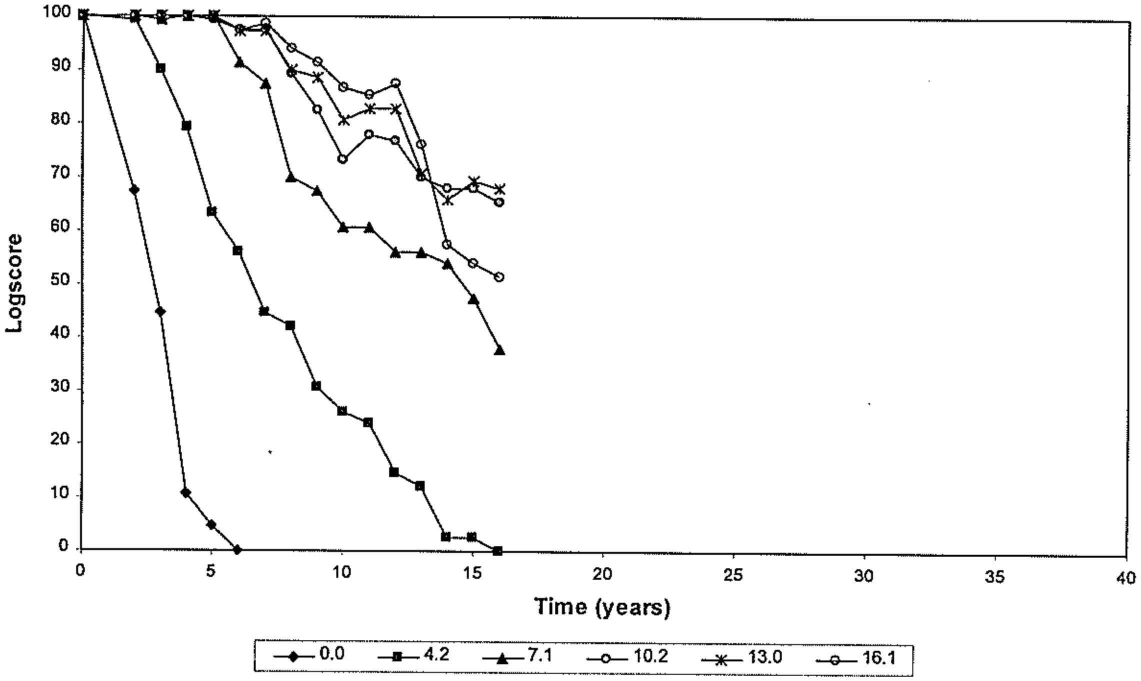
[1] *This is not a commercial formulation*

Figure 17: Performance at Westham Island of stakes treated with a range of rententions of ACQ[2]



CQ[1]

Figure 18: Severe damage by tunnelling bacteria in a ponderosa pine stake treated with 16kg/m^3 ACQ[2] after 10 years exposure at Westham Island

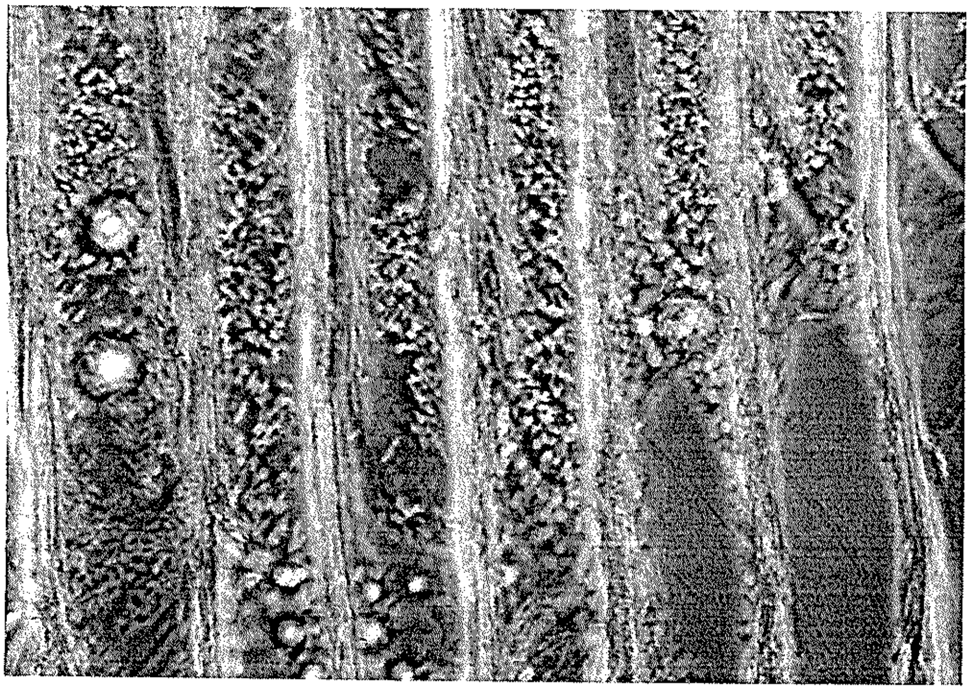


Figure 19: Performance at Westham Island of stakes treated with a range of retentions of copper-8-quinolinolate