FIELD TESTING OF WOOD PRESERVATIVES IN CANADA
I. STAKE TESTS AT WESTHAM ISLAND

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Summary

Forintek's field test database supports the existing Canadian wood preservation standards and permits the relevant codes and standards authorities to make informed decisions regarding the evolution of those standards. This paper covers selected data on currently accepted preservatives and some new formulations which are being introduced in North America or Europe. Only a few of these alternatives provide equivalent performance to the preservatives with which they are designed to compete. Acid Copper Chromate has shown particular promise as an alternative to Chromated Copper Arsenate.

This paper also provides a partial explanation of the unusually rapid decay rate of wood treated with copper based preservatives at the Westham Island test site. The presence of a copper tolerant brown-rot fungus and the preferential attack of tunnelling bacteria on wood treated with Ammoniacal copper arsenate are two of the factors responsible for this phenomenon. The uptake of iron into the stakes at this site may also play a role, but this has not yet been proven.

Introduction

Stake testing confirms, under natural conditions, the results of laboratory experiments on preservative efficacy. It is required by international authorities for approval of any new or modified preservatives. Forintek Canada Corp. is the principal source in Canada for the development of performance data on preservatives currently accepted for use, and on alternative preservatives which have been identified as potentially useful for the Canadian wood treating industry. Three sites are maintained for this purpose, containing several thousand treated stakes. These are located at Petawawa National Forestry Institute near Chalk River, Ontario; at Forintek's Eastern Laboratory in Ottawa; and at Westham Island, near Vancouver, B.C. This paper presents selected preservative performance data from the site at Westham Island.

Westham Island has been known for some time as a site with unusually rapid decay of wood treated with copper based preservatives compared to other test sites in temperate climates

(Morris and Ingram 1988, Ruddick and Morris 1991). A hypothesis has been put forward that this rapid decay rate may be associated with the presence of a copper tolerant brown-rot fungus, *Leucogyrophana* sp., and/or the movement of iron into wood at this site. To further investigate the cause of this phenomenon, an analysis was done using polarised light microscopyy on decayed and sacrificial stakes removed from service at Westham Island. While the decayed stakes were in service for various lengths of time, the sacrificial stakes were all exposed for eight years. The aim of this work was to determine the type and extent of decay in stakes treated with copper based preservatives.

In addition to this work, an experiment was set up to compare decay rates at Westham Island to a location with a different soil, but a similar climate. This location was the grassed courtyard of the original Forintek building on the campus of UBC, Vancouver, B.C.

Materials and Methods

Preparation of Stakes

Ponderosa pine (*Pinus ponderosa* Laws.) sapwood stakes, prepared from kiln-dried timber and free from visible defects as outlined in the IUFRO standard (Becker, 1972) were used for the routine stake testing of preservatives. The stakes had dimensions after drying and conditioning of 2.5 x 5.0 x 50 cm. Other wood species, such as Aspen (*Populus sp.*), were also utilized.

The full cell process was used to treat the stakes. An initial vacuum of 55 cm Hg was maintained for 30 minutes prior to impregnating the stakes with solution under a pressure of not less than 700 kPa for a minimum of two hours. The difference between the initial and final weights for each stake was used to calculate its preservative retention. After treatment stakes treated with some formulations were wrapped in plastic for 48 hours to condition. They were then air dried in open piles for a minimum period of one month.

Twenty-five stakes were selected for each preservative retention level (choosing those closest to the target retention) and installed in the test plot; 15 stakes for long-term exposure and 10 stakes for removal at selected time intervals to study chemical leaching and fungal colonization processes.

For each preservative, five levels of retention were normally used. Two of these were below (40 and 60 percent) that considered to be the recommended retention (100 percent), while two were above (130 and 160 percent) the recommended levels. When the toxic threshold was not known with certainty, an additional higher retention level (190 percent) was incorporated in the test. Control stakes, treated with the preservative solvent, were also included for each preservative.

Stake Installation and Inspection

Treated stakes were installed during the spring or summer. During the annual inspection, between August and October, each stake was removed from the ground and examined for evidence of decay. It was then rated using the numerical rating suggested in the IUFRO standard The stakes were evaluated using the IUFRO rating scale (Becker 1972) of 0 (sound) to 4 (failure). When the annual stake evaluation was completed the results were added to the computerized data base, converted to the American Wood Preservers Association (AWPA) rating scale (AWPA 1991a) and an average 'log' stake score was determined for each preservative treatment level. A 'log' stake score of 70 was regarded as the level below which a given retention of a particular preservative was no longer providing adequate protection.

A more detailed description of the stake testing procedure, and installation of material, has been provided in Annual Reports to the Canadian Forestry Service (e.g. Ruddick and Ralph 1985).

Microscopic Observations on CCA- and ACA-Treated Stakes

Stakes treated with Chromated Copper Arsenate type C (CCA-C) and modified Ammoniacal Copper Arsenate (ACA) of retention levels 2 (4.3 kg/m^3), 3 (6.5 kg/m^3) and 4 (8.7 kg/m^3) were used in this study.

Radial cross-sections were obtained from each stake at three positions:

1. approximately 1 mm from the surface halfway from the groundline to the base of the stake
2. approximately 1 mm from the surface just below the groundline.
3. in the centre of the stake at the groundline

These sections were mounted on microscope slides in lactophenol and observed under the microscope using polarized light. The extent of decay was rated as to the percentage of the section in the field of view with each of the following types of decay: white rot, brown rot, soft rot and tunnelling bacteria. The levels at which these were rated are shown in Table 1.

Investigation of Rapid Decay at Westham Island

Ponderosa pine sapwood stakes 12.5 x 25 x 250 mm were treated to 2.6 kg/m^3 with CCA-C or ACA. Solvent-treated control stakes were also prepared for each preservative. Stake preparation, treatment, leaching and chemical analysis followed the procedure described by Smith, et.al., 1986. Forty five replicate stakes were selected for each variable: forty test stakes and five sacrificial stakes. Each set of 180 stakes at each of the sites was installed in 20 columns of 9 rows using random number tables with each stake centre 95 mm from all neighbouring stake centres. Stakes were planted to a depth of 125 mm using a measured guide stake.

The CCA- and ACA-treated stakes were evaluated at 3 month intervals and the solvent treated controls were evaluated at 1.5 month intervals after the first three months.

In addition the CCA- and ACA-treated sacrificial stakes were examined for the type of decay present and analyzed for iron uptake. Thin hand sections were removed from 10 mm below the groundline 0.5 mm below the surface and examined under polarised light. The extent of decay was rated as described previously. Iron analysis was done using a Tracor Northern X ray spectrometer on pellets made from cross sections cut from just below the groundline and 20 mm from the base.

Results and Discussion

Site Conditions

The test site located at Westham Island in the Fraser river delta, British Columbia, is owned by the Canadian Wildlife Service. 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 is received during July and 150 mm during December. The soil at the site is an orthic gleysol, a silty clay loam, with a pH of 5.7 to 6.0 (somewhat acidic) and a high organic matter content. Soil drainage is poor due to a high water table and fine soil texture. Standing water is common in winter months.

Chromated Copper Preservatives

Acid copper chromate (ACC) one of the non-arsenical alternatives has given equivalent performance to CCA-C, the benchmark waterborne preservative for ground contact in North America. CCA-C itself, at the standard retention of 6.4 kg/m^3 required in North American standards, has performed reasonably well during 13 years in test, with a current log stake score of 77 (Figure 1). A first impression from Figure 1 suggested diminishing returns from increases in preservative retention above 6.4 kg/m^3, however, this needs to be confirmed by mathematically modelling the data. This work is currently in progress.

In 1987 Forintek put into test material which better represented the preservative retentions in the treated zone of commodities which had been CCA-treated to CSA O80 standards (Morris and Ingram 1988). As an example, nominal 2 inch lumber treated precisely to meet CSA O80-15 would have a retention of 8.0 kg/m^3 in the 16 mm assay zone but the preservative would have penetrated only 10 mm of this. The retention of preservative in the 10 mm deep treated zone would therefore be 8.0 X 16/10 or 12.8 kg/m^3. After 3 years exposure all of the stakes treated with high retentions were showing negligible signs of decay.

A number of alternatives to CCA-C, in which the arsenic has been replaced by less toxic elements, are in test at Westham Island. These include Chromated Copper Fluoride (CFK), which is approved for ground contact applications in Germany (K stands for chromium in Germany), Chromated Copper Phosphate (CCP), which is accepted for use in Scandinavia, and Chromated Copper Borate (CKB), a preservative recently proposed for inclusion in CSA O80. ACC is a preservative approved by the AWPA for ground contact at a retention of 8.0 kg/m^3 (AWPA 1991b). Three of these alternatives, CFK, CCP and CKB at around 6.4 kg/m^3 all failed (fell below a rating of 70) within two years of installation (Figure 2). Even retentions as high as 10 kg/m^3 did not provide equivalent performance to CCA-C at 6.4 kg/m^3 (e.g. Figure 3).

In the case of CFK and CKB the poor performance was probably caused by leaching of the fluoride or borate which are not readily fixed, unlike copper and arsenic. In the case of CCP the decay rate in the first year was much more rapid than for any other chromated copper preservative, almost suggesting a stimulatory effect of the phosphorous (Figure 3). Phosphorous is the P in NPK, as any gardener will know. Interestingly a significant part of the Danish treatment industry has recently moved from CCA to CCP (Koch and Sheard 1991). Our data, and that of Koch and Sheard (1991), would suggest that this was a mistake. These authors demonstrated, in a laboratory test, that retentions of approximately 14 kg/m^3 (oxides) of CCP failed to prevent decay of wood by a brown-rot fungus. This should provide a warning against propelling the Canadian industry precipitately towards abandoning CCA.

In contrast to performance of the other three non-arsenical CCA alternatives, ACC at around the AWPA recommended retention of 8.0 kg/m^3 gave equivalent performance to CCA-C at 6.4 kg/m^3 after 11 years in test (Figure 4). This was probably due to the fact that all of that 8.0 kg is 'fixed' copper or 'fixative'. ACC is not accepted for ground contact use in the CSA standards (CSA 1989) and there is a proposal to remove it from the standard for lack of use. This is unfortunate because ACC could be an excellent alternative for the Canadian treating industry for commodities where the arsenic content of CCA has caused concern, whether or not this concern has any foundation in fact. The wood preservation industry could add ACC to its product line with minimal capital cost and no change in processes.

Ammoniacal Copper Preservatives

Ammoniacal copper quaternary ammonium compound (ACQ), one of the non-arsenical alternatives to ACA has shown equivalent performance to ACA in Forintek's stake tests but ACA itself has not performed well. ACA is an equal mixture of copper and arsenic oxides in ammonium hydroxide; whereas modified ACA contains a higher percentage of copper. Both are accepted in Canada for protection of wood in ground contact. Modified ACA has outperformed conventional ACA but, after 13 years in test at Westham Island, both must be considered failures, with log stake scores of less than 70 at the recommended retention of 6.4 kg/m^3 (Figure 5). Although ACA has not performed as well as CCA at other sites (Gjovik and Gutzmer 1989), nowhere has the performance been as inadequate as at Westham Island. Nor has this poor performance been noted in commercial use.

It has been suggested that the relatively small dimensions of the test stakes may have allowed rapid evaporation of the ammonia after treatment resulting in poor distribution or fixation. It was therefore proposed that wrapping ACA-treated wood in plastic for 48 hours after treatment would simulate the slower evaporation expected from larger dimension commodities. Stakes treated with modified ACA in this manner have been in test for 4 years and may be performing better than the original ACA (Figure 6), with log stake scores of over 90 at the standard retention. However, it is too soon to analyze the data statistically. A complementary or alternative explanation may be offered by the degree of brown rot (*Leucogyrophana sp.*) and bacterial attack of ACA-treated material at this site. These phenomena are discussed below.

Ammoniacal copper borate (ACB) and ACQ are alternatives to ACA in test at Westham Island. ACQ is a 1:1 mixture of MB-80 (an alkyldimethylbenzylammonium chloride) and ammoniacal copper oxide. ACB failed completely within a few years of installation while ACQ has given equivalent performance to ACA over 8 years in test (Figure 5).

Oilborne Preservatives

Copper naphthenate has performed better than pentachlorophenol (PCP), at their respective recommended retentions, at Westham Island despite the presence of a copper tolerant brown-rot fungus (Figure 7). Pentachlorophenol is the standard oilborne preservative for wood in ground contact. Copper naphthenate is used as a brush treatment for cross-cut surfaces of treated wood, and has recently been approved by the AWPA for ground contact use. The P-9 oil solvent used for these preservatives also provided some protection against decay and the log stake score of solvent-treated control stakes remained above 70 for 11 years. PCP, at 3.0 kg/m^3 and above, had log stake scores of over 70 after 13 years in test. Copper naphthenate has performed very well indeed, with log stake scores of 83 and above for all retentions after 12 years. This preservative is currently being considered for inclusion in CSA O80 standards. There were some concerns about the performance of this preservative in areas with copper-tolerant brown-rot fungi (DeGroot, Link and Huffman 1988). These should be dispelled by the excellent performance of the preservative in P9 oil at Westham Island, a site with an extremely aggressive copper-tolerant brown-rot fungus.

Ponderosa Pine Heartwood

When ponderosa pine heartwood stakes were CCA-treated to meet CSA standards natural durability contributed nothing to their performance. Water-treated ponderosa pine heartwood controls failed within 3 years, illustrating its low natural durability. Sapwood stakes failed within one or two years. The difference between the performance of non-durable heartwood and perishable sapwood reflects the lower nutrient status of the heartwood as well as the presence of some fungitoxic heartwood extractives. Heartwood treated to 2.9 kg/m^3 gave a much better performance than sapwood treated to a similar retention (Figure 8) suggesting some synergism between natural and artificial durability. However, heartwood treated to 6 kg/m^3 CCA-C gave equivalent performance to sapwood treated to a similar retention. This suggests that at retentions of 6 kg/m^3 and above the contribution of natural durability to the performance of the treated wood is negligible. The performance is dependant entirely on the preservative.

Aspen

Aspen requires extremely high preservative loadings to give equivalent performance to treated pine. All aspen stakes performed poorly with stakes treated up to 18.7 kg/m^3 of ACA having log scores of under 70 after 6 years exposure (Figure 9). CCA-treated stakes at 14.2 kg/m^3 and 18.4 kg/m^3 remained above 70 after 6 years (Figure 10). These results contradicted laboratory data where ACA-treated aspen performed better than CCA-treated aspen (Morris and Parker 1988) but they may be linked to the unusually poor performance of ACA at Westham Island. In this field test 14.2 kg/m^3 of CCA in aspen gave a similar performance to 4.3 kg/m^3 CCA in pine after 6 years exposure. However, this type of comparison is imprecise. Mathematical modelling of the data, currently underway, should reveal what retention of CCA in aspen is equivalent to 6.4 kg/m^3 in pine. No conclusions can be drawn at this time concerning recommendations for treatment of aspen.

Microscopic Observations on CCA- and ACA-Treated Stakes

The major difference between CCA- and ACA-treated stakes was the presence of brown rot and tunnelling bacteria (the latter were described by Daniel, Nilsson and Singh 1987) only in ACA-treated material. The slight decay due to brown-rot fungi (Table 2) at the lowest retention of ACA examined (4.5 kg/m^3) may be related to greater depletion of arsenic in ACA compared to that in CCA, as demonstrated by Ruddick & Minchin (1986). A number of copper-tolerant brown-rot fungi are known to attack copper based preservatives with no arsenic. Although the positions selected for microscopic examination showed extensive brown rot in only one ACA-treated stake, a visual examination showed that brown rot was involved in the failure of three of the five stakes at 4.5 kg/m^3.

Tunnelling bacteria were prominent at all retention levels of ACA. This is in contrast to CCA-treated stakes where little or no bacterial decay was found. This major difference in presence of tunnelling bacteria in the two preservatives may be due to one or more of the following factors: 1. more depletion of arsenic in ACA than in CCA, 2. the difference in fixation mechanism for copper and arsenic in the two preservatives, 3. the presence of nitrogen in the ACA formulation. Whether tunnelling bacteria affect the performance of ACA-treated wood at sites other than Westham Island is yet to be determined.

Soft rot was equally prominent in ACA and CCA-treated stakes (Tables 2 and 3). No discernible pattern was observed as to the difference in performance of the two preservatives with respect to this type of decay. CCA-treated stakes showed levels of soft rot, decreasing with increasing retention, but no brown rot or tunnelling bacteria (Table 3).

Investigation of Rapid Decay Rate at Westham Island

The observed pattern of decay related to the presence of a copper tolerant brown-rot fungus provided part of the explanation for the unusually rapid decay rate at Westham Island. The failure of stakes was found to progress outwards from a point source (Figures 11 - 14). After 9 months exposure three ammonia treated controls were removed due to failure in bending. *Leucogyrophana sp.* mycelium was observed on all three plus six other stakes in the immediate area (Figure 11). No further recording of *Leucogyrophana sp.* mycelium was done until the 33 month inspection but the failure of stakes revealed where this fungus was active through 18 and 21 months.

After 18 months exposure a further seventeen stakes failed (14 controls and 3 ACA-treated stakes) in the area where *Leucogyrophana sp.* was previously noted (Figure 12). In contrast, outside this area only two controls failed. After 21 months exposure 55 controls, 26 ACA-treated and 11 CCA-treated stakes had failed and all but 6 of these (all untreated controls) were within a radius of 0.95 m of the original centre of *Leucogyrophana sp.* infection (Figure 13). Outside this radius no ACA or CCA-treated stakes had failed. After 33 months exposure *Leucogyrophana* mycelium was noted on all but one of the stakes which failed at this time and on 13 of the remaining stakes. All but one of these *Leucogyrophana* infected stakes were located in a broad swath 0.5 m wide extending outwards from the radius of active decay at 21 weeks (Figure 14). Within this radius the only stakes remaining were CCA-treated. The pattern of failure matching the progress of *Leucogyrophana sp.* confirms that this fungus is quite aggressive towards CCA-treated material and extremely aggressive towards ACA-treated material. This behaviour also characterises whatever factor, or factors, cause the accelerated decay rate at Westham Island.

The degree to which *Leucogyrophana* was responsible for this accelerated decay was quantified by dividing the block of stakes into two, on paper, one half originally with *Leucogyrophana* and one half without, and plotting change in decay ratings for CCA- and ACA-treated stakes (Figures 15 and 16). This revealed that the decay rate for CCA-treated wood in the half block at Westham Island originally without *Leucogyrophana sp.* was similar to the decay rate in the Courtyard up to the time when *Leucogyrophana* moved into this area, 30 months after installation (Figure 15). The decay rate for CCA-treated stakes in the half block with *Leucogyrophana sp.* was 3.0 times this decay rate. The overall factor of acceleration (for the full block) for Westham Island versus the Courtyard was 2.6 which is within the range given for the acceleration rate of Westham Island compared to other field test sites in the temperate zones (Morris and Ingram 1988). It would appear that the presence of *Leucogyrophana sp.* at Westham Island could account for this acceleration factor for CCA-treated material.

For ACA-treated material, stakes in the half block originally without *Leucogyrophana sp.* decayed faster than those in the Courtyard, but not as fast as the stakes in the half block with *Leucogyrophana sp.* (Figure 16). This suggests then there may be a second factor accelerating the decay of ACA-treated wood at Westham Island. One candidate for this factor was the preferential attack of bacterial decay on ACA-treated wood described above. However, microscopic examination of sacrificial stakes showed that there was no apparent difference in the degree of surface bacterial decay (or soft-rot) after 30 months between material exposed at Westham Island or in the Courtyard (Table 5).

A further factor influencing the poor performance of ACA-treated wood at Westham Island was thought to be the greater leaching from ACA-treated wood noted by Ruddick and Minchin 1986. However, the leaching hazard in the Courtyard was found to be similar to that at Westham Island (Morris and Ingram 1991) probably because the Courtyard also suffers from extremely wet conditions in the winter months. It is possible that *Leucogyrophana sp.* could merely be taking advantage of the impact of another factor on the performance of CCA and ACA. This third factor could be the movement of iron into test stakes (Ruddick and Morris 1991). The iron content of the stakes was between 1.4 and 2 times higher at Westham Island than the Courtyard (Table 4) thus iron could be responsible in part for the differences in preservative performance of the two sites. The role of iron in accelerating decay has not yet been fully elucidated.

One, or a combination, of leaching, bacteria and iron uptake may increase the susceptibility of treated wood to attack by *Leucogyrophana sp.* This fungus was not present in the Courtyard thus the treated wood may have been preconditioned for brown rot but the fungus was not there to do its work. *Leucogyrophana* species have been isolated worldwide from wood in houses and in ground contact but this fungus is not as common as the more well known brown-rot fungi used in standard decay tests (Morris and Ingram 1988).

Westham Island appears to possess several factors, each of which may occur singly at other locations, but which come together at this site to create a particularly severe decay hazard for treated wood. In the light of this severe decay hazard, the excellent performance of copper naphthenate in P9 oil and Acid Copper Chromate is good news for a Canadian treating industry under pressure to offer wood products treated with alternative preservatives.

Conclusions

1. The Canadian treating industry should consider using ACC at 8.0 kg/m^3 for commodities in ground contact where the arsenic content of CCA may be an obstacle to the use of this preservative.

2. ACQ gave equal performance to ACA over eight years of testing.

3. After 13 years exposure, 0.4 kg/m^3 copper naphthenate in P9 oil gave equal performance to 10.6 kg/m^3 PCP in P9 oil.

4. When treated with CCA-C to meet CSA standards, stakes of non-durable ponderosa pine heartwood have performed the same as perishable ponderosa pine sapwood after 11 years exposure.

5. *Leucogyrophana sp.* plays a major role in the unusually rapid decay rate of CCA- and ACA-treated wood at Westham Island.

6. A higher susceptibility to *Leucogyrophana sp.* and bacterial decay of ACA-treated wood compared to CCA-treated wood may be responsible for the relatively poor performance of ACA at the Westham Island test site.

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Table 1. Decay rating scale

% of Cross-section in field of view with a given type of decay	Rating
0	0
1-10	1
10-50	2
50-90	3
90-100	4

Table 2. Summary of Decay Ratings for ACA-treated stakes at Retention Levels 2, 3 & 4

<u>Preservative:</u> <u>Modified ACA</u>

Retention kg/m^3	Average Age (yrs)	Section	Average Microscopic Rating						
			WR mean	BR mean	(SD)	SR mean	(SD)	TB mean	(SD)
4.5	7.00 (1.87)	3	0	0.80	(1.78)	0.40	(0.89)	0.80	(1.10)
		2	0	0.80	(1.09)	1.60	(1.50)	2.00	(0.71)
Level 2		1	0	0.40	(0.89)	1.00	(1.00)	2.00	(1.41)
6.6	7.75 (0.50)	3	0	0		0.25	(0.50)	0.25	(0.50)
		2	0	0		2.75	(0.50)	1.75	(1.50)
Level 3		1	0	0		2.00	(1.41)	3.25	(0.50)
8.8	8.00 (0.00)	3	0	0		0	0		
		2	0	0		2.30	(1.15)	2.66	(0.58)
Level 4		1	0	0		0.33	(0.57)	2.33	(0.58)

Notes:
Section 3: Ground-line - Centre
Section 2: Ground-line - Surface
Section 1: Below Ground - Surface
(See Fig. 1)

Table 3. Summary of Decay Ratings for CCA-treated stakes at Retention Levels 2, 3 & 4

Preservative: CCA-Type C

Retention kg/m^3	Average Age (yrs)	Section	Average Microscopic Rating					
			WR mean	BR mean	SR mean	(SD)	TB mean	(SD)
4.3	5.50(1.52)	3	0	0	1.4	(0.89)	0.2	(0.45)
		2	0	0	3.6	(1.89)	0	
Level 2		1	0	0	1.8	(0.84)	0.2	(0.45)
6.5	8.00(0.00)	3	0	0	0.30	(0.58)	0	
		2	0	0	0.60	(0.58)	0	
Level 3		1	0	0	0.30	(0.58)	0	
8.7	8.00(0.00)	3	0	0	0.30	(0.58)	0	
		2	0	0	1.67	(1.53)	0	
Level 4		1	0	0	1.00	(1.73)	0	

Notes:

Section 3: Ground-line - Centre
Section 2: Ground-line - Surface
Section 1: Below Ground - Surface
(See Fig. 1)

Table 4. Iron content of treated stakes after 30 months exposure in two field test sites

Test location	Sample location	Fe content kg/m^3			
		CCA-treated		ACA-treated	
		mean	(SD)	mean	(SD)
Westham Island	groundline	0.11	(0.05)	0.12	(0.02)
	base	0.33	(0.09)	0.31	(0.08)
Courtyard	groundline	0.05	(0.01)	0.06	(0.01)
	base	0.23	(0.08)	0.18	(0.04)

Table 5. Decay ratings from microscopic observations in CCA- and ACA-treated stakes after 30 months exposure at two test sites

Test Site	Preservative	White-Rot mean	Brown-rot mean	Soft-rot mean (SD)	Tunnelling Bacteria mean (SD)
Westham Island	CCA	0	0	1.8 (1.1)	0
	ACA	0	0	1.6 (0.5)	0.6 (0.5)
Courtyard	CCA	0	0	2.0 (0.7)	0
	ACA	0	0	1.0 (1.0)	1.4 (0.9)

Figure 1: Decay of Stakes Treated with a Range of Retentions of Chromated Copper Arsenate Type C

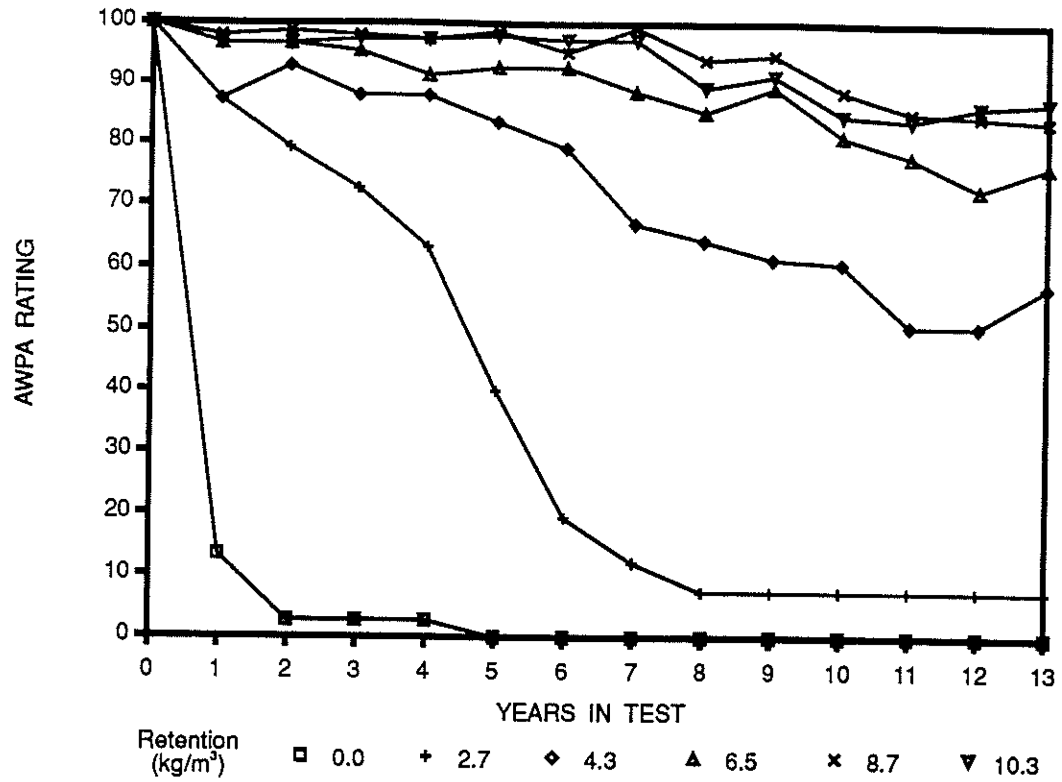

Figure 2: Comparison of Chromated Copper Preservatives

at approx. 6.4 kg/m³

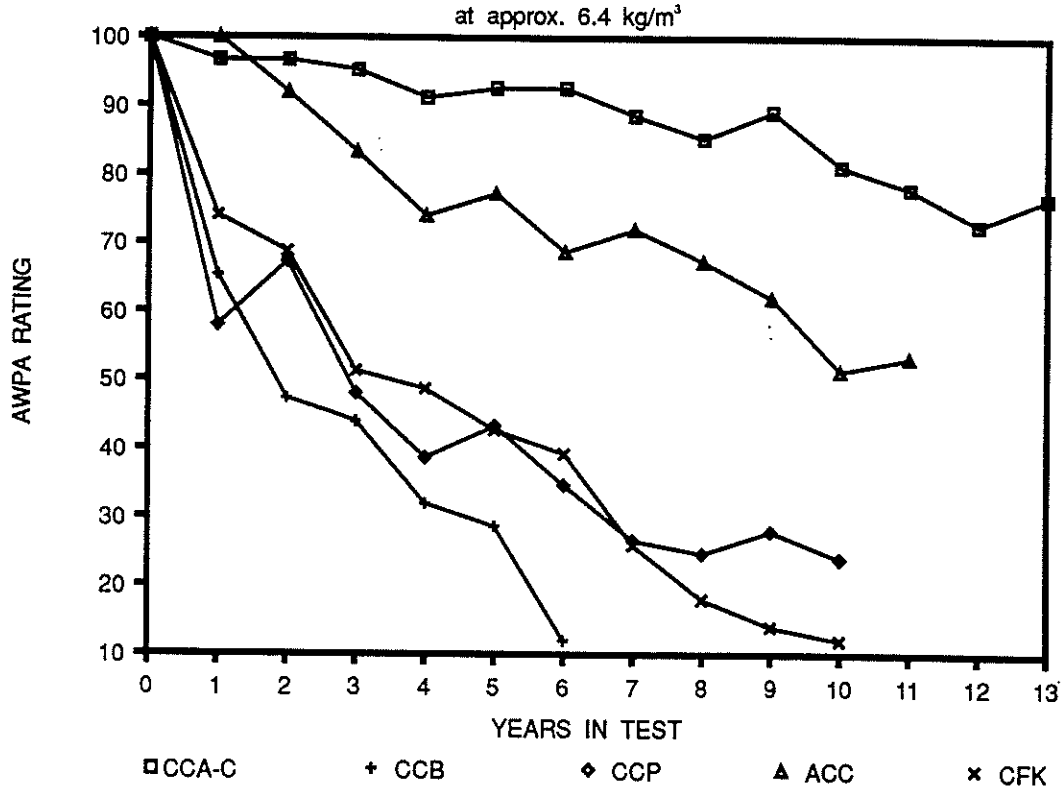

Figure 3: Decay of Stakes Treated with a Range of Retentions of Chromated Copper Phosphate

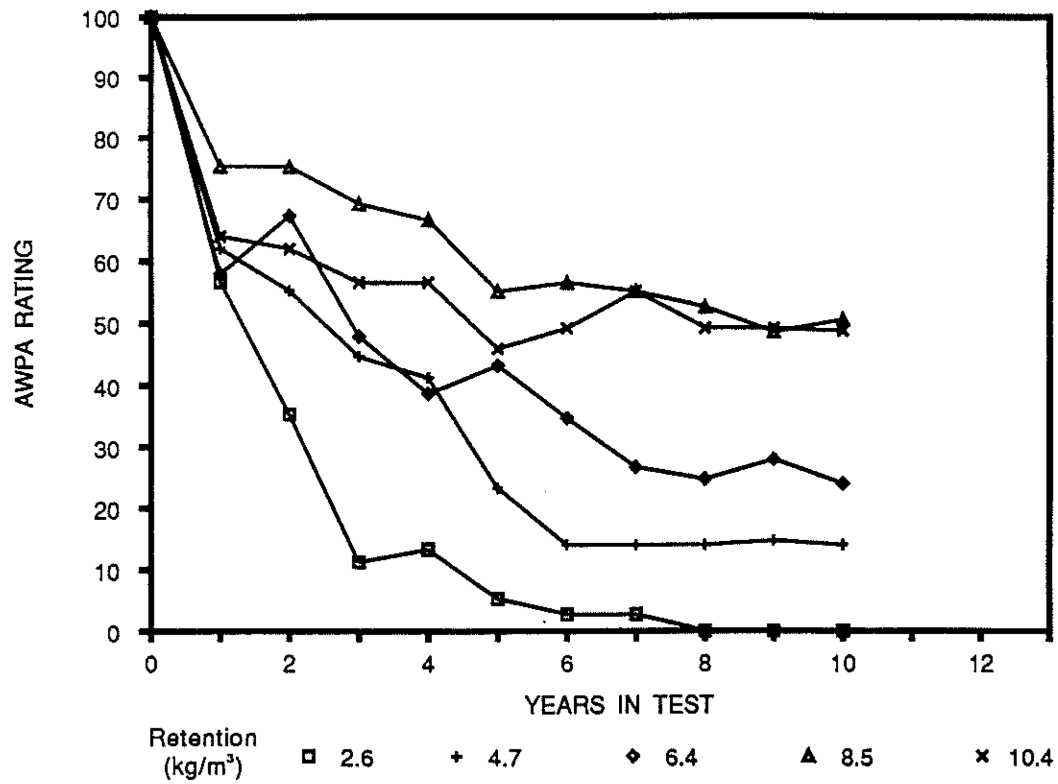

Figure 4: Comparison of Chromated Copper Preservatives

CCA at 6.4, others at 8 kg/m³

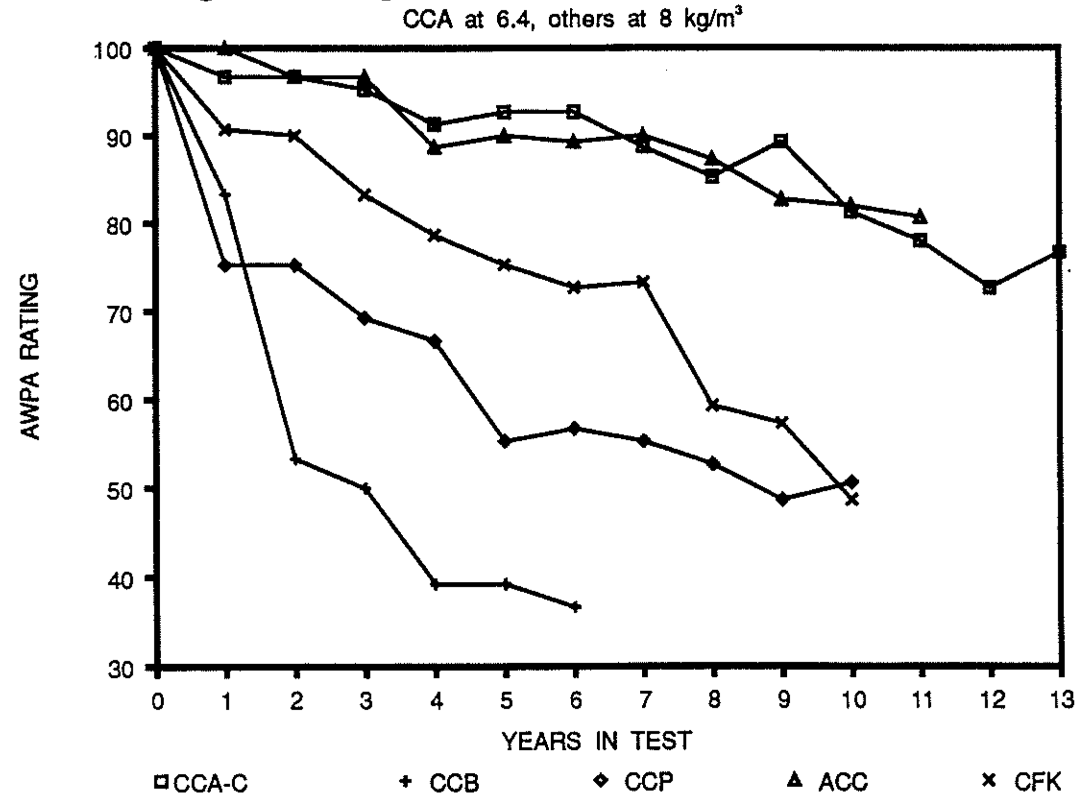

Figure 5: Comparison of Ammoniacal Preservatives

at approx. 6.4 kg/m³

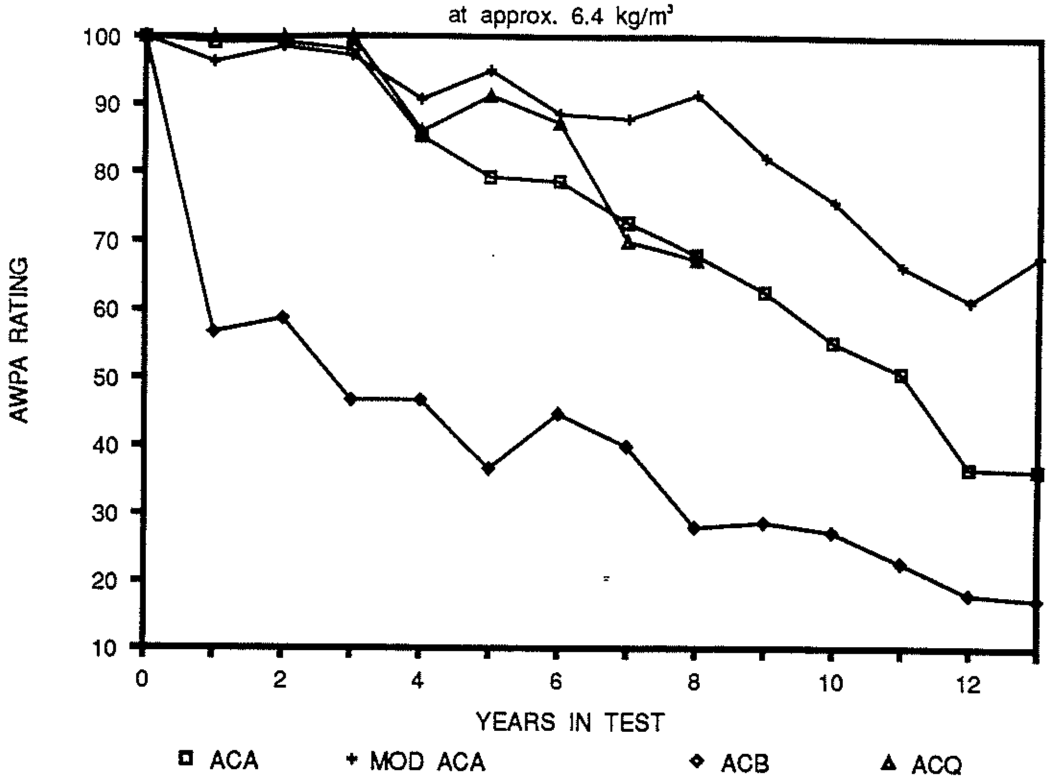

Figure 6: Performance of Wrapped and Unwrapped Modified ACA

after 4 years in test

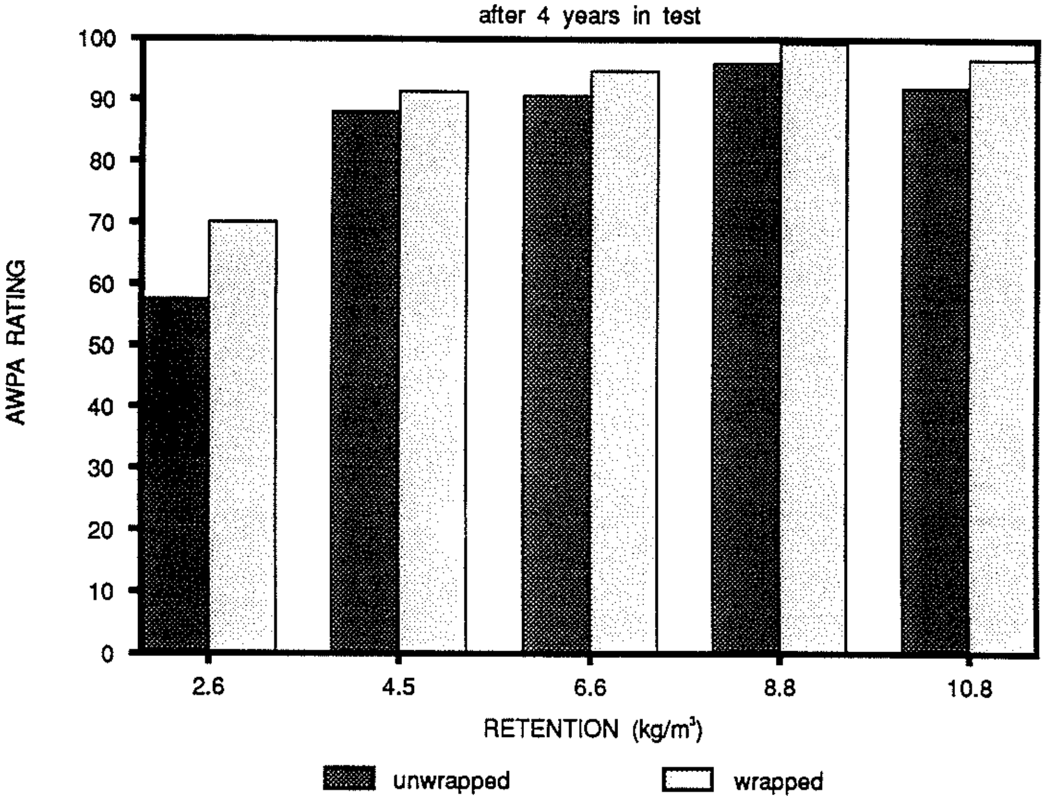

Figure 7: Comparison of P9 Oil, PCP, Cu Naph

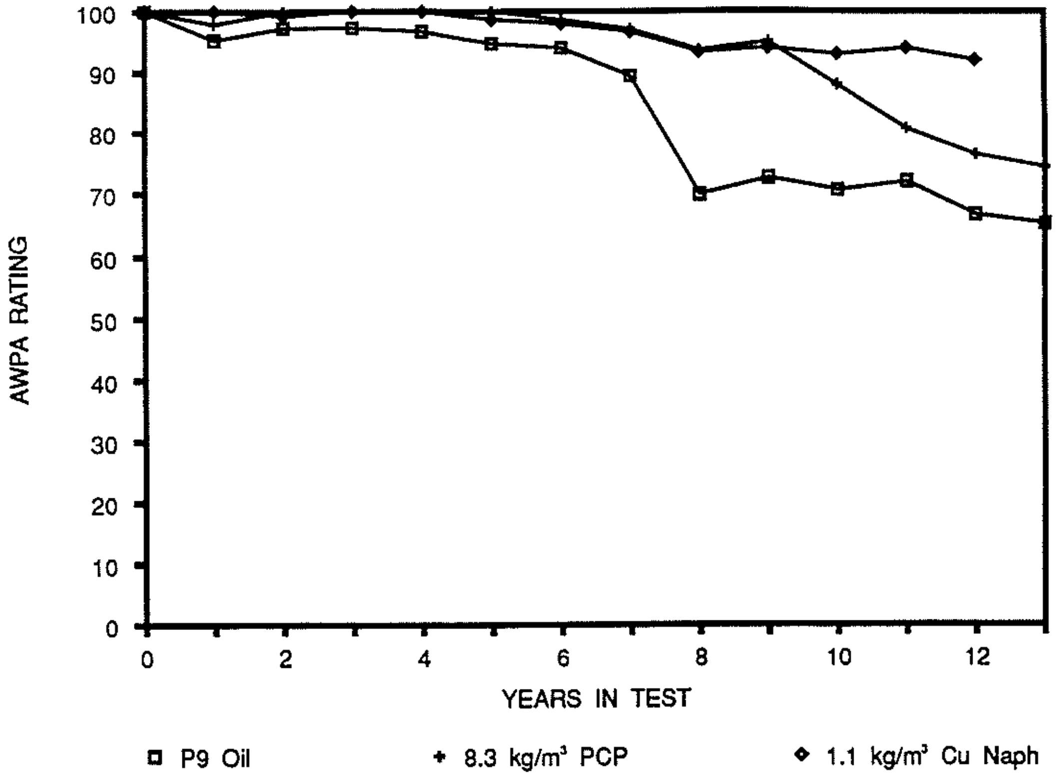

Figure 8: CCA-C Treated P. pine Sap. and Heartwood

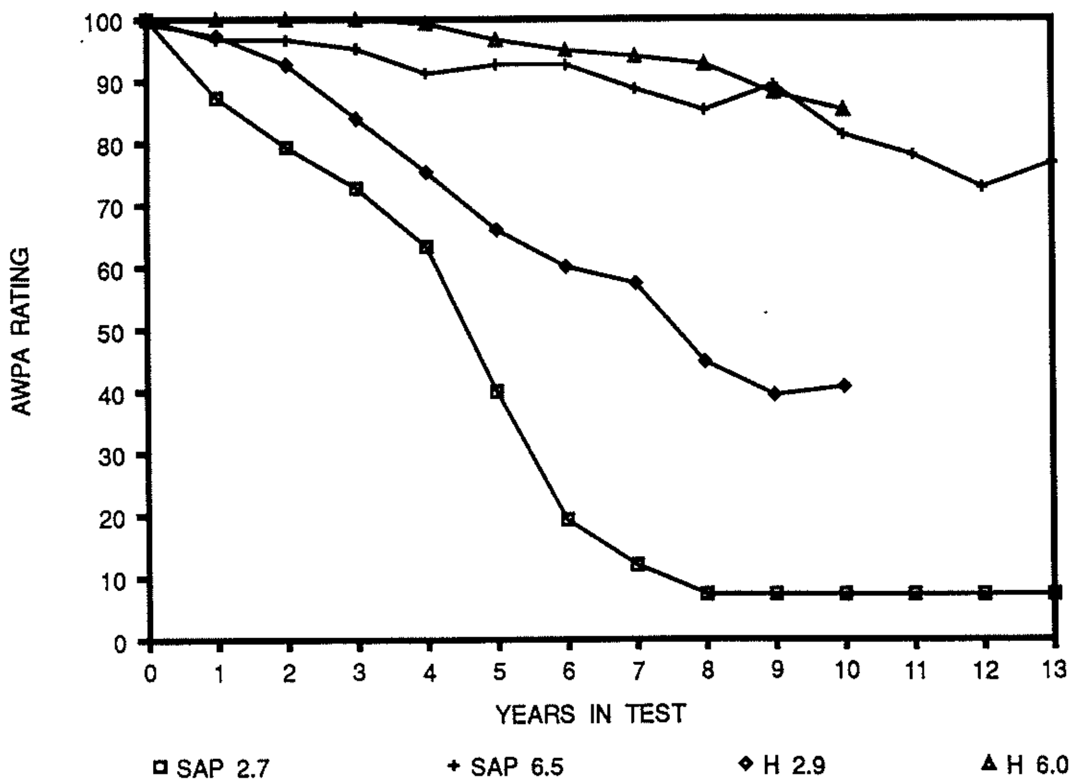

Figure 9:

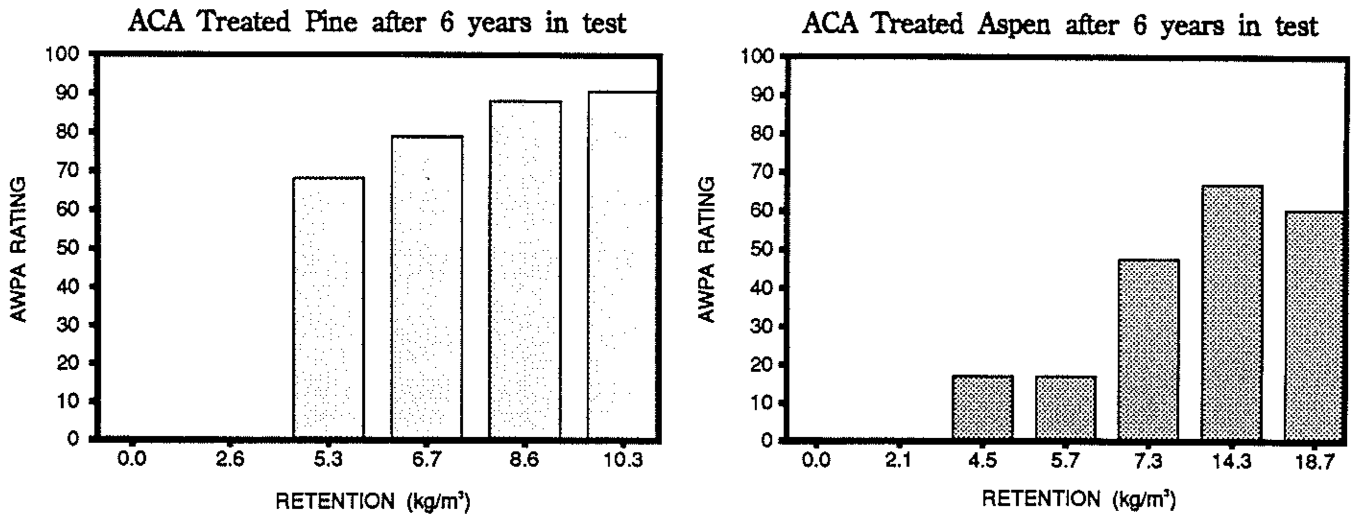

Figure 10:

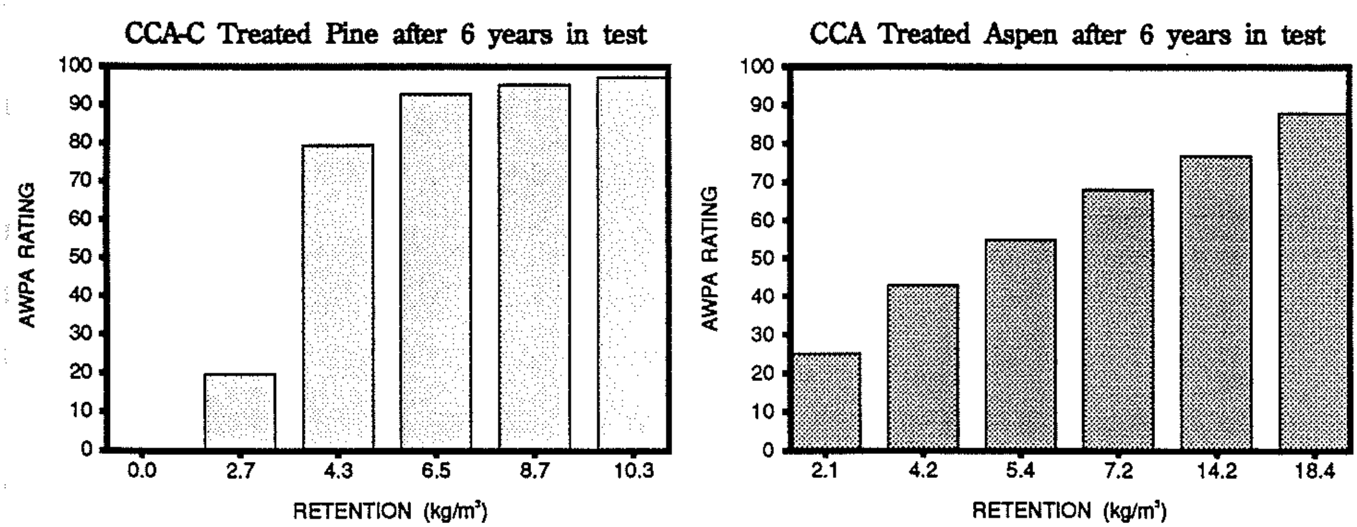

Figure 11: Stake Failures at Westham Island - 9 months

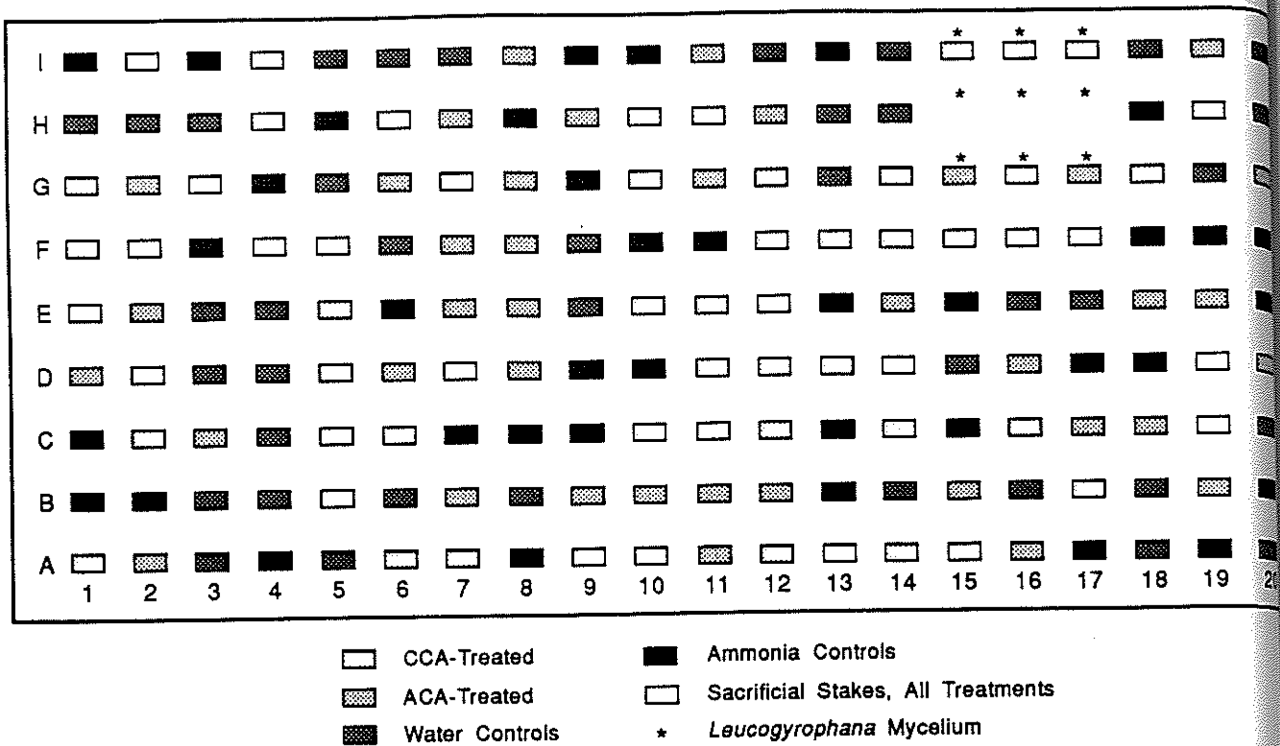

Figure 12: Stake Failures at Westham Island - 18 months

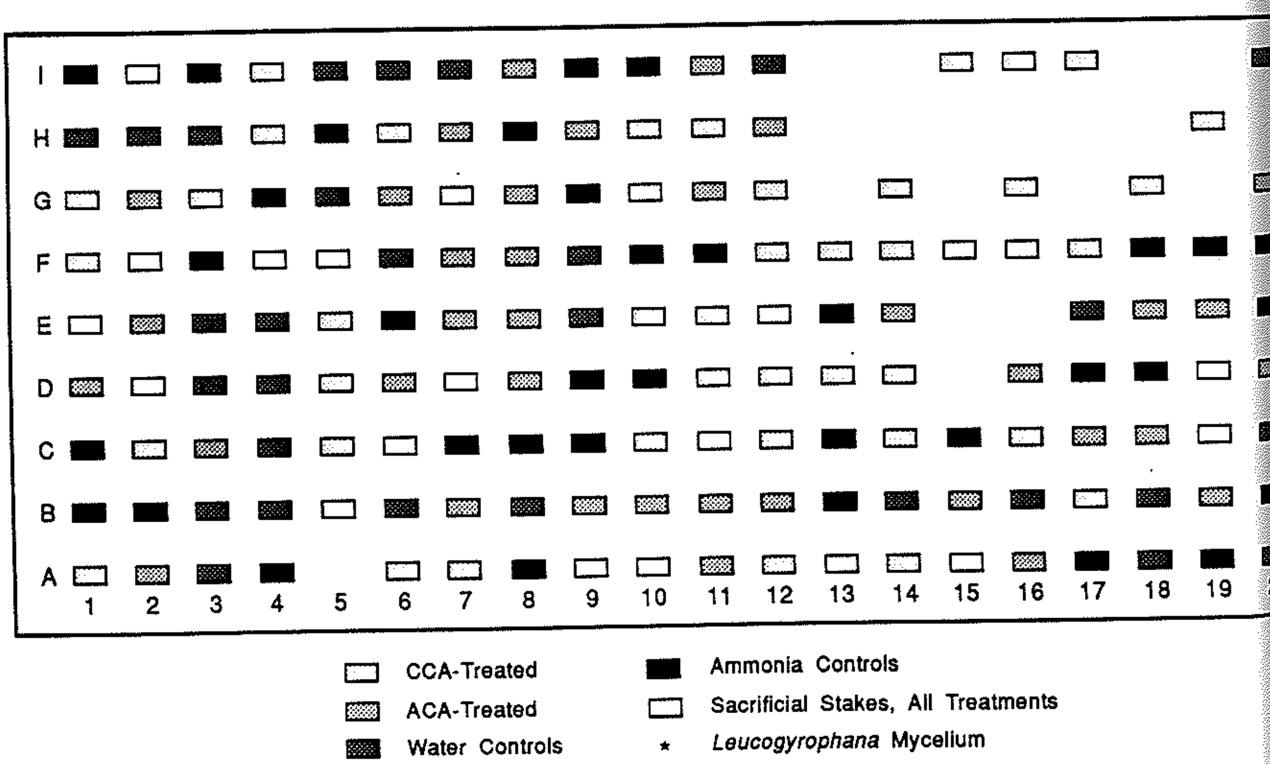

Figure 13: Stake Failures at Westham Island - 21 months

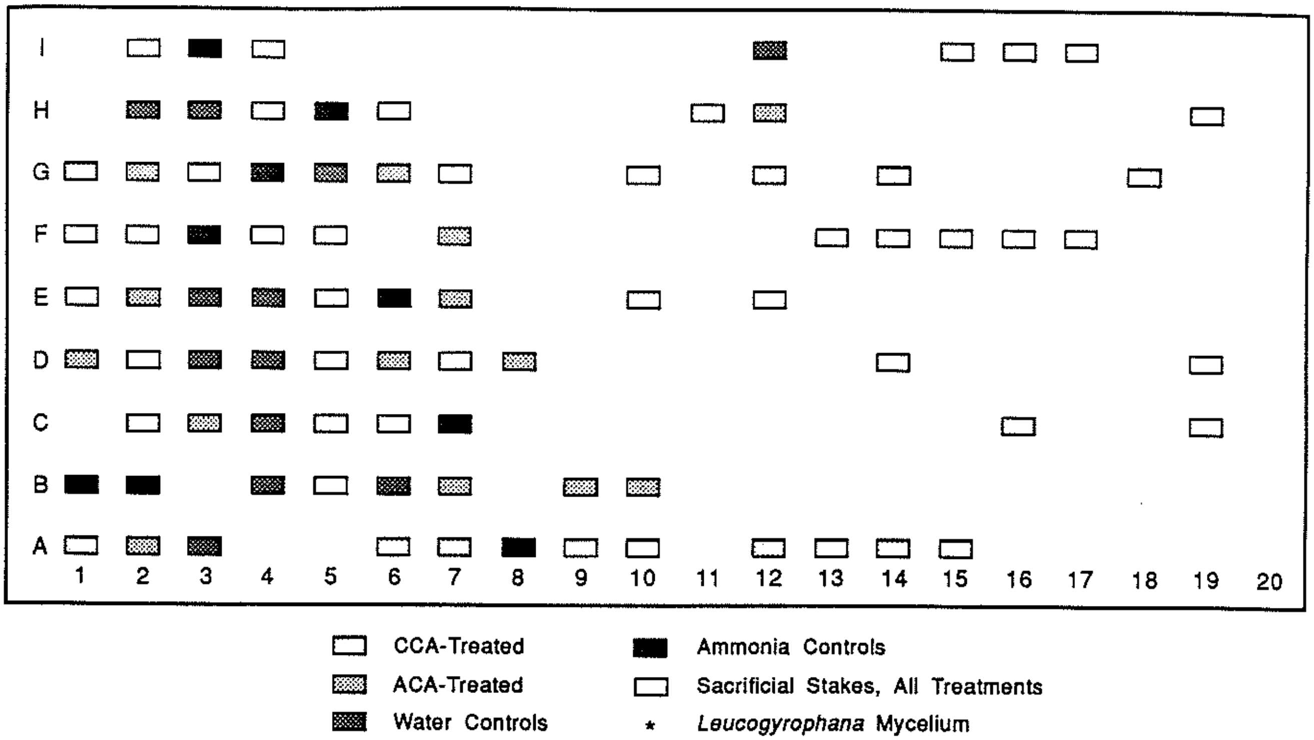

Figure 14: Stake Failures at Westham Island - 33 months

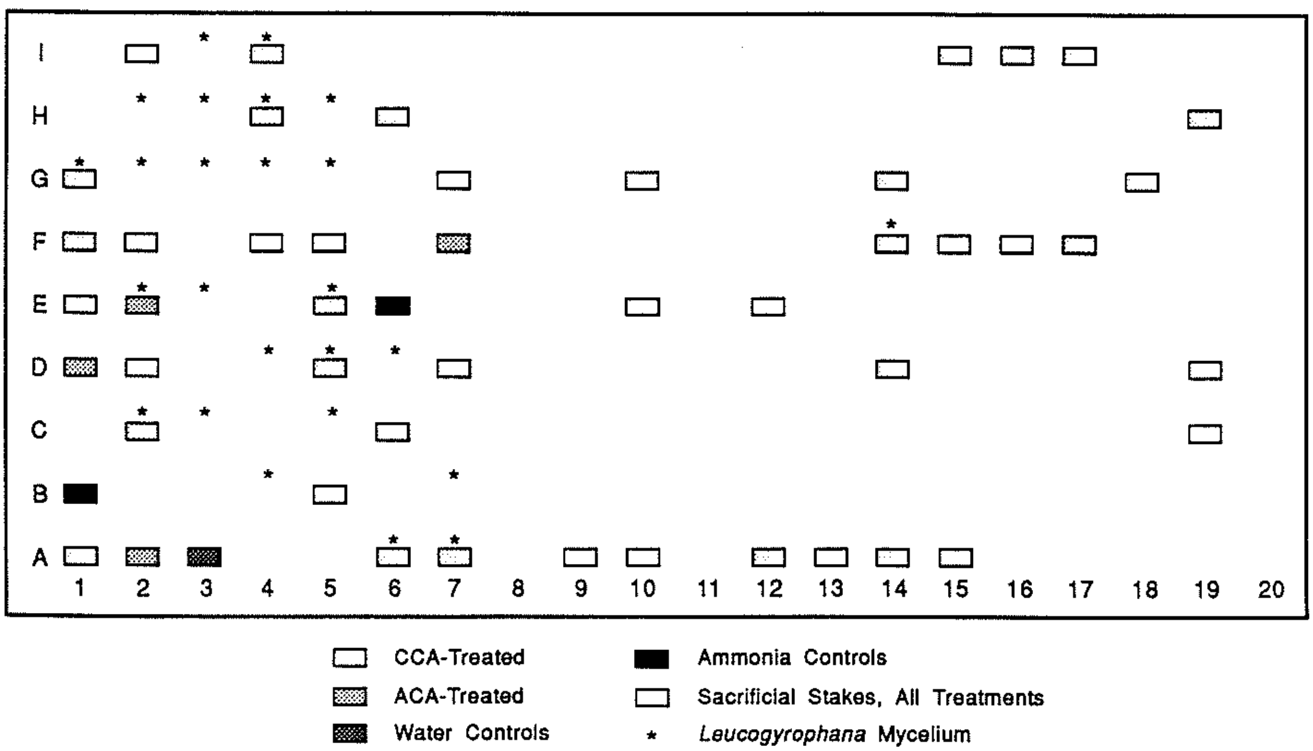

Figure 15: Decay Rates for Small CCA-Treated Stakes at 2.5 kg/m³

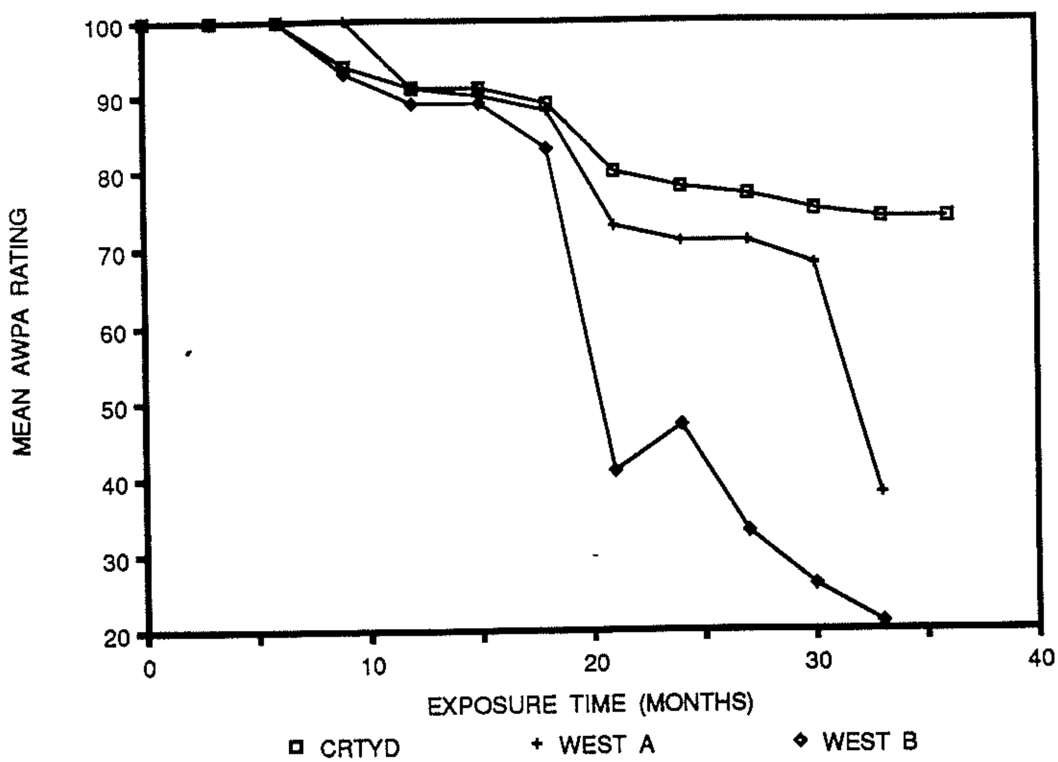

Figure 16: Decay Rates for Small ACA-Treated Stakes at 2.5 kg/m³